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Review
Surfaces for selective absorption of solar energy: an annotated bibliography 1955–1981

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A comprehensive classified list of annotated references on surfaces which combine high solar absorptance with low thermal emittance is presented, covering the period 1955–1981. The list embraces papers printed in scientific journals and in published conference proceedings. An index of authors and on surface coatings studied is appended.

1. Introduction

The concept of spectral selectivity for efficient photothermal conversion of solar energy is easily understood from Fig. 1. Dashed curves in the lower right-hand part show thermal radiation spectra for black bodies at three temperatures in the range of most interest for practical solar energy utilization. The exitance is seen to be significant only in the $2 \lesssim \lambda \lesssim 50\,\mu$m wavelength interval. The solid curve to the left refers to a typical spectrum of solar radiation at ground level. The irradiance is substantial only for $0.3 \lesssim \lambda \lesssim 2\,\mu$m. The clearcut wavelength separation makes it possible to take advantage of *spectral selectivity* for providing efficient conversion of solar energy into useful heat. Most of today's solar collecting devices employ non-transparent solar-absorbing plates placed under solar-transparent convection shields of glass or plastic. The absorbing surface, ideally, should exhibit zero reflectance over the solar range and unity reflectance (i.e., zero emittance) over the thermal range. The second condition serves to improve the performance by suppressing radiative heat losses. The wavelength at which the reflectance should shift, λ_c, depends to some extent on the intended operating temperature of the device. Judging from Fig. 1b we have $2 \lesssim \lambda_c \lesssim 4\,\mu$m. The "ideal" spectral profile indicated by the dotted lines in Fig. 1a is drawn with $\lambda_c = 3\,\mu$m. Below we present a detailed bibliography covering work on surfaces which approximate this kind of spectrally selective property, reported in the period 1955–1981.

The role of spectral selectivity for obtaining specific radiative properties has been known almost since the beginning of this century (M. C. Féry, *J. Phys. Paris* 8 (1909) 758), and some surfaces with very low reflectance at short wavelengths and high reflectance at long wavelengths were reported as early as in the 30's and 40's (A. H. Pfund, *J. Opt. Soc. Amer.* 23 (1933) 375; L. Harris, R. T. McGinnies and B. M. Siegel, *J. Opt. Soc. Amer.* 38 (1948) 582). However, practically useful surfaces for selective absorption of solar energy were not realized until 1955, when the work by Tabor [65, 66] in Israel and by Gier and Dunkle [10] in the US was presented at the first Solar Energy Conference held in Tucson, Arizona. The surfaces described by them comprised some oxide and sulphide layers, produced by chemical conversion or electroplating, on metal sheet. The general interest in solar utilization was low in the 50's and 60's, but it rapidly soared in the mid-70's as a consequence of the renewed interest in alternative energy resources which resulted from the "oil crisis". At that time it also became clear that a number of advanced multilayer coatings, which had been developed for satellite temperature control within the US and Soviet space programmes, were useful also for terrestrial applications. These coatings were mostly prepared by vacuum deposition techniques.

In recent years there have been very active and widespread efforts to obtain superior selectively solar-absorbing surfaces. The work has ranged from the formulation of basic theories of the optical properties of candidate materials, over investigations of a variety of coating fabrication techniques and develop-

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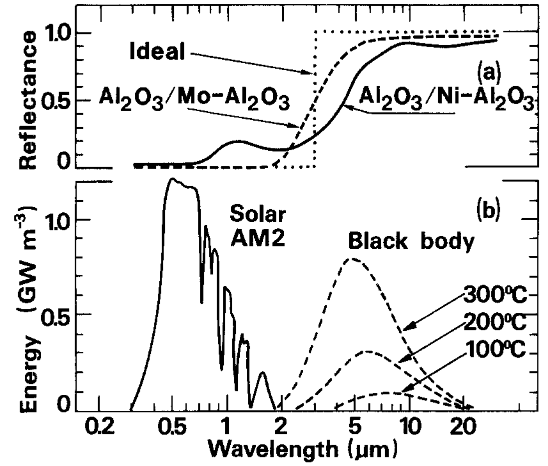

Figure 1 Part (a) shows reflectance spectra of an ideal surface for converting solar energy into useful heat (dotted lines), a commercial Ni–Al_2O_3 composite layer overcoated with Al_2O_3 and backed by aluminium (solid curve; from [441]), and a research-type Mo–Al_2O_3 composite layer overcoated with Al_2O_3 and backed by molybdenum (dashed curve; from G. A. Nyberg and R. A. Buhrman, *Appl. Phys. Lett.* **40** (1982) 129). Part (b) depicts the AM2 solar spectrum pertaining to clear weather and the Sun standing 30° above the horizon (solid curve; from P. Moon, *J. Franklin Inst.* **230** (1940) 583), and black body spectra corresponding to three temperatures (dashed curves).

ments of appropriate measurement and analysis techniques, to testing of surfaces by accelerating ageing as well as in the field. A few of the hundreds of different surfaces investigated have reached commercialization (a useful survey is given by S. A. Herzenberg and R. Silberglitt, *Proc. Soc. Photo-Opt. Instrum. Eng.* **324** (1982) 92): the most widely used – at least in Europe and the US – are "black chrome" which is a complex graded Cr–Cr_2O_3 composite produced by electroplating [321–408], nickel-pigmented Al_2O_3 produced by electrolytic colouration of anodized aluminium sheet [441, 443–5, 451–2], and "MAXORB" produced by chemical conversion of nickel foil [303–5, 320]. The solid curve in Fig. 1a depicts a reflectance spectrum for nickel-pigmented anodic Al_2O_3. Surfaces of this kind yield a high solar absorptance (92 to 97%) and a concomitant low hemispherical thermal emittance (10 to 26%). These numbers are rather typical also for other types of commercial specimens. For comparison, the dashed curve in Fig. 1a shows a reflectance curve for a research coating comprising a rough graded co-evaporated Mo–Al_2O_3 composite layer overcoated with Al_2O_3 and deposited onto molybdenum (G. A. Nyberg and R. A. Buhrman, *Appl. Phys. Lett.* **40** (1982) 129). This surface exhibits a remarkable 99.2% solar absorptance combined with a normal thermal emittance <8%. These properties, in particular the high solar absorptance, demonstrate as far as we know the best optical performance yet reported for any selectively solar absorbing surface. We see no reason why surfaces of a comparable quality could not be produced on a large scale for practical applications, even if their fabrication is likely to pose more severe problems than those of the present commercial surfaces.

Fig. 2 serves to illustrate the dramatic growth of the research on selectively solar-absorbing surfaces as mirrored by the publication rate. The number of published papers per year lay on an annual average of ~3 until the oil crisis in 1973, at which time this number went up and hit a maximum of 118 in 1979. We feel that there is now a need for a detailed bibliography of this field of research. Earlier review articles and books on the subject fulfil the need to a limited extent only.

The surfaces embraced by the bibliography obtain their spectral selectivity by various physical mechanisms. The most straight-forward is to employ a material whose *intrinsic optical properties* display selective absorption. Recent work on ZrB_2 [260–1] has shown very promising results with regard to optical performance and high-temperature stability. *Semiconductor-metal tandems* can show a useful spectral selectivity by absorbing short-wavelength radiation in a semiconductor with a bandgap of ~0.6 eV and having a low thermal emittance as a result of the underlying metal substrate. Antireflection coatings are needed to cut down the front surface loss, which would otherwise be prohibitively large. The most well known work in this area is that of Seraphin's group at the University of Arizona, who investigated coatings based on silicon produced by chemical vapour deposition [227–31, 251–6, 262–6]. *Multilayer absorbers* are useful for tailoring the optical surface properties to meet a specific demand. They can be constructed so as to cover the major part of the solar spectrum. Their optical properties are easily computed, so that an optimization of the design is rather easy. An interesting example is Al_2O_3/Mo/Al_2O_3, whose descent goes back to the US space programme, which has recently

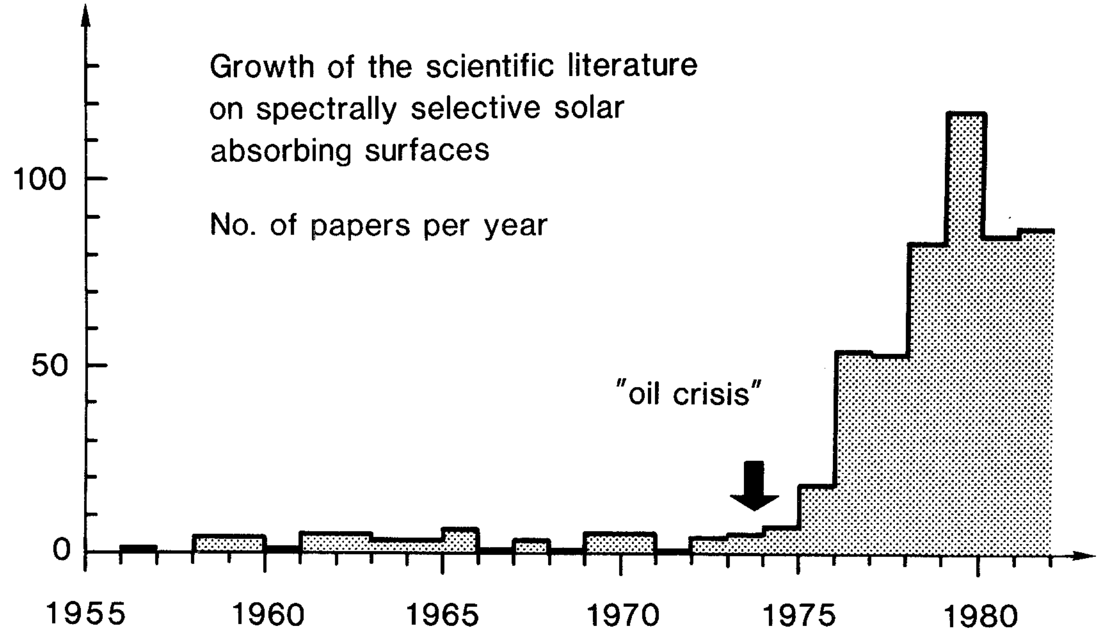

Figure 2 Publication rate for reports on spectrally selective solar absorbing surfaces during 1955–81. The arrow points at the time of the Arab oil embargo against the US, which was enforced in October 1973. That event sparked the dramatic publication rate increase.

been produced by large area magnetron sputtering by Thornton *et al.* [221]. The high-temperature stability is good. Physical vapour deposition of multilayer coatings is traditionally held as an inherently expensive technique. However the advent of high-productivity large-area sputtering units with load-locks is likely to change the situation radically; as an example, this technique is now used for making transparent three-layer coatings on commercial architectural glass. *Metal–dielectric composite coatings* make it possible to produce very efficient selectively solar-absorbing surfaces by a variety of techniques such as co-deposition by evaporation or sputtering, chemical vapour deposition, electroplating etc. With sufficiently small particles the optical properties of the composite are intermediate between those of the metal and the dielectric. Optimization of the solar selectivity can be made with regard to the choice of constituents (which also influences the microgeometry), coating thickness, and particle concentration (which may be graded), size, shape and orientation. The solar absorptance can be boosted by the use of suitable substrate materials and antireflection coats. Two of today's most widely used coatings – "black chrome" and nickel-pigmented anodic Al_2O_3 – definitely belong to this class of materials. Other interesting surfaces of a particular nature are "black molybdenum" produced by chemical vapour deposition [234–8, 245–6] and "black zinc" produced by anodizing zinc sheet [446]. The possibility of tailoring the optical performance, the availability of appropriate coating techniques, and the emergence of detailed theoretical models for the effective optical properties, taken together, make the use of metal–dielectric composite coatings extremely fruitful for harnessing the Sun's energy. The final approach to be considered is the *textured surface absorbers.* Their high solar absorptance is due to multiple reflections against metal dendrites which are $\sim 2\,\mu$m apart while the long-wavelength thermal radiation is rather unaffected by the texture. The most well known example is dendritic tungsten produced by chemical vapour deposition [239–42, 259]. Our discussion is not exhaustive but serves to illustrate the large number of physical mechanisms that can be used to obtain selective solar absorption.

Most practical surfaces take advantage of several of the above mechanisms for obtaining spectral selectivity, even if one of them may be of major importance. For example, the dashed curve in Fig. 1a stems from a textured metal–dielectric composite absorber integrated in a multilayer configuration. For this reason, and also since the dominant cause of the selectivity is not well known for some of the most important surfaces, it is not possible to categorize the published reports after the selectivity mechanism. Instead we have chosen to number the references consecutively and group them according to the technique used for producing the selectively solar-absorbing surfaces under several headings each of which is alphabetically ordered. After a listing of reviews (Section 3.1; entries 1–78) there follows vacuum evaporation (Section 3.2; entries 79–127); reactive evaporation and gas evaporation (Section 3.3; entries 128–151); sputter deposition and sputter etching (Section 3.4; entries 152–226); chemical vapour deposition and related techniques (including plasma deposition, glow-discharge deposition, and pyrolytic reduction; Section 3.5; entries 227–269); deposition from solution: chemical reactions (including metallo-organic deposition; Section 3.6; entries 270–320); deposition from solution; electrochemical reactions (Section 3.7; entries 321–454); thermal oxidation (Section 3.8; entries 455–473); painting (Section 3.9; entries 474–494); enamelling (Section 3.10; entries 495–503); and by use of miscellaneous techniques (Section 3.11; entries 504–530). The section on electrochemical deposition is divided into three parts: black chrome (Section 3.7.1; entries 321–408), other electroplated coatings (Section 3.7.2; entries 409–439), and anodic coatings (Section 3.7.3; entries 440–454). The bibliography is concluded with a listing of selected papers on theoretical and computational matters (Section 3.12; entries 531–565). Cross-references are given at the beginning of each section. A brief note accompanies the reference except when the title is self-explanatory; this note mentions the materials studied, the techniques employed, particularly noteworthy results, etc. Appendices I and II are indices, for 1955–1981, of authors and surface coatings studied, respectively. We attempt to cover papers in scientific journals and in published conference proceedings. Internal reports and unpublished conference papers are generally omitted. Technical reports on the influence of spectral selectivity on the overall solar collector efficiency are left out. Our goal has been to provide a complete coverage of the literature, which is of course an impossible task. Nevertheless, we are confident that not too many papers have been forgotten.

In closing the Introduction it is tempting to speculate whither the research on selectively solar-absorbing surfaces is going. We can observe from Fig. 2 that the publication rate has remained high since 1978 with no discernible downwards tendency. Is this going to continue? In our opinion a further increase in pure research is unlikely. Rather we expect the field to mature and that an increasing number of technically oriented studies will appear together with a gradual decrease of the more fundamental investigations of optical properties as such, etc. Obviously, this does not imply that there is not ample room for good and innovative work. High-rate sputtering techniques are likely to be of growing importance, and we believe that the work by J. Thornton *et al.* at Telic Corporation in the US and by G. L. Harding *et al.* at the University of Sydney in Australia is pointing a way towards the future. It is also worth noting that efficient photothermal conversion is not contingent on selective absorption but can be achieved alternatively with black body-like absorber plates under selectively solar-transmitting covers which are reflecting for $\lambda \gtrsim 3\,\mu$m. This second concept holds promises for extreme durability since the candidate coatings (mainly heavily doped oxides of indium and tin) do not have to operate at high temperatures and have proven chemical inertness, substrate adherence, etc. The utilization of selective transmission has been hampered by the difficulty of obtaining coatings with sufficient solar transmittance, but recent work on MgF_2-coated indium tin oxide may lead to superior properties (I. Hamberg, A. Hjortsberg and C. G. Granqvist, *Appl. Phys. Lett.* **40** (1982) 362).

2. Abbreviations

a = amorphous (for example a-silicon = amorphous silicon).
AES = Auger electron spectroscopy.
b = black (for example b-chrome = black chrome).
CVD = chemical vapour deposition.
e-beam = electron beam.
EMT = effective-medium theory (-ies).
ESR = electron spin resonance.
IR = infrared.
UV = ultraviolet.

QSE = quantum size effect(s).
R = reflectance.
RBS = Rutherford backscattering.
SEM = scanning electron microscopy.
SIMS = secondary ion mass spectroscopy.
SS = stainless steel(s).
SSAS = selective solar absorbing surface(s).
T = transmittance.
TEM = transmission electron microscopy.
TS = thermal stability.
XPS = X-ray photoelectron spectroscopy (also known as ESCA = electron spectroscopy for chemical analysis).
α = fraction of solar irradiance absorbed (most papers giving this quantity also show $R(\lambda)$).
ϵ = emittance (i.e. ratio of the radiant exitance of a body at a given τ to that of a black body radiator at the same τ).
λ = wavelength.
τ = temperature.

Chemical symbols are used throughout for brevity. Hyphens are used to connect the symbols for two constituents in a composite material (example: A–B) with the metallic component stated first. Strokes are used to designate multilayer structures (example: A/B/A) with the outermost material stated first.

3. Bibliography 1955–1981

3.1. Review articles

(See also [91, 192, 216–9, 227, 254, 264–5, 289, 334, 497, 549–52, 562].)

1. K. ABEL, "Sonnenkollektoren; Auf die Selektive Schicht kommt es an", *Sanit. u. Heizungstech.* **44** (1979) 447.
   Brief and popular review.
2. O. P. AGNIHOTRI and B. K. GUPTA, "Solar Selective Surfaces" (Wiley-Interscience, New York, 1981); 215 pages.
   Chap. 5 of this book gives the most extensive (~ 100 pages) previous review over SSAS. The contents are grouped under several headings: intrinsic materials, absorber–reflector tandems (with b-nickel, b-chrome, b-copper, b-iron, cobalt oxide, tungsten oxide), conversion coatings (Cu_2S, b-zinc, coloured SS, aluminium oxide), pure semiconductors (silicon, germanium, PbS), metal silicides and carbides, paints, multilayer interference stacks, optical trapping systems, and composite materials coatings. Fabrication and measurement techniques are discussed and representative data on α and ϵ are given in tables. Discussion of EMT for the optical properties of composite materials and of QSE.
3. P. BAUMEISTER, "A Comparison of Solar Photothermal Coatings", *Proc. Soc. Photo-Opt. Instrum. Eng.* **85** (1977) 47.
   A balanced brief review of SSAS, including a comparison of the cost of various methods of surface preparation.
4. P. BEUCHERIE, "Selective Absorbant Surfaces for High Temperature Solar Collectors", in "Solar Thermal Power Generation", Course at Ispra, Italy, 1979 (Elsevier Sequoia, Lausanne, 1980) p. 125.
5. A. CHANDRA, "Selective Coatings for Water Heaters", *Sun World* **3** (1979) 106.
   Brief popular review.
6. F. DANIELS, "Selective Radiation Surfaces", in "Direct Use of the Sun's Energy" (Yale University Press, New Haven, 1969) Chap. 12.
   Review of some early work.
7. H. D. EINHORN, "Spectral Characteristics for Improving Solar Collector Performance", *Trans. S. Afr. Inst. Electr. Eng.* **70** (1979) 244.
8. J. C. C. FAN, "Wavelength-Selective Surfaces for Solar Energy Utilization", *Proc. Soc. Photo-Opt.*

Instrum. Eng. **85** (1976) 39.

Review of the author's work on electroplated b-chrome on copper, and on radio frequency sputtered Au–MgO composites on molybdenum.

9. J. C. C. FAN, "Wavelength-Selective Surfaces", *Adv. in Chem.* **163** (1977) 149.

   Review of the author's work on metal–insulator composite SSAS.

10. J. T. GIER and R. V. DUNKLE, "Selective Spectral Characteristics as an Important Factor in the Efficiency of Solar Collectors", in Transactions of the Conference on the Use of Solar Energy, The Scientific Basis, Tucson, October 31–November 1, 1955 (University of Arizona, Tucson, 1958) Vol. 2, Part 1A, p. 41.

    Review of basic principles for obtaining SSAS. Data on $R(\lambda)$ for various materials, especially copper oxide prepared by chemical treatment.

11. G. GOUHMAN, M. KOUDRACHOVA, N. MITEVSKAYA and F. EYDINOVA, "Surfaces Sélectives: Propriétés Optiques et Estimation de l'Efficacité Energétique dans l'Application aux Récepteurs Solaries", *Rev. Phys. Appl.* **15** (1980) 393.

    Brief review mainly of some Russian work.

12. C. G. GRANQVIST, "Optical Properties of Cermet Materials", *J. Phys.* (*Paris*) **42** (1981) C1-247.

    Comparison of EMT and optical data on discontinuous metal films, gas evaporated coatings, coevaporated and cosputtered layers, electrodeposited films, and electrolytically and integrally coloured anodic aluminium-oxide coatings; largely a review of the author's own work.

13. C. G. GRANQVIST, "Radiative Heating and Cooling with Spectrally Selective Surfaces", *Appl. Opt.* **20** (1981) 2606.

    Review on SSAS and other types of spectrally selective surfaces. Numerous references are given; these are grouped according to the fabrication technique.

14. R. W. GRIFFITH, "Solar Energy Utilization: Solid State Science and a High Efficiency Amorphous-Silicon Absorber", in "Sharing the Sun: Solar Technology in the 70's" Vol. 6, edited by K. W. Böer, (Winnipeg, Canada, 1976) Vol. 6, p. 205.

    Review of the physical properties a-Si with a view to its applications as SSAS.

15. R. W. GRIFFITH, "Amorphous Semiconductor Thin Films in Solar Thermal Conversion", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 289.

    See [14].

16. R. E. HAHN and B. O. SERAPHIN, "Spectrally Selective Surfaces for Photothermal Solar Energy Conversion", *Phys. Thin Films* **10** (1978) 1.

    Authoritative and extensive (70 pages) review covering principles for SSAS and a discussion of the optical properties obtainable with intrinsic materials, absorber–reflector tandems, multilayer inference stacks, textured surfaces and composite materials coatings.

17. J. HANUS, "Optique des Matériaux et Conversion Thermique de l'Energie Solaire", "Energie Solaire, Conservation et Application", Institut d'été, Cargèse, France, June 19 1977 (Centre Nationale de la Recherche Scientifique, Paris, 1978) p. 303.

18. M. G. HUTCHINS, "Solar Absorber Coatings", *Helios* (7) (1978) 3.

    Brief and popular review.

19. M. G. HUTCHINS, "Spectrally Selective Solar Absorber Coatings", *Appl. Energy* **5** (1979) 251.

    Brief review of various kinds of SSAS.

20. M. G. HUTCHINS, "Thin-Film Coatings in Solar Water Heating Systems", *IEE Conf. Publ.* **171** (1979) 249.

    Review of the properties of b-chrome, b-nickel, copper oxide, chromated zinc, blue SS-oxide and paints; durability studies.

21. J. JURISSON, R. E. PETERSON and H. Y. B. MAR, "Principles and Applications of Solar Selective Coatings", *J. Vac. Sci. Technol.* **12** (1975) 1010.

    Review of early work on SSAS.

22. J. JURISSON, "Historical Perspective – Coatings for Solar Collectors", in Proceedings of the

Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 137.

See [21].

23. R. W. KEYES, "Solid State Physics and Solar Energy", *Comments Solid State Phys.* **4** (1972) 183.

Brief review of the principles for SSAS.

24. K. KÖHNE, "Der Wirkungsgrad von Flachkollektoren Unter Besonderer Berücksichtigung Selektiver Schichten", in *Heizen mit Sonne*, 1st Meeting, Göttingen, February 23–24 1976 (Deutsche Gesellschaft für Sonnenergie, Gräfeling, Germany, 1976) p. 95.

Brief review of SSAS including a discussion of the efficiency of solar collectors.

25. M. M. KOLTUN, "Selective Surfaces and Coatings for Solar Technology", *Geliotekh.* **7** (5) (1971) 70 (*Appl. Solar Energy* **7** (5) (1971) 52).

Review of early Russian work on SSAS.

26. M. M. KOLTUN, "Selektivnye Opticheskie Poverkhnosti Preobrazovatelei Solnechnoi Energi" (Nauka Press, Moscow, 1979). English translation: "Selective Optical Surfaces for Solar Energy Converters" (Allerton Press, New York, 1981) 245 pages.

Sections 3.1–3.6 of this book give a detailed (50 pages) review of SSAS with emphasis on Russian, and some early American work on multilayer coatings. The connection between terrestrial applications and space applications of various spectrally selective surfaces is discussed.

27. M. M. KOLTUN, "Present State of Research on Selective Coatings for Solar-Energy Converters", *Geliotekh.* **16** (6) (1980) 34 (*Appl. Solar Energy* **16** (6) (1980) 30).

Review mainly of Russian work on SSAS and other spectrally selective surfaces.

28. M. M. KOLTUN, "Combined Solar-Energy Converters with Selective Coatings", *Geliotekh.* **17** (1) (1981) 54 (*Appl. Solar Energy* **17** (1) (1981) 48).

See [27].

29. C. M. LAMPERT, "Coatings for Enhanced Photothermal Energy Collection I. Selective Absorbers", *Solar Energy Mater.* **1** (1979) 319.

Detailed review with tables of α, ϵ and TS for many kinds of SSAS.

30. C. M. LAMPERT, "Coatings for Enhanced Photothermal Energy Collection II. Non-selective and Energy Control Films", *Solar Energy Mater.* **2** (1979) 1.

See [29]; this review contains data only for surfaces with moderate to low spectral selectivity.

31. C. M. LAMPERT, "Metal Foils for Direct Application of Absorber Coatings on Solar Collectors", in American Electroplaters' Society Second Coatings for Solar Collectors Symposium, St. Louis, USA, October 16–17 1979.

32. C. M. LAMPERT, "Selective Absorber Coated Foils for Solar Collectors", *Plating Surf. Finish.* **67** (11) (1980) 52.

Review of foils for application in solar collectors. Data for various adhesives and cost estimates.

33. R. J. H. LIN, "Low Temperature Solar Coatings", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 205.

Review of research on SSAS at Honeywell.

34. R. L. LONG, "Review of Recent Air Force Research on Selective Solar Absorbers", *Trans. ASME* (*J. Eng. for Power*) **87** (1965) 277.

Review of early results for various microporous surfaces, "contaminated gold" produced by metallo-organic deposition, and vacuum evaporated multilayer films.

35. K. D. MASTERSON, "Spectrally Selective Surfaces for High-Temperature Photothermal Solar Energy Conversion", *Proc. Soc. Photo-Opt. Instrum. Eng.* **68** (1975) 147.

Review of results for CVD produced silicon-based multilayer stacks and other types of SSAS.

36. K. D. MASTERSON, "Selective Surfaces for Solar-Thermal Conversion", *J. Solid State Chem.* **22** (1977) 41.

Review including cost estimates for several kinds of SSAS.

37. D. M. MATTOX, "Solar Energy Materials Preparation Techniques", *J. Vac. Sci. Technol.* **12** (1975) 1023.

Review of SSAS and other types of surfaces for solar applications. The emphasis is on preparation techniques.

38. D. M. MATTOX, "Application of Thin Films to Solar Energy Utilization", *J. Vac. Sci. Technol.* **13** (1976) 127.

See [37].

39. D. M. MATTOX, "Optical Materials for Solar Energy Applications", *Opt. News* **2** (Summer 1976) 12.

See [37].

40. D. M. MATTOX, "Coatings and Surface Treatments in Solar Energy Applications", *Plating Surf. Finish.* **63**(1) (1976) 55.

See [37].

41. D. M. MATTOX, "Preparation of Thin Films for Solar Energy Utilization", *J. Vac. Sci. Technol.* **17** (1980) 370.

See [37].

42. D. M. MATTOX and R. R. SOWELL, "A Survey of Selective Solar Absorbers and Their Limitations", *J. Phys. (Paris)* **42** (1981) C1-19.

Review of various kinds of SSAS, including a discussion of fabrication processes and degradation modes.

43. G. E. McDONALD, "Survey of Coatings for Solar Collectors", in Proceedings of the Workshop on Solar Collectors for Heating and Coating of Buildings, New York, November 1974 (University of Maryland, College Park, Georgia, 1975) p. 407.

Brief review on results for b-chrome, b-nickel, b-zinc, b-copper and enamels. Cost estimates are given.

44. A. B. MEINEL, "Progress in Development and Application of Selective Surfaces", in International Conference on Heliotechnique and Development, Dhahran, Saudi Arabia, November 2–6 1975, edited by M. A. Kettani and J. E. Soussou (Development Analysis Association Inc., Cambridge, Massachusetts, 1976) Vol. 1, p. 166.

Review of SSAS with emphasis on absorber–reflector tandems and multilayer interference stacks. Thermal degradation is discussed.

45. A. B. MEINEL and M. P. MEINEL, "Applied Solar Energy: An Introduction", (Addison-Wesley, Reading, Pennsylvania, 1976) 651 pages.

Chap. 9 of this book gives an extensive (50 pages) review of SSAS. It contains treatment of intrinsic materials, absorber–reflector tandems, multilayer interference stacks, optical trapping systems and QSE. Optical properties of metals are discussed.

46. L. MELAMED, "Development of Selective Absorber Coatings for Solar Thermal Power Systems", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 13.

47. L. MELAMED and C. M. KAPLAN, "Survey of Selective Absorber Coatings for Solar Energy Technology", *J. Energy* **1** (1977) 100.

Brief review with emphasis on high-temperature stable SSAS.

48. G. PELLEGRINI, "Experimental Methods for the Preparation of Selectively Absorbing Textured Surfaces for Photothermal Solar Conversion", *Solar Energy Mater.* **3** (1980) 391.

Review of various methods for the production of textured surfaces: unidirectional solidification of eutectic alloys, X-ray lithography, ion-exchange reaction between metals, vapour–liquid–solid mechanism, CVD, vacuum deposition, and oxidation of metals at high temperatures.

49. J. P. PETITJEAN and H. VAN DER POORTEN, "Les Revêtements Sélectifs et leur Rôle dans l'Amélioration des Performances des Collecteurs Solaires", *Surf. Technol.* **11** (1980) 229.

50. P. K. C. PILLAI and R. C. AGARWAL, "Spectrally Selective Surfaces for Photothermal Conversion of Solar Energy", *Phys. Status Solidi A* **60** (1980) 11.

Review on different principles for obtaining SSAS, and on experimental data for coatings produced by electrodeposition, chemical conversion, painting, vapour deposition and CVD.

51. A. C. RATZEL and R. B. BANNEROT, "Optimal Material Selection for Flat-Plate Solar Energy Collectors Utilizing Commercially Available Materials", *Nucl., Solar and Process Heat Transfer, AIChE Symposium Series,* No. 164, Vol. 73 (1977) p. 186.

Review of data for commercially available materials for use in flat-plate solar collectors, including a description of methods for application of SSAS. Data for α, ϵ, durability, temperature limits, and cost are given.

52. I. T. RITCHIE and J. SPITZ, "Thermal Degradation of Cermet Solar Selective Absorbers", *J. Phys. (Paris)* **42** (1981) C1-301.

Review of degradation mechanisms for electroplated b-chrome, reactively sputtered metal carbides and silicides, and vacuum coevaporated cermets (metal–insulator composites).

53. B. O. SERAPHIN, "Material Science Aspects of Thin-Film Systems Used for Solar Energy Conversion – An Introduction", in Symposium on the Materials Science Aspects of Thin Film Systems for Solar Energy Conversion, Tucson, May 20–22 1974, edited by B. O. Seraphin (University of Arizona, Tucson, 1974) p. 7.

54. B. O. SERAPHIN, "Solid State Aspects of Solar Energy Conversion", *J. Jpn. Soc. Appl. Phys. Suppl.* **44** (1975) 11.

Brief review.

55. B. O. SERAPHIN and A. B. MEINEL, "Photothermal Solar Energy Conversion and the Optical Properties of Solids", in "Optical Properties of Solids – New Developments", edited by B. O. Seraphin (North-Holland, Amsterdam, 1976) Chap. 17, p. 927.

Extensive (40 pages) review; see [16].

56. B. O. SERAPHIN, "Spectrally Selective Surfaces and their Impact on Photothermal Solar Energy Conversion", in "Solar Energy Conversion: Solid State Physics Aspects", Vol. 31 of "Topics in Applied Physics", edited by B. O. Seraphin (Springer, Berlin, Heidelberg, 1979) p. 5.

Extensive (50 pages) review; see [16].

57. B. O. SERAPHIN, "Spectrally Selective Surfaces in Photothermal Solar Energy Conversion", in "Solar Energy Conversion: An Introductory Course", edited by A. E. Dixon and J. D. Leslie (Pergamon, New York, 1979) p. 287.

Extensive (40 pages) tutorial review; see [16].

58. A. V. SHEKLEIN, "Application of Selective Coatings in Solar Thermogenerators", *Geliotekh.* **4** (1) (1968) 42 (*Appl. Solar Energy* **4** (1) (1968) 28).

Brief review of early Russian work on SSAS and other types of spectrally selective surfaces.

59. A. J. SIEVERS, "Spectral Selectivity of Composite Materials", in "Solar Energy Conversion: Solid State Physics Aspects", Vol. 31 of "Topics in Applied Physics", edited by B. O. Seraphin (Springer, Berlin, Heidelberg, 1979) p. 57.

Authoritative and extensive (60 pages) review on emissivity of metal surfaces and EMT for composite materials. Experimental data and model calculations of $R(\lambda)$ for composite SSAS are treated. See also [562].

60. G. B. SMITH, "Selective Coatings for Solar Collectors", *Met. Australasia* (9) (1977) 204.

Brief and popular review.

61. G. B. SMITH and T. M. SABINE, "Coatings and Cover Plates for Efficient Solar Energy Collection", *J. Austr. Ceram. Soc.* **14**(1) (1979) 4.

See [60].

62. I. I. SOBELMAN, "Exploitation of Solar Energy", *Usp. Fiz. Nauk.* **120** (1976) 85 (*Sov. Phys. Usp.* **19** (1976) 758).

Brief review of SSAS, including a discussion of solar absorption in vapours of Br_2, I_2 and IBr.

63. J. SPITZ, "Selective Surfaces for High Temperature Solar Photo-Thermal Conversion", *Thin Solid Films* **45** (1977) 31.

Brief review mainly on principles for SSAS.

64. J. SPITZ, A. AUBERT, J. M. BEHAGHEL, S. BERTHIER, J. LAFAIT and J. RIVORY,

"Matériaux Sélectifs pour la Conversion Photothermique de l'Energie Solaire", *Rev. Phys. Appl.* **14** (1979) 67.

Review covering principles for SSAS and data for electroplated b-chrome and sputter deposited TiN_x and TiC_x.

65. H. TABOR, "Selective Radiation I. Wavelength Discrimination", in Transactions of the Conference on the use of Solar Energy. The Scientific Basis, Tucson, October 31–November 1 1955, Vol. 2, Part 1A (University of Arizona, Tucson, 1958) p. 24. Also in *Bull. Res. Counc. Israel* **5A** (1956) 119.

   Review of basic principles for SSAS and experimental data for b-nickel and copper oxide on aluminium.

66. H. TABOR, "Selective Radiation II. Wavefront Discrimination", in Transactions on the Conference on the Use of Solar Energy. The Scientific Basis, Tucson, October 31–November 1 1955, Vol. 2, Part 1A (University of Arizona, Tucson, 1958) p. 34. Also in *Bull. Res. Counc. Israel* **5A** (1956) 129.

   Review of SSAS utilizing controlled large-scale texture.

67. H. TABOR, "Solar Collectors, Selective Surfaces and Heat Engines", *Proc. Natl. Acad. Sci.* (*USA*) **47** (1962) 1271.

   Review including results for b-nickel.

68. H. TABOR, "Selective Surfaces for Solar Collectors", in "Low Temperature Engineering Applications of Solar Energy", edited by R. C. Jordan (ASHRAE, 1967) p. 41.

69. H. TABOR, "Selective Surfaces for Solar Collectors", in "Application of Solar Energy for Heating and Cooling of Building", edited by R. C. Jordan and Y. H. Lui (ASHRAE, 1977) Chap. 6.

70. H. TABOR, "Status Report on Selective Surfaces", in Proceedings of the International Solar Energy Congress, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 829.

   Brief review mainly on the principles for obtaining SSAS.

71. H. TABOR, "Selective Surfaces", in "Solar Energy Conversion: An Introductory Course", edited by A. E. Dixon and J. D. Leslie (Pergamon, New York, 1979) p. 253.

   Authoritative review of the general principles for obtaining SSAS and a brief discussion of several practically used coatings.

72. Y. S. TOULOUKIAN and D. P. DeWITT, "Thermal Radiative Properties: Metallic Elements and Alloys", Vol. 7 of the series "Thermophysical Properties of Matter" (IFI/Plenum, New York, 1970) 24 + 47 + 1540 + 14 pages.

   Very extensive compilation of published work on $R(\lambda)$, α, ϵ and other radiative properties. The data are given in tables and figures. Measurement techniques are treated in the introduction. The results apply to metallic elements and alloys including different surface treatments of these.

73. Y. S. TOULOUKIAN and D. P. DeWITT, "Thermal Radiative Properties: Nonmetallic Solids", Vol. 8 of the series "Thermophysical Properties of Matter" (IFI/Plenum, New York, 1972) 34 + 48 + 1763 + 41 pages.

   See [72]; the results apply to nonmetallic solids and different treatments of these.

74. Y. S. TOULOUKIAN, D. P. DeWITT and R. S. HERNICZ, "Thermal Radiative Properties: Coatings", Vol. 9 of the series "Thermophysical Properties of Matter" (IFI/Plenum, New York, 1972) 34 + 58 + 1378 + 95 pages.

   See [72]; the results apply to a large number of combinations of coatings and substrates.

75. M. VAN DER LEIJ and M. SIKKENS, "Properties of Spectrally Selective Materials", *Natuurkd.* (*Netherlands*) **A44** (1978) 19.

   Brief and popular review.

76. J. V. WIENSKOWSKI, "Selektive Absorber", in Proceedings of the 1st Deutsches Sonnenforum, Hamburg, September 26–28 1977, Vol. 2, p. 365.

77. R. M. WINEGARNER, "Selective Absorbers for Flat Plate Collectors", *Sun World* **1** (4) (1977) 12.

   Brief and popular review.

78. G. A. ZERLAUT, "Fundamental Materials Considerations for Solar Collectors", in "Critical Materials Problems in Energy Production", edited by C. Stein (Academic Press, New York, 1976) Chap. 13, page 389.

Extensive (50 pages) review of SSAS and other components of solar collectors.

3.2. Vacuum evaporation

(See also [139, 141–2, 161, 218, 306–7, 318, 427, 457, 515, 521–3, 530].)

79. N. ASHCROFT, R. AURBACH, R. BUHRMAN, H. CRAIGHEAD, W. LAMB, A. SIEVERS, R. SMALLEY, D. TROTTER, J. W. WILKINS and D. WOOD, "Optical Properties of Metallic Surfaces, Small Particles and Composite Coatings for Solar Energy Conversion Applications", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 317.

Discussion of EMT, emissivity of metals and optical properties of cermet films; mainly a survey of work of the Cornell group.

80. N. W. ASHCROFT, R. A. BUHRMAN, H. G. CRAIGHEAD, W. LAMB, A. J. SIEVERS, R. SMALLEY, D. M. TROTTER, J. W. WILKINS, L. WOJCIK and D. M. WOOD, "A study of Metal/Insulator Composite Media and Metal Surfaces for Use in Selective Absorber Systems", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 77.

See [79].

81. R. C. BASTIEN, R. R. AUSTIN and T. P. POTTENGER, "Inhomogeneous Metal/Dielectric Selective Solar Absorbers", *Proc. Soc. Photo-Opt. Instrum. Eng.* **140** (1978) 140.

Cermet coatings were produced by e-beam coevaporation from two sources. Nickel and titanium particles dispersed in Al_2O_3, Hf_2O_3, MgF_2, MgO, CeF_3, Y_2O_3 and Nd_2O_3 were studied. The combination Ni–Al_2O_3 showed the best results. Measurements of $R(\lambda)$ at room temperature were used to calculate α and ϵ (450° C). Short term TS tests and AES analysis were conducted.

82. V. A. BAUM, B. A. GARF, M. D. KUDRIASHOVA and J. D. MALEVSKY, "Effet de la Selectivité dans les Installations Solaires Energetiques", *Rev. Int. Héliotech. Fr.* 2 (1973) 33.

Multilayer interference coatings were produced by deposition of a thin nickel film and two antireflecting dielectric layers onto a copper substrate. Improved spectral selectivity was obtained by a mechanical treatment of the substrate.

83. W. BRÜNGER, "Thin Film Solar Absorber Consisting of Au-Particles in SiO_2", in Proceedings of the 2nd Internationales Sonnenforum, Hamburg, July 12–14 1978, Vol. 1 (COMPLES/DGS, 1978) p. 351.

Films were produced by codeposition of gold from a tungsten-boat and SiO_2 from an e-beam source. Hemispherical $R(\lambda)$ and ϵ were measured. TEM studies were performed.

84. W. BRÜNGER, "A Thin Film Solar Absorber Consisting of Gold Particles in Silicon Dioxide", *Vacuum* **30** (1980) 125.

See [83].

85. R. A. BUHRMAN and H. G. CRAIGHEAD, "Composite Film Selective Absorbers", in "Solar Materials Science", edited by L. E. Murr (Academic, New York, 1980) Chap. 9, p. 277.

Extensive (40 pages) report on an investigation of cermet films produced by e-beam coevaporation. Optical constants were determined for Ag–Al_2O_3, Ni–Al_2O_3, Au–Al_2O_3 and Au–MgO and compared with EMT. SSAS with graded composition profiles were designed. Hemispherical $R(\lambda)$ and temperature dependent ϵ (by calorimetry) were measured for Ni–Al_2O_3 and Pt–Al_2O_3 films. TS for $\tau < 600°$ C was verified by heating of such films in air.

86. G. BURRAFATO, G. GIAQUINTA, N. A. MANCINI, A. PENNISI and S. TROIA, "Thin Film Solar Acceptors", in "Heliotechnique and Development", Vol. 1, edited by M. A. Kettani and J. E. Soussou (Cambridge, Massachusetts, 1976) p. 180.

Thin InSb films were produced by flash evaporation onto vacuum deposited silver. The spectral selectivity is discussed in terms of QSE.

87. H. G. CRAIGHEAD, R. BARTYNSKI, R. A. BUHRMAN, L. WOJCIK and A. J. SIEVERS, "Metal/Insulator Composite Selective Absorbers", *Solar Energy Mater.* **1** (1979) 105.

    $Ni-Al_2O_3$ and $Pt-Al_2O_3$ cermet films were produced by e-beam coevaporation. EMT and the design of SSAS with graded composition are treated. Hemispherical $R(\lambda)$, ϵ (by calorimetry) and TS are reported.

88. H. G. CRAIGHEAD and R. A. BUHRMAN, "Optical Properties of Selectively Absorbing Ni/Al_2O_3 Composite Films", *Appl. Phys. Lett.* **31** (1977) 423.

    $Ni-Al_2O_3$ cermet films were produced by e-beam coevaporation. $R(\lambda)$ and TS were studied. The structure was investigated by TEM.

89. H. G. CRAIGHEAD and R. A. BUHRMAN, "Optical Properties of Selectively Absorbing Metal/Insulator Composite Films", *J. Vac. Sci. Technol.* **15** (1978) 269.

    See [88]. $V-Al_2O_3$, $V-SiO_2$, $V-MgO$, $Fe-Al_2O_3$ and $Fe-MgO$ cermet films were also studied.

90. H. G. CRAIGHEAD, R. E. HOWARD, J. E. SWEENEY and R. A. BUHRMAN, "Graded-Index $Pt-Al_2O_3$ Composite Solar Absorbers", *Appl. Phys. Lett.* **39** (1981) 29.

    Graded $Pt-Al_2O_3$ cermet films, produced by e-beam coevaporation, were coated with e-beam deposited SiO_x. The surface was then textured by reactive ion etching in CF_4. Measurements of $R(\lambda)$ gave $\alpha \approx 0.98$. The film structure was analysed by TEM and SEM.

91. L. F. DRUMMETER Jr and G. HASS, "Solar Absorptance and Thermal Emittance of Evaporated Coatings", *Phys. Thin Films* **2** (1964) 305.

    Review of coatings designed primarily for space vehicle applications, including results for SSAS of the multilayer interference type: Ge/SiO on aluminium, SiO/Ge/SiO on aluminium, SiO/Cr/SiO on aluminium, and $SiO_2/Pt/SiO_2$ on platinum. $R(\lambda)$ and TS are reported.

92. L. E. FLORDAHL and R. KIVAISI, "Vacuum Evaporated Thin Films For Solar Collectors", *Vacuum* **27** (1977) 379.

    E-beam evaporated germanium and PbS films, overlaid with SiO, were deposited onto aluminium, nickel and chromium. $R(\lambda)$ was measured. TS under humid conditions was investigated.

93. U. Kh. GAZIEV, Sh. A. FAIZIEV, V. V. LI and V. S. TRUKHOV, "Investigation of Light-Absorbing Coatings Produced by Joint Condensation of Vapors of a Metal and a Dielectric", *Geliotekh.* **16** (1980) 30 (*Appl. Solar Energy* **16** (1980) 30).

    Cermet films were produced by thermal evaporation of pellets pressed from a powdered mixture of metal (nickel, chromium) and dielectric (SiO_2, CeO_2) onto SS. Data are given on $R(\lambda)$, α, ϵ, and TS. Uniform coatings with 30 to 50 wt% nickel in SiO_2 have $\alpha = 0.92$ and $\epsilon = 0.08$.

94. M. GOLOMB, "Diffraction Gratings and Solar Selective Thin Film Absorbers: An Experimental Study", *Opt. Commun.* **27** (1978) 177.

    Films of silicon on aluminium and of carbon on copper were deposited by e-beam evaporation onto holographically produced gratings to give rough surfaces. Hemispherical $R(\lambda)$ was measured and compared to theory.

95. G. HASS, H. H. SCHROEDER and A. F. TURNER, "Mirror Coatings for Low Visible and High Infrared Reflectance", *J. Opt. Soc. Amer.* **46** (1956) 31.

    Study of vacuum deposited multilayer interference coatings: Ge/SiO on aluminium, gold and copper; SiO/Al/SiO, MgF_2/Inconel/MgF_2, SiO/Inconel/SiO and ZnS/Inconel/ZnS on aluminium.

96. C. M. HORWITZ, "New Solar Selective Surface", *Opt. Commun.* **11** (1974) 210.

    Data on hemispherical $R(\lambda)$ for aluminium-micromeshes.

97. C. M. HORWITZ, "Solar-Selective Globular Metal Films", *J. Opt. Soc. Amer.* **68** (1978) 1032.

    Particulate globular tin films were prepared by e-beam evaporation onto heated glass substrates. Specular and hemispherical $R(\lambda)$ and scattered light were measured and compared to theoretical models.

98. C. M. HORWITZ, R. C. McPHEDRAN and J. A. BEUNER, "Interference and Diffraction in Globular Metal Films", *J. Opt. Soc. Amer.* **68** (1978) 1023.

    See [97].

99. R. T. KIVAISI, "Optical Properties of Selectively Absorbing Chromium Films Deposited at Oblique Angle of Incidence", *Solar Energy Mater.* **5** (1981) 115.

Chromium films were produced by e-beam evaporation. Specular $R(\lambda)$ and $T(\lambda)$ were used to derive effective optical constants. Hemispherical $R(\lambda)$ and spectral ϵ (80° C) were determined. The spectral selectivity is believed to be caused by the nonhomogeneous character of the films.

100. R. T. KIVAISI and L. E. FLORDAHL, "Optical Behaviour of Selectively Absorbing Surfaces at Elevated Temperatures", *Solar Energy Mater.* **2** (1980) 403.

Investigation of $R(\lambda)$ at 200° C and at room temperature for the films in [92]. Composition depth profiles were obtained by AES.

101. M. M. KOLTUN, "Multilayered Black Mirror", *Zh. Priklad. Spektrosk.* **12** (1970) 350 (*Soviet J. Appl. Spectrosc.* **12** (1970) 270).

Brief report on multilayer interference coatings produced by depositing alternate layers of nickel and SiO_2 onto aluminium by thermal or e-beam evaporation. $R(\lambda)$ is given for various angles of incidence.

102. M. M. KOLTUN, "Radiation Characteristics and Stability of Selective Optical Coatings", *Geliotekh.* **6** (6) (1970) 33 (*Appl. Solar Energy* **6** (6) (1970) 65).

Properties of $Ni/SiO_2/Ni/SiO_2$ interference films are discussed.

103. M. M. KOLTUN, "Selective Coatings with Variable Ratio α_s/ϵ of the Integral Optical Coefficients", *Geliotekh.* **8** (5) (1972) 38 (*Appl. Solar Energy* **8** (5) (1972) 29).

Report of the use of multilayer interference films, consisting of nickel and ZnS, to obtain $0.12 < \alpha < 0.88$ together with a low ϵ.

104. M. D. KUDRYASHOVA, "New Selective Coatings for Collector Surfaces of Solar Plants", *Geliotekh.* **5** (4) (1969) 47 (*Appl. Solar Energy* **5** (4) (1969) 82).

Nickel films were deposited onto copper or aluminium substrates. They were antireflected by one or two dielectric coatings. Specular $R(\lambda)$ at various angles of incidence and diffuse $R(\lambda)$ were measured. TS was studied.

105. V. V. LI, Sh. A. FAIZIEV, U. Kh. GAZIEV and V. S. TRUKHOV, "Thin-Film Black-and-White Coatings for Solar Energy Collectors", *Geliotekh.* **13** (6) (1977) 52 (*Appl. Solar Energy* **13** (6) (1977) 40).

$SiO_2/Mo/SiO_2$ and $CeO_2/Mo/CeO_2$ multilayer films were deposited onto SS, aluminium and molybdenum foil by thermal evaporation. $R(\lambda)$, $\alpha \approx 0.9$ and $\epsilon \approx 0.1$ are reported.

106. R. J. H. LIN, "Evaporated Coatings for Solar Collectors", American Electroplaters' Society Second Coatings for Solar Collectors Symposium, St. Louis, USA, October 16–17 1979.

A survey of coatings produced by evaporation.

107. R. MARCHINI and R. GANDY, "Selective Absorption Properties of Lead–Sulfide–Aluminium Coatings as a Function of Lead Sulfide Thickness", *J. Appl. Phys.* **49** (1978) 390.

PbS films were deposited onto aluminium by thermal evaporation. α/ϵ up to 25 was measured. These results are compared to theory.

108. D. R. McKENZIE, "Effect of Substrate on Graphite and Other Solar Selective Surfaces", *Appl. Opt.* **17** (1978) 1884.

Graphite films were produced by e-beam evaporation onto copper, silver, nickel and titanium. Near-normal $R(\lambda)$ and TS were studied. The paper also presents a theoretical analysis of the influence of the substrate on the radiative properties of a SSAS.

109. D. R. McKENZIE, "Gold, Silver, Chromium and Copper Cermet Selective Surfaces for Evacuated Solar Collectors", *Appl. Phys. Lett.* **34** (1979) 25.

Graded cermet films of thermally evaporated gold, silver, chromium and copper dispersed in e-beam deposited Al_2O_3 and $MgO \cdot Al_2O_3$ (spinel) were studied. The films were deposited onto copper. Surfaces with $\alpha > 0.90$, $\epsilon < 0.05$ and TS for $\tau > 500°$ C are reported.

110. T. J. McMAHON and S. N. JASPERSON, "PbS/Al Selective Solar Absorbers", *Appl. Opt.* **13** (1974) 2750.

PbS was vacuum evaporated onto aluminium. α and ϵ were evaluated from $R(\lambda)$. Excellent spectral selectivity with $\alpha/\epsilon > 40$ is reported.

111. T. J. McMAHON and D. L. STIERWALT, "Cost-Effective PbS–Al Selective Solar Absorbing Panel", *Proc. Soc. Photo-Opt. Instrum. Eng.* **68** (1975) 169.

Further analysis of the surfaces of [110]. The film structure was studied by SEM. The film is unstable when exposed to UV radiation in air.

112. S. MISAWA, S. YOSHIDA and J. OHHATA, "Al_2O_3/Mo/Al_2O_3/Mo Solar Selective Absorber", *Bull. Electrotech. Lab.* (*Tokyo*) **44** (1, 2) (1980) 35.

Multilayer interference films were deposited onto SS and molybdenum. The optical properties were optimized by use of calculations. TS for $\tau < 800°$ C is reported.

113. S. MOKHTAR and W. OSMAN, "The Use of Tellurium in Thin-Film Spectrally Selective Solar Absorbing Coatings", *Opt. Acta* **28** (1981) 619.

Aluminium was antireflected by tellurium films overcoated with SiO. R is reported for $0.4 < \lambda < 2.5\,\mu$m.

114. G. A. NIKLASSON and C. G. GRANQVIST, "Selective Solar Energy Absorption by Co–Al_2O_3 Cermet Films", in Solar World Forum, International Solar Energy Society Congress, Brighton, England, August 23–28 1981, edited by D. O. Hall and J. Morton (Pergamon, New York, 1982) p. 221.

Cermet films were prepared by e-beam coevaporation onto silver surfaces and onto IR-transparent substrates. Optical constants were derived from $R(\lambda)$ and $T(\lambda)$ and compared to EMT. The structure was studied by TEM.

115. M. OKUYAMA, K. FURUSAWA and Y. HAMAKAWA, "Ni Cermet Selective Absorbers for Solar Photothermal Conversion", *Solar Energy* **22** (1979) 479.

Ni–SiO_2 and Ni–MgO cermet films were prepared by e-beam evaporation from pressed mixtures of metal and dielectric. They were deposited onto nickel and antireflected by SiO_2 films. $R(\lambda)$ and $\epsilon(\tau)$ were measured. Optical constants are reported for the films.

116. K. PARK and R. SCHMIDT, "High-Temperature Space-Stable Selective Solar Absorber Coatings", *Appl. Opt.* **4** (1965) 917.

Multilayer interference films were produced by e-beam evaporation onto molybdenum. Results are given for MgF_2/Mo/CeO_2, MgF_2/Mo/MgF_2/Mo/MgF_2, MgF_2/CeO_2/Mo/MgF_2 and Al_2O_3/Mo/Al_2O_3/Mo/Al_2O_3/Mo/Al_2O_3. Hemispherical $R(\lambda)$ and ϵ were measured at 260° C, 538° C and room temperature. UV degradation was insignificant.

117. R. PASQUETTI and F. PAPINI, "Étude et Réalisation d'une Surface Sélective Destinée a la Conversion Thermique de l'Énergie Solaire: Application a la Moyenne Temperature", *Nouv. Rev. Opt.* **7** (1966) 375.

PbS films with an antireflecting layer of ZnS were deposited on aluminium, zinc or nickel. $R(\lambda)$ is reported before and after thermal treatments at $\tau < 200°$ C.

118. M. J. PETERSON and F. H. COCKS, "The Preparation of Textured Te Thin Films with Pronounced Acicular Morphology and Concomitant High Absorptivity", *J. Mater. Sci.* **14** (1979) 2709.

Tellurium was thermally evaporated onto aluminium at an oblique angle of incidence. The strongly textured surface was studied by SEM. α was estimated from normal $R(\lambda)$ in the 0.4 to 0.7 μm range.

119. M. J. PETERSON and F. H. COCKS, "Selenium and Tellurium Selective Absorber Coatings Produced by an Oblique Vacuum Deposition Technique", *Solar Energy* **24** (1980) 249.

The films were thermally evaporated at an incidence angle of 80° onto aluminium, copper, chromium and molybdenum. Estimates of α and normal emittance are given; see [118].

120. T. SATO, K. Y. SZETO and G. D. SCOTT, "Optical Properties of Aggregated Gold on Aluminium", *Appl. Opt.* **18** (1979) 3119.

Gold was vacuum evaporated onto aluminium substrates heated to 300° C. After annealing at 300° C for 2 h, very rough $AuAl_2$ surfaces were formed. These were studied by SEM and by electron diffraction. $R(\lambda)$ was measured at various angles of incidence before and after thermal treatment. Typical results are $\alpha \approx 0.95$ and $\epsilon = 0.1$ for samples heated in air to 350° C for 190 h.

121. R. N. SCHMIDT and J. E. JANSSEN, "Selective Coatings for Vacuum-Stable High-Temperature Solar Absorbers", in Symposium on Thermal Radiation of Solids, edited by S. Katzoff, NASA SP – 55 (NASA, Washington, 1965) p. 509.

Detailed report on several kinds of SSAS: multilayer interference films with alternate layers of Al_2O_3 and molybdenum produced by thermal evaporation of Al_2O_3 and e-beam evaporation of molybdenum; Ta_2O_5 films prepared by anodization in oxalic acid or by thermal evaporation onto molybdenum; beryllium + 1% copper alloy anodized in NaOH. Hemispherical $R(\lambda)$ and ϵ were measured at $\tau < 540°$ C.

122. A. M. SCHNEIDERS and P. BEUCHERIE, "Sélectivité Spectrale par Effet de Structure de Couches Minces Déposées de Nickel et de Chrome", *J. Phys. (Paris)* **42** (1981) C1-123.

    Rough chromium and nickel films were prepared by evaporation onto SS at 550° C. They were then oxidized in air at 500° C. $\alpha \approx 0.9$, $\epsilon \approx 0.2$ and TS for $\tau < 300°$ C in air are reported.

123. G. K. WEHNER, "Auger Thin-Film Analysis as Applied to Various Aspects in Solar Energy Conversion", in Symposium on the Materials Science Aspects of Thin-Film Systems for Solar Energy Conversion, Tucson, May 20–22 1974, edited by B. O. Seraphin (University of Arizona, Tucson, 1974) p. 135.

    Composition depth profiles of $Al_2O_3/Mo/Al_2O_3$ and of silicon on silver are reported.

124. R. M. WINEGARNER, "Selective Absorber Coatings by Interference Techniques", American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, Georgia, November 9–10 1976, p. 37.

    Four-layer interference coatings were produced by thermal evaporation or by sputtering. Films with $\alpha = 0.95$ and $\epsilon = 0.06$ are reported.

125. S. YOSHIDA, "Selective Solar Absorber Coatings", *Oyo Butsuri* **45** (1976) 477.

    Multilayers of Ge/SiO on aluminium, $Al_2O_3/Mo/Al_2O_3$ on molybdenum and $Al_2O_3/Mo/Al_2O_3/Mo/Al_2O_3$ on molybdenum were investigated.

126. S. YOSHIDA and S. MISAWA, "Selective Solar Absorbers Produced by Optical Multilayer Coatings", *Bull. Electrotech. Lab. (Tokyo)* **44** (1980) 14.

    Vacuum evaporated Ge/SiO coatings on aluminium were investigated and optimized for use as SSAS.

127. H. R. ZELLER and D. KUSE, "Optical Properties of Electrically Insulating Granular Metal Films", *J. Appl. Phys.* **44** (1973) 2763.

    Discontinuous multilayer films consisting of tin particles in MgF_2 were produced by successive vacuum evaporations. $R(\lambda)$ and $T(\lambda)$ are reported.

3.3. Reactive evaporation and gas evaporation

(See also [198, 344, 536, 543, 546].)

128. F. H. COCKS and M. J. PETERSON, "Tellurium and Selenium Selective Absorber Thin Films Produced by Gas-Evaporation Methods", *J. Vac. Sci. Technol.* **16** (1979) 1560.

    Coatings were produced by gas evaporation in argon onto aluminium substrates. Normal $R(\lambda)$ (0.4 to 0.7 μm range) and normal emittance were measured. The structure was studied by SEM.

129. A. W. CZANDERNA, E. T. PRINCE and H. F. HELBIG, "Preparation and Degradation of Reactively Evaporated Black Chrome", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 34.

    Reactive evaporation of chromium in O^{18} gave metallic chromium, b-chrome, or Cr_2O_3 depending on chromium flux and O^{18} pressure. The structure was studied by SEM, AES and XPS. The structure of b-chrome is believed to be metal chromium grains in a chromium oxide matrix.

130. C. DOLAND, P. O'NEILL and A. IGNATIEV, "Particulate Nature of the Solar Absorbing Films: Gold Black", *J. Vac. Sci. Technol.* **14** (1977) 259.

    Gold was evaporated in helium gas and the particles produced were investigated by TEM. Optical data were compared with theoretical models.

131. M. C. A. FANTINI, J. R. MORO and M. ABRAMOVICH, "Thin Films of Gas-Evaporated Co for Use in Photothermal Conversion", *J. Phys. (Paris)* **42** (1981) C1-317.

    Cobalt was evaporated in mixtures of argon and oxygen and the particles produced were studied by TEM. $T(\lambda)$ measurements were compared to EMT, following the procedure in [132].

132. C. G. GRANQVIST and O. HUNDERI, "Optical Properties of Ultrafine Gold Particles", *Phys. Rev.* **B16** (1977) 3513.

Particulate gold coatings were produced by evaporation in air and analysed by TEM. Data on $T(\lambda)$ were subjected to a quantitative theoretical analysis based on various EMT. Numerous references to earlier work on "metal blacks" are given.

133. C. G. GRANQVIST and G. A. NIKLASSON, "Selective Absorption of Solar Energy in Ultrafine Chromium Particles", *Appl. Phys. Lett.* **31** (1977) 665.

A preliminary study reported more fully in [134].

134. C. G. GRANQVIST and G. A. NIKLASSON, "Ultrafine Chromium Particles for Photothermal Conversion of Solar Energy", *J. Appl. Phys.* **49** (1978) 3512.

Chromium was evaporated in a mixture of argon and air and the particles were studied by TEM. A detailed comparison of measured $T(\lambda)$ and EMT is presented. TS was found for $\tau \lesssim 200°$ C.

135. H. S. GUREV, "Thin-Film CrO$_x$ Selective Absorbers Stable Above 500° C in Proceedings of the 1977 Annual Meeting of the American Section of ISES, Orlando, Florida, June 1977, Vol. 1, edited by C. Beach and E. Fordyce (American Section of the International Solar Energy Society, Cape Canaveral, Florida) p. 5.5.

Chromium was reactively evaporated onto silver in 2×10^{-4} torr of air. The CrO$_x$ coatings were then covered with e-beam evaporated SiO$_2$. Specular $R(\lambda)$ was measured at room temperature and at 500° C. TS for short periods at 650° C.

136. G. L. HARDING, "Evaporated Chromium Black Selective Solar Absorbers", *Thin Solid Films* **38** (1976) 109.

Chromium was gas evaporated in argon onto copper substrates and the particles produced were studied by TEM. Specular $R(\lambda)$ was studied before and after themal treatments.

137. B. P. KOZYREV and O. E. VERSHININ, "Determination of Spectral Coefficients of Diffuse Reflection of Infrared Radiation from Blackened Surfaces", *Opt. Spektrosk.* **6** (1959) (*Opt. Spectrosc.* **6** (1959) 345).

Hemispherical $R(\lambda)$ measurements were performed on bismuth, zinc, tellurium and antimony "blacks" produced by evaporation in oxygen, and on carbon "blacks". Many curves show some degree of spectral selectivity.

138. CHONG-WON LEE, "Optimization of Particulate Type Selective Solar Absorber", in Proceedings of the 1977 Annual Meeting of the American Section of ISES, Orlando, Florida, June 1977, Vol. 1, edited by C. Beach and E. Fordyce (American Section of the International Solar Energy Society, Cape Canaveral, Florida, 1977) p. 4.11.

Gold was evaporated in a mixture of argon and oxygen and the particles were studied by TEM. Hemispherical $R(\lambda)$ and $T(\lambda)$ were measured. Optimization of the coatings was performed by the use of radiative transfer theory.

139. D. M. MATTOX and G. J. KOMINIAK, "Deposition of Semiconductor Films with High Solar Absorptivity", *J. Vac. Sci. Technol.* **12** (1975) 182.

Germanium and silicon were e-beam evaporated in argon (pressure < 0.02 torr). Germanium, silicon and PbS were also vacuum evaporated. Film structure was studied by SEM. Normal solar R and ϵ were measured. Films with high α had rough surfaces.

140. D. R. McKENZIE, "Selective Nature of Gold-Black Deposits", *J. Opt. Soc. Amer.* **66** (1976) 249.

Gold was evaporated from a tungsten source in nitrogen with and without addition of oxygen. $R(\lambda)$ and electrical properties are reported. Mie theory is used to explain the optical data. The role of deposited WO$_3$ is discussed.

141. D. R. McKENZIE, "Gold Black and Gold Cermet Absorbent Surfaces", *Glass* **55** (1978) 384.

See [109, 140].

142. D. R. McKENZIE, "Gold Black and Gold Cermet Absorbing Surfaces", *Gold Bull.* **11** (1978) 49.

See [109, 140].

143. P. O'NEILL, C. DOLAND and A. IGNATIEV, "Structural Composition and Optical Properties of Solar Blacks–Gold Black", *Appl. Opt.* **16** (1977) 2822.

See [130].

144. P. O'NEILL, C. DOLAND, A. IGNATIEV and A. F. HILDEBRANDT, "The Dependence of Optical Properties on the Structural Composition of Solar Absorbers", in Proceedings of the 1977 Annual Meeting of the American Section of ISES, Orlando, Florida, June 1977, Vol. 1, edited by C. Beach and E. Fordyce (American Section of the International Solar Energy Society, Cape Canaveral, Florida, 1977) p. 4.4.

145. P. O'NEILL and A. IGNATIEV, "Influence of Microstructure on the Optical Properties of Particulate Materials: Gold Black", *Phys. Rev. B* **18** (1978) 6540.

The optical properties of the gold "blacks" of [130] are interpreted in terms of EMT.

146. P. O'NEILL, A. IGNATIEV and C. DOLAND, "The Dependence of Optical Properties on the Structural Composition of Solar Absorbers: Gold Black", *Solar Energy* **21** (1978) 465.

See [145].

147. G. A. NIKLASSON and C. G. GRANQVIST, "Selective Absorption of Solar Energy by Ultrafine Metal Particles", in Proceedings of the International Solar Energy Society Congress, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 870.

See [134].

148. G. A. NIKLASSON and C. G. GRANQVIST, "Ultrafine Nickel Particles for Photothermal Conversion of Solar Energy", *J. Appl. Phys.* **50** (1979) 5500.

Nickel was evaporated in argon and the particles produced were then partially converted to NiO by heating to 400° C in air. The samples were analysed by TEM. $T(\lambda)$ was measured at $0.3 < \lambda < 30\,\mu\text{m}$ before and after heat treatments, and a detailed comparison with EMT was performed. TS was found for $\tau < 600°$ C.

149. M. J. PETERSON and F. H. COCKS, "Tellurium Selective Absorber Surfaces", *Mater. Sci. Eng.* **41** (1979) 143.

See [128].

150. S. YOSHIDA, "Antireflection Coatings on Metals for Selective Solar Absorbers", *Thin Solid Films* **56** (1979) 321.

A theoretical discussion of antireflection coatings on metal surfaces is given. TiO_x films were deposited onto titanium by reactive evaporation in oxygen with pressure from 2×10^{-4} to 10^{-5} torr. Optical constants of the TiO_x films were determined from $R(\lambda)$.

151. S. YOSHIDA, "Antireflection Coatings on Metal for Selective Solar Absorbers", *Bull. Electrotech. Lab. (Tokyo)* **44** (1980) 23.

See [150].

3.4. Sputter deposition and sputter etching

(See also [90, 124, 318, 330, 526].)

152. D. E. ACKLEY and J. TAUC, "Silicon Films as Selective Absorbers for Solar Energy Conversion", *Appl. Opt.* **16** (1977) 2806.

Films of a-silicon were prepared by r.f. sputtering in argon and then annealed at 500° C for 5 h. The optical constants of amorphous and crystalline silicon were determined from T for $1 < \lambda < 5\,\mu\text{m}$ at τ up to 800° C. Calculated α and ϵ are given.

153. R. S. BERG and G. J. KOMINIAK, "Surface Texturing by Sputter Etching", *J. Vac. Sci. Technol.* **13** (1976) 403.

Copper surfaces with a natural oxide or a thin carbon layer were sputter etched and studied by SEM. $\alpha = 0.97$ and $\epsilon = 0.3$ are given for one sample.

154. R. BLICKENSDERFER, D. K. DEARDOFF and R. L. LINCOLN, "Spectral Reflectance of TiN_x and ZrN_x as Selective Solar Absorbers", *Solar Energy* **19** (1977) 429.

Reactive sputtering of titanium and zirconium was performed on silver-coated SS in argon mixed with nitrogen, CO or oxygen. Films were also prepared by thermal oxidation of sputtered zirconium in air at 200 to 350° C. Measurements of normal $R(\lambda)$ and of emittance are reported for TiN_x, ZrN_x, ZrC_x, ZrC_xN_y and ZrO_xN_y films. Typical results are $\alpha = 0.88$ and $\epsilon(327°\,\text{C}) = 0.06$.

155. R. BLICKENSDERFER, "Metal Oxycarbonitride Solar Absorbers", in Proceedings of the Depart-

ment of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 371.

See [154]; this report also includes data for hafnium compounds and for etched $ZrAl_3$ with rough surface. TS in vacuum was investigated.

156. P. BOUCHUT and A. CHENEVAS-PAULE, "Influence de L'Hydrogene sur les Propriétés Optiques du Silicium Amorphe", *J. Phys.* (*Paris*) **42** (1981) C1-439.

The properties of a-SiH_x are reviewed. Films were prepared by r.f. sputtering of silicon in argon mixed with hydrogen. R and T were recorded and the absorption coefficient was determined.

157. G. CHASSAING, J. C. FRANÇOIS, P. GRAVIER, M. SIGRIST, L. ROUX and J. CHEVALLIER, "Spectral Selectivity of Titanium Nitride and Carbonitride Coatings", in Proceedings of the Eighth International Vacuum Congress, Cannes, France, September 22–26 1980, Vol. 1, edited by F. Abélès and M. Croset (Société Française du Vide, Paris, 1980) p. 389.

Coatings were produced by reactive sputtering of titanium in N_2, C_2H_2 or $N_2 + C_2H_2$. $R(\lambda)$ at normal and 70° incidence were used to derive the optical constants. Thermoreflectance was measured.

158. S. CRAIG and G. HARDING, "Solar Selective Properties of Rough Sputtered Copper Films", *Solar Energy Mater.* **4** (1981) 245.

Textured copper films of thickness 0.5 to 10 μm were produced by planar magnetron sputtering in argon onto glass. The morphology was studied by SEM. Hemispherical $R(\lambda)$, and ϵ (25° C) were measured. A SSAS with $\alpha \approx 0.90$ and $\epsilon \approx 0.04$ was produced by coating the rough copper film by a reactively sputtered homogeneous SS-carbide layer. TS at $\tau < 450°$ C in vacuum.

159. S. CRAIG and G. L. HARDING, "Effects of Argon Pressure and Substrate Temperature on the Structure and Properties of Sputtered Copper Films", *J. Vac. Sci. Technol.* **19** (1981) 205.

Magnetron sputtered copper films, produced according to [158], were analysed by SEM. They are classified according to structure and surface topography.

160. S. CRAIG and G. L. HARDING, "Effects of Argon Pressure on the Structure of d.c. Cylindrical Magnetron Sputtered Thin Copper Films", *J. Vac. Sci. Technol.* **19** (1981) 754.

See [159].

161. H. G. GRAIGHEAD, R. E. HOWARD and D. M. TENNANT, "Textured Thin-Film Si Solar Selective Absorbers Using Reactive Ion Etching", *Appl. Phys. Lett.* **37** (1980) 653.

Silicon was e-beam evaporated onto molybdenum-coated SS and then textured by reactive ion-etching using argon mixed with oxygen and $CClF_2$. The structure was studied by SEM. SSAS with $\alpha \approx 0.9$, ϵ (200° C) ≈ 0.2 and TS at $\tau < 500°$ C in air are reported.

162. P. M. CURMI and G. L. HARDING, "Surface Texturing of Copper by Sputter Etching with Applications for Solar Selective Absorbing Surfaces", *J. Vac. Sci. Technol.* **17** (1980) 1320.

Textured copper surfaces were produced by sputter etching bulk copper sheet seeded by a flux of titanium atoms in a planar magnetron system. The surfaces were studied by SEM. A typical SSAS had $\alpha \approx 0.90$ and ϵ (25° C) ≈ 0.10.

163. S. EBISAWA, "Coated Method of Solar-Selective Absorber Onto Pipe", *J. Vac. Soc. Jpn.* **22** (1979) 118 (*Shinku* **22** (1979) 46).

An r.f. sputtering apparatus is described. $R(\lambda)$ is reported for HfC_x films on hafnium.

164. S. EBISAWA, S. GONDA, S. SAWADA, S. KOMIYA and Y. NOGUCHI, "Fabrication of Long Collector Pipes Coated with ZrC_x/Zr Selective Absorber", *Bull. Electrotech. Lab.* (*Tokyo*) **44** (1980) 65.

An r.f. sputtering apparatus is described.

165. S. EBISAWA, H. IHARA and F. SHINOKI, "Solar-Selective Surface Utilizing Zirconium Carbide Film", *J. Vac. Soc. Jpn.* **21** (1978) 113 (*Shinku* **21** (1978) 1).

ZrC_x films were produced by reactive r.f. sputtering in argon mixed with CH_4 onto zirconium. XPS studies showed that the films were mixtures of ZrC and carbon. A SSAS with $\alpha = 0.90$, $\epsilon = 0.05$ and TS at $\tau < 800°$ C is reported. A thin oxide overlayer was found to further increase α.

166. S. EBISAWA, H. IHARA and F. SHINOKI, "ZrC_x/Zr Solar Selective Absorber", *Bull. Electrotech.*

Lab. (*Tokyo*) **44** (1980) 46.

See [165]; this report also contains data for HfC_x films on hafnium and for MoC_x films on molybdenum.

167. S. EBISAWA and Y. NAKAYAMA, "Coating of Metal–Carbide HfC_x/Hf Solar Selective Absorber onto Pipes", *Bull. Electrotech. Lab.* (*Tokyo*) **44** (1980) 61.

Discussion of r.f. sputtering of hafnium in argon mixed with CH_4 onto SS pipes.

168. J. C. C. FAN, "Selective-Black Absorbers Using Sputtered Cermet Films", *Thin Solid Films* **54** (1978) 139.

Review of the work in [170, 171]. EMT calculations of optical properties of composite films are included.

169. J. C. C. FAN, "Sputtered Films for Wavelength-Selective Applications", *Thin Solid Films* **80** (1981) 125.

Review of the work in [170, 171].

170. J. C. C. FAN and S. A. SPURA, "Selective Black Absorbers Using r.f. sputtered Cr_2O_3/Cr Cermet Films", *Appl. Phys. Lett.* **30** (1977) 511.

Films were prepared by r.f. co-sputtering from two targets. Optical constants for $0.3 < \lambda < 5\,\mu m$ were evaluated from R and T. $Cr–Cr_2O_3$ composite films overcoated with Cr_2O_3 and deposited onto molybdenum-coated SS had $\alpha > 0.9$, $\epsilon < 0.1$ and TS at $\tau < 300°$ C in air.

171. J. C. C. FAN and P. M. ZAVRACKY, "Selective Black Absorbers Using MgO/Au Cermet Films", *Appl. Phys. Lett.* **29** (1976) 478.

Films were prepared by r.f. sputtering in argon from a composite target. Optical constants for $0.3 < \lambda < 5\,\mu m$ were evaluated from R and T. A SSAS with $\alpha > 0.9$, $\epsilon < 0.1$ and TS on molybdenum-coated SS at $\tau < 400°$ C in air is reported.

172. L. R. GILBERT, R. MESSIER and R. ROY, "Black Germanium Solar Selective Absorber Surfaces", *Thin Solid Films* **54** (1978) 149.

Non-crystalline germanium films were prepared by r.f. sputtering in argon. Etching in 30% H_2O_2 produced very rough surfaces as found by SEM. The best surfaces had $\alpha = 0.97$. Some results are given on TS.

173. J. I. GITTLEMAN, "Application of Granular Semiconductors to Photothermal Conversion of Solar Energy", *Appl. Phys. Lett.* **28** (1976) 370.

Cermet films were produced by cosputtering of germanium and Al_2O_3. $R(\lambda)$ was measured and compared with EMT.

174. J. I. GITTLEMAN, "Composite Dielectrics", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 305.

See [176].

175. J. I. GITTLEMAN, B. ABELES, P. ZANZUCCHI and Y. ARIE, "Optical Properties and Selective Solar Absorption of Composite Material Films", *Thin Solid Films* **45** (1977) 9.

Cermet films of W–MgO, Au–MgO, Au–CaF_2 and Si–MgO were prepared by r.f. cosputtering from composite targets. Their structure was studied by TEM and SEM. Optical constants for $0.3 < \lambda < 3\,\mu m$ were obtained from measurements of R and T and compared with EMT. Photothermal conversion efficiency versus solar concentration is reported.

176. J. I. GITTLEMAN, E. K. SICHEL and Y. ARIE, "Composite Semiconductors: Selective Absorbers of Solar Energy", *Solar Energy Mater.* **1** (1979) 93.

Cermet films of Si–CaF_2 and Ge–CaF_2 were obtained by r.f. cosputtering from composite targets. They were characterized by AES, XPS and atomic absorption analysis. Optical constants were derived from measurements of R and T. Photothermal conversion efficiency versus solar concentration was computed.

177. J. I. GITTLEMAN, E. K. SICHEL, H. W. LEHMAN and R. WIDMER, "Textured Si: A Selective Absorber for Solar Thermal Conversion", *Appl. Phys. Lett.* **35** (1979) 742.

Single-crystal silicon was textured by reactive sputter etching in a chlorine plasma, and the structure was studied by SEM. Typical results are $\alpha \approx 0.85$ and $\epsilon \approx 0.25$.

178. G. L. HARDING, "Sputtered Metal Carbide Solar Selective Absorbing Surfaces", *J. Vac. Sci. Technol.* **13** (1976) 1070.

Reactive sputtering of chromium, iron, molybdenum, nickel, tantalum, tungsten and Fe–Cr–Ni was performed in argon mixed with CH_4 onto copper. Typical results are $\alpha \approx 0.80$, $\epsilon(25° C) \approx 0.02$ and TS for $\tau < 250° C$. ϵ versus τ is reported.

179. G. L. HARDING, "Improvements in a d.c.-Reactive Sputtering System for Coating Tubes", *J. Vac. Sci. Technol.* **14** (1977) 1313.

Methods for establishing the gas flow in the sputtering system are discussed. The uniformity of a carbide coating along a copper tube was studied by measurements of R and electrical resistance.

180. G. L. HARDING, "Sputtered Metal Silicide Solar Selective Absorbing Surfaces", *J. Vac. Sci. Technol.* **15** (1978) 65.

Reactive sputtering of chromium, iron, molybdenum, tantalum, titanium, tungsten and SS was performed in argon mixed with SiH_4 onto copper, nickel, aluminium and SS. The best results for multilayer silicide films are $\alpha > 0.9$, $\epsilon(25° C) \approx 0.03$ and TS for $\tau < 500° C$. ϵ versus τ is reported.

181. G. L. HARDING, "Alternative Grading Profile for Sputtered Solar Selective Surfaces", *J. Vac. Sci. Technol.* **16** (1979) 2111.

SS-carbide coatings, comprised 3 or 5 individual layers, were deposited onto copper by magnetron sputtering. α and ϵ were studied as a function of layer thickness and composition.

182. G. L. HARDING, "Absorptance and Emittance of Metal Carbide Selective Surfaces Sputter Deposited onto Glass Tubes", *Solar Energy Mater.* **2** (1980) 469.

Reactive sputtering of chromium and SS was performed in argon mixed with C_2H_2 and both homogeneous and graded carbide films were formed on copper. Graded films had $\alpha \approx 0.94$, $\epsilon(25° C) \approx 0.04$ and TS at $\tau < 300° C$ in vacuum. ϵ versus τ is reported. A light overcoating of carbon particles gave $\alpha \approx 0.96$. The theoretical efficiency of an evacuated collector using a carbide SSAS is discussed.

183. G. L. HARDING and S. CRAIG, "Magnetron Sputtered Metal Carbide Solar Selective Absorbing Surfaces", *J. Vac. Sci. Technol.* **16** (1979) 857.

A system for magnetron sputtering onto tubes is described. Reactive sputtering of chromium, molybdenum, titanium and SS was performed in argon mixed with CH_4 or C_2H_2 and both homogeneous and graded films were produced on copper. The best graded films showed $\alpha > 0.90$ and $\epsilon(25° C) \approx 0.03$. Degradation was found to occur by diffusion.

184. G. L. HARDING and S. CRAIG, "Composition and Degradation of Graded Metal–Carbon Solar Selective Absorbing Surfaces", *Solar Energy Mater.* **4** (1981) 413.

Graded SS–carbon films were produced as discussed in [194] and analysed by AES before and after heat treatments. Degradation mechanisms are discussed.

185. G. L. HARDING and S. CRAIG, "Effect of Metal Base Layer on the Absorptance and Emittance of Sputtered Graded Metal–Carbon Selective Absorbing Surfaces", *Solar Energy Mater.* **5** (1981) 149.

Graded SS–carbon films were produced in the apparatus described in [194] onto base layers of smooth aluminium, copper, nickel and SS as well as textured copper. α varied by $< 1\%$ for the different base layers. ϵ was lowest for smooth aluminium and copper.

186. G. L. HARDING, S. CRAIG, P. CURMI and M. LAKE, "Selective Properties of Rough Sputtered Films", *J. Phys. (Paris)* **42** (1981) C1-87.

Textured copper surfaces were produced by the techniques discussed in [159, 162, 199]. After overcoating with a homogeneous SS–carbon layer, a SSAS with $\alpha \approx 0.90$, $\epsilon(25° C) \approx 0.04$ and TS for $\tau < 500° C$ in vacuum was obtained.

187. G. L. HARDING and M. R. LAKE, "Sputter Etched Metal Solar Selective Absorbing Surfaces for High Temperature Thermal Collectors", *Solar Energy Mater.* **5** (1981) 445.

Textured surfaces of copper, nickel and SS were produced by sputter etching bulk sheet or tube material seeded by a flux of titanium atoms in a cylindral magnetron system. The surfaces were studied by SEM. SSAS with $0.90 < \alpha < 0.95$, $0.10 < \epsilon(25° C) < 0.25$ and TS for $\tau < 500° C$ in vacuum and $\tau < 400° C$ in air are reported. Degradation mechanisms are discussed.

188. G. L. HARDING, D. R. McKENZIE and B. WINDOW, "The d.c. Sputter Coating of Solar-Selective Surfaces onto Tubes", *J. Vac. Sci. Technol.* **13** (1976) 1073.

A cylindral sputtering apparatus for coating glass tubes is briefly described.

189. G. L. HARDING and T. T. MOON, "Calorimetric Measurement of Absorptance and Emittance of the Sydney University Evacuated Collector", *Solar Energy* **26** (1981) 281.

A method for the measurement of α and ϵ for whole evacuated tubular collectors is described. Results are given for SS-carbide and CrC_x coatings on copper.

190. G. L. HARDING and I. T. RITCHIE, "DC Reactively Sputtered Metal Carbide and Metal Silicide Selective Absorbing Surfaces", in Proceedings of the International Solar Energy Society Conference, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 845.

See [178, 180].

191. G. L. HARDING and B. WINDOW, "Graded Metal Carbide Solar Selective Surfaces Coated onto Glass Tubes by a Magnetron Sputtering System", *J. Vac. Sci. Technol.* **16** (1979) 2101.

Preliminary report on the work described in [182].

192. G. L. HARDING and B. WINDOW, "Materials Problems in Evacuated Solar Energy Collectors", *J. Phys. (Paris)* **42** (1981) C1-173.

Review of the authors' work on SSAS of the metal–carbon type.

193. G. L. HARDING, B. WINDOW, C. HORWITZ, A. R. COLLINS and D. R. McKENZIE, "Production and Properties of Selective Surfaces Coated onto Glass Tubes by a Magnetron Sputtering System", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1912.

See [194]. The effect of heat treatment on $R(\lambda)$ and ϵ is discussed.

194. G. L. HARDING, B. WINDOW, D. R. McKENZIE, A. R. COLLINS and C. M. HORWITZ, "Cylindrical Magnetron Sputtering System for Coating Solar Selective Surfaces onto Batches of Tubes", *J. Vac. Sci. Technol.* **16** (1979) 2105.

The construction and operation of a cylindrical magnetron system for coating 1.5 m long tubes with SS–carbide SSAS is described.

195. C. H. HENAGER Jr, "Reflectance Modification Through Controlled Surface Texturing by Sputter Etching", *Solar Energy Mater.* **4** (1981) 403.

Textured surfaces were produced by sputter etching of bulk copper in the presence of SS. The structure was studied by SEM. Moderately good SSAS were obtained.

196. C. M. HORWITZ, "Vacuum Preparation of Antireflecting Glass", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. M. Glenn (Pergamon, New York, 1979) p. 1935.

Reactively sputtered SnO_2 on glass was masked with a discontinuous aluminium layer and then sputter etched. The rough films thus produced were overcoated by sputtered copper to form a SSAS with, typically, $\alpha = 0.9$ and $\epsilon = 0.06$.

197. H. IHARA, S. EBISAWA and A. ITOH, "Solar-Selective Surface of Zirconium Carbide Film", in Proceedings of the Seventh International Vacuum Congress and Third International Conference on Solid Surfaces, Vienna, September 12–16 1977, Vol. 2, edited by R. Dobrozemsky, F. Rüdenauer, F. P. Viehböck and A. Breth (R. Dobrozemsky, F. Rüdenauer, F. P. Viehböck and A. Breth, Vienna, 1977) p. 1813.

See [165].

198. J. LAFAIT, J.-M. BEHAGHEL, S. BERTHIER and J. RIVORY, "Surfaces Sélectives Rugueuses de Nitrure de Titane: Propriétés Optiques et Modélisation", *J. Phys. (Paris)* **42** (1981) C1-133.

TiN_x films were prepared by reactive sputtering. $R(\lambda)$ was measured and the optical constants were derived. Rough TiN_x surfaces were produced by activated reactive e-beam evaporation. $R(\lambda)$ of these surfaces were compared with a theoretical model and SSAS with $\alpha = 0.92$ and $\epsilon(300° C) = 0.19$ were predicted for optimized coatings.

199. M. R. LAKE and G. L. HARDING, "Cylindrical Magnetron Co-sputter Etching of Copper with Applications for Solar Selective Absorbing Surfaces", *J. Vac. Sci. Technol.* **19** (1981) 173.

Textured copper surfaces were produced by sputter etching bulk copper sheet seeded by a flux of titanium atoms in a cylindrical magnetron system. The surfaces were studied by SEM. An optimized SSAS has $\alpha \approx 0.92$, $\epsilon(25^\circ \text{C}) \approx 0.18$ and TS for $\tau < 500^\circ$ C in vacuum.

200. R. L. LINCOLN, D. K. DEARDOFF and R. BLICKENSDERFER, "Development of ZrN_xO_y Films for Solar Absorbers", *Proc. Soc. Photo-Opt. Instrum. Eng.* **68** (1975) 161.

Preliminary results for the work reported in [154].

201. D. R. McKENZIE, "Production of Solar Absorbing Cermet Films by Dual Cathode d.c. Magnetron Sputtering", *Thin Solid Film* **62** (1979) 317.

Methods for grading the composition of cosputtered $Fe-SiO_x$ and $Cu-Al_2O_3$ cermet films are described. $\alpha = 0.90$, $\epsilon(25^\circ \text{C}) = 0.04$ and TS for $\tau < 400^\circ$ C in vacuum.

202. D. R. McKENZIE, "Properties of Solar Absorbing Films Produced by an In-Line Sputter Coating Plant", *J. Vac. Sci. Technol.* **19** (1981) 181.

The production of graded SS–carbide coatings, using the sputter plant in [178], is discussed.

203. D. R. McKENZIE and L. M. BRIGGS, "Properties of Hydrogenated Carbon Films Produced by Reactive Magnetron Sputtering", *Solar Energy Mater.* **6** (1981) 97.

Transparent carbon films were prepared by reactive sputtering in argon mixed with C_2H_2. The structure was studied by TEM and electron microprobe analysis. Optical constants for $0.4 < \lambda < 0.7\,\mu$m were obtained from measurement of R and T. A structural model was proposed and used to explain the thermal degradation at $\tau > 300^\circ$ C.

204. D. R. McKENZIE, B. WINDOW, G. L. HARDING, A. R. COLLINS and D. W. J. MACKEY, "In-Line Production System for Sputter Deposition of Graded Index Solar Absorbing Films", *J. Vac. Sci. Technol.* **19** (1981) 93.

A magnetron sputtering system for producing SSAS on 1.4 m long glass tubes is described.

205. J. A. McMILLAN, D. E. SOULE, R. T. KAMPWIRTH and E. M. PETERSON, "Role of Spectral Selectivity in Hybrid Solar Energy Conversion", in Solar Diversification, Proceedings of the American Section of the International Solar Energy Society Meeting, Denver, August 28–31 1978, Vol. 2, edited by K. W. Böer and G. E. Frank (American Section of the International Solar Energy Society, Cape Canaveral, 1978) p. 300.

Optimization of the efficiency of a hybrid photovoltaic–photothermal system is discussed. Results on α and ϵ are given for a-SiH_x films produced by d.c. magnetron sputtering and CVD.

206. R. MESSIER, S. V. KRISHNASWAMY, L. R. GILBERT and P. SWAB, "Black a-Si Solar Selective Absorber Surfaces", *J. Appl. Phys.* **51** (1980) 1611.

R.f. sputtered a-silicon films were etched in a solution of HF and HNO_3. The textured surfaces thus produced were studied by SEM. $R < 0.02$, was found for $\lambda < 1\,\mu$m.

207. I. T. RITCHIE, "The Structure of Reactively Sputtered Metal Carbide and Metal Silicide Solar Selective Absorbers", *Thin Solid Films* **72** (1980) 65.

Magnetron sputtering of titanium was performed in argon mixed with CH_4 or SiH_4, and the produced carbide and silicide films were studied by TEM, electron diffraction and electron microprobe analysis. The films were found to consist of small particles of TiC_x or $TiSi_x$ embedded in a porous matrix of carbon or silicon.

208. I. T. RITCHIE and G. L. HARDING, "Sputtered Metal Carbide and Metal Silicide Solar Absorbing Surface", *Thin Solid Films* **57** (1979) 315.

Films of FeC_x and $FeSi_x$ were produced by reactive sputtering in argon mixed with CH_4 or SiH_4. Optical constants for $0.3 < \lambda < 2.5\,\mu$m were obtained from R and T and compared to EMT. The best graded films had $\alpha \approx 0.94$ and $\epsilon(25^\circ \text{C}) \approx 0.03$.

209. J. RIVORY, J. M. BEHAGHEL, S. BERTHIER and J. LAFAIT, "Optical Properties of Substoichiometric TiN_x", *Thin Solid Films* **78** (1981) 161.

Films of TiN_x were produced by reactive sputtering. Optical constants for $0.3 < \lambda < 2.5\,\mu$m were determined by Kramers–Kronig analysis of $R(\lambda)$ and interpreted in terms of interband and intraband transitions. See also [198].

210. K. SENZAKI, F. SHINOKI, S. YOSHIDA and S. MISAWA, "Solar Selective Absorbers Fabricated by $Zr-CH_4$ Reactive Sputtering", *Bull. Electrotechn. Lab.* (*Tokyo*) **44** (1980) 55.

ZrC_x films were sputter deposited onto glass, quartz and SS. Optical properties were studied as a function of CH_4 partial pressure.

211. M. SIGRIST, G. CHASSAING, J. C. FRANÇOIS, P. GRAVIER, L. ARMAND, R. PIERRISNARD, L. ROUX, D. PAILHAREY, P. KAYOUN and J. CHEVALLIER, "Propriétés Optiques des Nitrures et Carbonitrures de Titane – Selectivité Spectrale", *J. Phys. (Paris)* **42** (1981) C1-453.

    Coatings of TiN_x and TiC_xN_y were produced by reactive sputtering onto titanium at 300° C in a mixture of argon, nitrogen and C_2H_2. Specular R and thermoreflectance were measured for $0.3 < \lambda < 5\ \mu m$. The bandstructure of these compounds is discussed.

212. M. SIKKENS and J. C. FRANCKEN, "Spectral Selective Properties of Nickel Carbide with Varying Carbon Content: Interpretation in Terms of an Electron Gas", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1907.

    Films of NiC_x were produced by sputtering in argon mixed with CH_4. $R(\lambda)$, $T(\lambda)$ and electrical resistivity were measured and compared with a theoretical model.

213. M. SIKKENS, "Spectrally Selective Absorption in Nickel Carbide and Nickel Nitride Films", *J. Phys. (Paris)* **42** (1981) C1-465.

    Films of NiC_x and NiN_x were prepared by reactive sputtering in argon mixed with CH_4 or nitrogen. They were studied by X-ray diffraction, XPS and electrical resistivity. Optical constants for $0.4 < \lambda < 2.5\ \mu m$ were obtained from R and T and compared with theory.

214. D. E. SOULE and G. T. REEDY, "Infrared Spectra of the Hydrogenated Amorphous Silicon Layers on Metallic Substrates for Solar Absorbers", *Thin Solid Films* **63** (1979) 175.

    Films of a-SiH_x were produced by d.c. reactive sputtering in hydrogen and by r.f. glow-discharge deposition in SiH_4. R for $2.5 < \lambda < 25\ \mu m$ was measured and discussed.

215. P. SWAB, S. V. KRISHNASWAMY and R. MESSIER, "Characterization of Black Ge Selective Absorbers", *J. Vac. Sci. Technol.* **17** (1980) 362.

    R.f. sputtered a-germanium films were etched in H_2O_2. The textured surfaces thus produced were studied by SEM and X-ray diffraction. $0.97 < \alpha < 0.99$ and $\epsilon \gtrsim 0.4$ was obtained.

216. J. A. THORNTON, "Large Area Magnetron Sputtering for Depositing Solar Collector Coatings", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 63.

    The sputtering process is reviewed and compared with electroplating. The properties of sputtered coatings – particularly of metal oxides – are discussed, and cost estimates are given.

217. J. A. THORNTON, "Sputter Deposited Selective Absorber Coatings", in American Electroplaters' Society Second Coatings for Solar Collectors Symposium, St. Louis, October 16–17 1979.

    See [216].

218. J. A. THORNTON, "Vacuum Deposited Selective Absorber Coatings for Solar Receivers", *SAMPE Quarterly* **12** (1980) 33.

    Review of vacuum deposition methods, primarily sputtering, and of the properties of coatings produced by these methods.

219. J. A. THORNTON, "Sputter Deposited Selective Absorber Coatings", *Plating Surf. Finish.* **67** (10) (1980) 46.

    See [218].

220. J. A. THORNTON and J. L. LAMB, "Sputter-Deposited $Pt–Al_2O_3$ Selective Absorber Coatings", *Thin Solid Films* **83** (1981) 377.

    Three types of SSAS were investigated: (i) a $Pt–Al_2O_3$ cermet with linearly graded composition, antireflected by an Al_2O_3 layer, deposited onto platinum-coated glass, (ii) a uniform $Pt–Al_2O_3$ cermet, with an Al_2O_3 antireflection layer, deposited onto platinum, chromium, and molybdenum-coated glass, (iii) $Al_2O_3/M/Al_2O_3$, with M being a uniform $Pt–Al_2O_3$ cermet, deposited onto platinum, chromium, and molybdenum-coated glass. All films were produced from cylindrical-post magnetron sources. Their cross-sectional composition was studied by AES. Typical results are $\alpha = 0.90$ and $0.10 < \epsilon < 0.13$. TS for $\tau < 600°$ C was found for platinum-coated substrates.

221. J. A. THORNTON, A. S. PENFOLD and J. L. LAMB, "Sputter-deposited $Al_2O_3/Mo/Al_2O_3$ Selective Absorber Coatings", *Thin Solid Films* **72** (1980) 101.

Three layer coatings were produced by large area magnetron sputtering onto molybdenum-coated SS. The films have $0.92 < \alpha < 0.95$, $0.06 < \epsilon(20° C) < 0.10$ and TS at $\tau < 700° C$ in vacuum and at $\tau < 550° C$ in air.

222. S. J. WALKER and D. R. McKENZIE, "Magnetron Sputtering of Solar Coatings Inside Tubes", *J. Vac. Sci. Technol.* **19** (1981) 700.

Description of a magnetron sputtering system for making SSAS.

223. F. W. WOOD and R. BLICKENSDERFER, "Stabilization of Absorber Stacks Containing Zr or Ti Compounds on Ag", *Thin Solid Films* **39** (1976) 133.

See [154]. Degradation mechanisms and ways to increase TS are discussed.

224. J. O. WHITE, T. R. KIRST and J. TAUC, "Amorphous Silicon as a Selective Absorber of Solar Energy: A Spectral Emissivity Study", *Appl. Opt.* **17** (1978) 2427.

Films of a-silicon were produced by r.f. sputtering and then annealed. The spectral emittance was measured at 400, 600 and 800° C for $3 < \lambda < 6.3\,\mu m$ and the absorption coefficient was calculated.

225. W. ZERNIAL, "Entwicklung und Optimierung eines Hermetich Verschlossenen Kollektors mit Gasfüllung/Selektive Schichten", in "Statusbericht Sonnenenergie" Vol. 1 (VDI-Verlag, Düsseldorf, 1980) p. 9.

Textured nickel films were prepared by reactive sputtering in argon mixed with hydrogen onto hot substrates of aluminium, copper, SS and glass. Coatings with $\alpha = 0.98$ and $\epsilon(40° C) = 0.06$ were obtained. Various durability tests were conducted.

226. J. J. ZYBERT and D. R. McKENZIE, "Enhancement of Absorptance of Selective Coatings with Colloidal Films", *Solar Energy Mater.* **6** (1981) 107.

SS–carbide films on copper-coated glass were produced according to [204]. α increases typically from 0.70 to 0.94, while ϵ is practically unaffected, when a layer of colloidally co-deposited carbon and silicon particles is applied as discussed in [515, 530].

3.5. Chemical vapour deposition and related techniques

(See also [205, 214, 521–3].)

227. D. D. ALLRED, "Selective Surfaces by Chemical Vapor Deposition", in American Electroplaters' Society Second Coatings for Solar Collectors Symposium, St. Louis, October 16–17 1979.

Review of the work of the University of Arizona group on crystalline and amorphous silicon, b-molybdenum, and molybdenum metal films.

228. D. C. BOOTH, D. D. ALLRED and B. O. SERAPHIN, "Stabilized CVD Amorphous Silicon for High Temperature Photothermal Solar Energy Conversion", *Solar Energy Mater.* **2** (1979) 107.

Amorphous silicon was produced by pyrolytic decomposition of SiH_4 in the presence of dopant gases (C_2H_2, NH_3, B_2H_6, GeH_4). The samples were characterized by TEM, X-ray diffraction, SIMS, electron microprobe analysis and ESR. Refractive index and absorption coefficient were determined. Carbon-doping gave stable a-silicon at $\tau < 1000° C$.

229. D. C. BOOTH, D. D. ALLRED and B. O. SERAPHIN, "Retarding Crystallization of CVD Amorphous Silicon by Alloying", *J. Non-Cryst. Solids* **35/36** (1980) 213.

The crystallization behaviour of a-silicon doped with carbon, nitrogen, boron or germanium was investigated; see [228].

230. D. C. BOOTH, M. JANAI, G. WEISER, D. D. ALLRED and B. O. SERAPHIN, "Chemical Vapor Deposited Amorphous Silicon for Use in Photothermal Conversion", *Proc. Soc. Photo-Opt. Instrum. Eng.* **161** (1978) 72.

231. D. C. BOOTH and B. O. SERAPHIN, "Amorphous Silicon Absorbers for Photothermal Solar Energy Conversion", in Proceedings of the Second Annual Conference on Absorber Surfaces for

Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 113.

See [228].

232. G. E. CARVER, "CVD Molybdenum Thin Films in Photothermal Solar Converters", *Solar Energy Mater.* **1** (1979) 357.

Films of b-molybdenum were produced by pyrolytic decomposition of $Mo(CO)_6$ in the presence of oxygen and a subsequent anneal in helium mixed with hydrogen. After overcoating with Si_3N_4, surfaces with $\alpha \approx 0.91$ and low ϵ were obtained.

233. G. E. CARVER, "Chemically Vapor Deposited Molybdenum Films of High Infrared Reflectance", *Thin Solid Films* **63** (1979) 169.

See [232].

234. G. E. CARVER and E. E. CHAIN, "CVD Molybdenum Films of High Infrared Reflectance and Significant Solar Absorptance", *J. Phys.* (*Paris*) **42** (1981) C1-203.

Films of highly IR-reflecting molybdenum metal and of b-molybdenum were produced as in [232, 245]. Reflecting films coated with silicon and Si_3N_4 gave $\alpha \approx 0.75$ and low ϵ. TS was obtained for $\tau < 500^\circ$ C in vacuum.

235. G. E. CARVER and B. O. SERAPHIN, "CVD Molybdenum Films of High Infrared Reflectance", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 99.

236. E. E. CHAIN, G. E. CARVER and B. O. SERAPHIN, "Highly Reflecting Molybdenum Thin Films Having Significant Solar Absorptance", *Thin Solid Films* **72** (1980) 59.

See [234].

237. E. E. CHAIN, K. A. GESHEVA and B. O. SERAPHIN, "Chemically Vapor-Deposited Black Molybdenum Films of High IR Reflectance and Significant Solar Absorptance", *Thin Solid Films* **83** (1981) 387.

Films of b-molybdenum were produced as in [232, 245]. Their composition was analysed by AES. b-molybdenum overcoated with Si_3N_4 and deposited onto SS gave $\alpha \approx 0.93$, low ϵ, and TS for $\tau < 500^\circ$ C in vacuum and $\tau < 350^\circ$ C in air.

238. E. E. CHAIN, K. SESHAN and B. O. SERAPHIN, "Optical and Structural Properties of Black Molybdenum Photothermal Converter Layers Deposited by the Pyrolysis of $Mo(CO)_6$", *J. Appl. Phys.* **52** (1981) 1356.

Films of b-molybdenum were prepared as in [232]. X-ray and electron diffraction, electron microprobe analysis and AES showed that the coatings were Mo–MoO_2 composites.

239. J. J. CUOMO, J. M. WOODALL and T. H. DiSTEFANO, "Dendritic Tungsten for Solar Thermal Conversion", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 133.

240. J. J. CUOMO, J. F. ZIEGLER and J. M. WOODALL, "New Concept for Solar–Thermal Energy Conversion", *Appl. Phys. Lett.* **26** (1975) 557.

Dendritic tungsten films were prepared by hydrogen-reduction of WF_6 at atmospheric pressure onto heated substrates of sapphire, tungsten and SS. The structure was studied by SEM. Surfaces with $\alpha \approx 0.96$ and $\epsilon \approx 0.3$ are reported.

241. T. H. DiSTEFANO, G. D. PETTIT and A. A. LEVI, "The Reflectance of Dendritic-Tungsten Surfaces", *J. Appl. Phys.* **50** (1979) 4431.

Dendritic tungsten films were prepared as in [240]. $R(\lambda)$ was explained in terms of a geometric optical model for multiple reflections.

242. T. H. DiSTEFANO, G. D. PETTIT, J. M. WOODALL and J. J. CUOMO, "Conformal Antireflective Coatings on a Textured Tungsten Surface", *Appl. Phys. Lett.* **32** (1978) 676.

Dendritic tungsten films were prepared as in [240] and an antireflecting WO_3 coating was applied by anodization. Small SSAS with $\alpha \approx 0.9$, $\epsilon(300^\circ \text{ C}) \approx 0.18$ and TS for $\tau < 275^\circ$ C in air are reported.

243. A. DONNADIEU, J. P. FERRATON, J. M. BERGER, A. DIVRECHY, C. RAISIN, J. ROBIN and

D. C. BOOTH, "The Effects of Surface Characteristics on the Visible and UV Optical Properties of CVD Amorphous Silicon Films", *Solar Energy Mater.* 2 (1980) 201.

Films of a-silicon were produced by pyrolytic decomposition of SiH_4 onto heated quartz substrates. The structure was studied by X-ray and electron diffraction and by SEM. $R(\lambda)$ for $0.1 < \lambda < 2.5\ \mu m$ was measured and discussed.

224. A. DONNADIEU, G. WEISER and J. BEICHLER, "The effect of Film Thickness on the Reflectivity of Glow-Discharge Amorphous Silicon", *Solar Energy Mater.* 4 (1981) 455.

Films of a-silicon were produced by an r.f. discharge in argon mixed with SiH_4. Diffuse and hemispherical R was measured for $0.2 < \lambda < 2.5\ \mu m$.

245. K. A. GESHEVA, E. E. CHAIN and B. O. SERAPHIN, "Black Molybdenum Photothermal Converter Layers Deposited by Pyrolytic Hydrogen Reduction of MoO_2Cl_2", *Solar Energy Mater.* **3** (1980) 415.

Films of b-molybdenum were produced by pyrolytic hydrogen reduction of MoO_2Cl_2 at $500 < \tau < 710°$ C onto different substrates. The composition was studied by electron microprobe analysis and AES. After overcoating with Si_3N_4, films with $\alpha = 0.94$, $\epsilon \approx 0.3$ and TS for $\tau < 500°$ C in vacuum were obtained.

246. K. A. GESHEVA, K. SESHAN and B. O. SERAPHIN, "Composition and Microstructure of Black Molybdenum Photothermal Converter Layers Deposited by the Pyrolytic Hydrogen Reduction of MoO_2Cl_2", *Thin Solid Films* **79** (1981) 39.

Films of b-molybdenum were prepared as in [245]. A structural characterization by X-ray diffraction, SEM, TEM and AES showed that the films are Mo–MoO_2 composites.

247. R. W. GRIFFITH, "Amorphous Semiconductors in Photovoltaic and Solar Thermal Conversion", in Proceedings of the International Solar Energy Society Congress, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 638.

Films of a-SiB_x were produced by glow-discharge decomposition of SiH_4 mixed with B_2H_6. Their utilization as SSAS is discussed.

248. D. P. GRIMMER, K. C. HERR and W. J. McCREARY, "A Possible Selective Solar Photothermal Absorber: Ni Dendrites Formed on Al Surfaces by the CVD of $Ni(CO)_4$", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, Georgia, November 9–10 1976, p. 79.

Dendritic nickel films were formed by pyrolytic decomposition of $Ni(CO)_4$ onto aluminium. They were studied by SEM. Surfaces with $\alpha \approx 0.95$ and $\epsilon(100°\ C) \approx 0.4$ are reported.

249. D. P. GRIMMER, K. C. HERR and W. J. McCREARY, "Possible Selective Solar Photothermal Absorber: Ni Dendrities Formed on Al Surfaces by the CVD of $Ni(CO)_4$", *J. Vac. Sci. Technol.* **15** (1978) 59.

See [248].

250. H. S. GUREV, "Optical Properties of Thin-Film Refractory Metals", *Proc. Soc. Photo-Opt. Instrum. Eng.* **85** (1976) 32.

Brief report showing $R(\lambda)$ for b-molybdenum produced by hydrogen-reduction of $MoCl_5$.

251. H. S. GUREV, R. E. HAHN and K. D. MASTERSON, "High Temperature Stable, Spectrally Selective Solar Absorbers for Thermochemical Hydrogen Production", *Int. J. Hydrogen Energy* 2 (1977) 259.

A review of the work of the University of Arizona group on silicon-based SSAS.

252. H. S. GUREV and B. O. SERAPHIN, "Progress in Chemical Vapour Deposition of Thin Films for Solar Energy Conversion", in Proceedings of the Conference on Chemical Vapor Deposition, 5th International Conference, Fulmer, 1975, edited by J. M. Blocher Jr, H. E. Hintermann and L. H. Hall (Princeton University, Princeton, 1975) p. 667.

Silicon-based absorber stacks were produced by CVD and deposited onto a silver layer. R was measured at 25 and 500° C. The possibility of obtaining improved absorber stacks and the feasibility of CVD for SSAS are discussed.

253. R. E. HAHN and B. O. SERAPHIN, "Thick Semiconductor Films for Photothermal Solar Energy Conversion", *J. Vac. Sci. Technol.* **12** (1975) 905.

Silicon overcoated with Si_3N_4 was deposited onto silver by CVD. R was measured at 20 and 500° C. Coatings with $\alpha \approx 0.75$, low ϵ and TS for $\tau < 450°$ C in vacuum are reported.

254. J. C. HAYGARTH, "Chemical Vapor Deposition and Solar Thermal Energy Conversion", *Thin Solid Films* **72** (1980) 51.

A review of CVD and of the properties of SSAS produced by this technique.

255. M. JANAI, D. D. ALLRED, D. C. BOOTH and B. O. SERAPHIN, "Optical Properties and Structure of Amorphous Silicon Films Prepared by CVD", *Solar Energy Mater.* **1** (1979) 11.

Films were deposited by pyrolytic decomposition of SiH_4 onto hot substrates, and studied by optical measurements and X-ray diffraction. The influence of deposition temperature and annealing on the crystallization was studied.

256. M. JANAI and B. KARLSSON, "Temperature Variation of the Absorption Edge of CVD Amorphous and Polycrystalline Silicon", *Solar Energy Mater.* **1** (1979) 387.

R and T of CVD-produced amorphous and polycrystalline silicon films were measured at $25 < \tau < 500°$ C. The optical absorption coefficient and refractive index were calculated.

257. M. OKUYAMA, K. SAJI, T. ADACHI, H. OKAMOTO and Y. HAMAKAWA, "Selective Absorber Using Glow-Discharge Amorphous Silicon for Solar Photothermal Conversion", *Solar Energy Mater.* **3** (1980) 405.

Doped a-silicon films were produced by plasma decomposition of SiH_4 mixed with hydrogen and B_2H_6. Optical constants were determined for $0.4 < \lambda < 10\,\mu m$ from R and T. a-silicon overcoated with TiO_2 and SiO_2 gave surface layers on aluminium with $\alpha \approx 0.8$ and low ϵ.

258. R. OLAISON, H. NORSTRÖM, B. KARLSSON, A. ALNAIMI, S. BERG and L. P. ANDERSSON, "Optical Absorption Edges in Hydrogenated i-Carbon Films", in Proceedings of the Eighth International Vacuum Congress, Cannes, September 22–26 1980, Vol. 1, edited by F. Abélès and M. Croset (Société Française du Vide, Paris, 1980) p. 332.

"Diamond-like" carbon films were grown from plasma excited hydrocarbon gases. $R(\lambda)$ of films deposited onto a SS substrate showed moderate spectral selectivity.

259. G. D. PETTIT, J. J. CUOMO, T. H. DiSTEFANO and J. M. WOODALL, "Solar Absorbing Surfaces of Anodized Dendritic Tungsten", *IBM J. Res. Dev.* **22** (1978) 372.

See [242].

260. E. RANDICH and D. D. ALLRED, "Chemically Vapor-Deposited ZrB_2 as a Selective Solar Absorber", *Thin Solid Films* **83** (1981) 393.

Coatings of TiB_2 and ZrB_2 were CVD-deposited onto graphite by hydrogen-reduction of BCl_3 and $TiCl_4$ or $ZrCl_4$. Their structure was studied by SEM. TiB_2 had $0.46 < \alpha < 0.59$, $0.06 < \epsilon(150° C) < 0.09$ and TS for $\tau < 325°$ C in air. ZrB_2 had $0.67 < \alpha < 0.77$, $0.06 < \epsilon(150° C) < 0.09$ and TS for $\tau < 525°$ C in air. A Si_3N_4 coating on ZrB_2 gave $\alpha \approx 0.93$ and an almost unchanged ϵ.

261. E. RANDICH and R. B. PETTIT, "Solar Selective Properties and High Temperature Stability of CVD ZrB_2", *Solar Energy Mater.* **5** (1981) 425.

See work on ZrB_2 in [260]. Coatings were deposited also onto Kovar. They were studied by scanning AES as well.

262. B. O. SERAPHIN, "Chemical Vapor Deposition of Thin Semiconductor Films for Solar Energy Conversion", *Thin Solid Films* **39** (1976) 87.

A review of work by the University of Arizona group on solar absorber stacks based on CVD silicon and on CVD germanium/silicon layers. The application of CVD to the production of graded composition profiles is discussed.

263. B. O. SERAPHIN, "High Temperature Spectrally Selective Coatings Fabricated by Chemical Vapor Deposition", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 249.

A review of work on SSAS by the University of Arizona group.

264. B. O. SERAPHIN, "Chemical Vapor Deposition of Spectrally Selective Surfaces for High-Temperature Photothermal Conversion", *Thin Solid Films* **57** (1979) 293.

See [263].

265. B. O. SERAPHIN, "Chemical Vapor Deposition of Spectrally Selective Surfaces for High-Temperature Photothermal Conversion", *J. Vac. Sci. Technol.* **16** (1979) 193.

See [263].

266. B. O. SERAPHIN, D. C. BOOTH and D. D. ALLRED, "Amorphous Silicon in Photothermal Conversion", *J. Phys.* *(Paris)* **42** (1981) C1-437.

Extended abstract on the work in [263].

267. B. O. SERAPHIN and V. A. WELLS, "Solar Energy Thermal Converters Fabricated by Chemical Vapor Deposition", in Proceedings Congrès Internationale Soleil au Service de l'Homme, Paris, 1973, Sect. 58.1.

268. K. SESHAN, P. D. HILLMAN, K. A. GESHEVA, E. E. CHAIN and B. O. SERAPHIN, "On the Mechanism of Growth and the Hydrogen Reduction of CVD Black Molybdenum Films", *Mater. Res. Bull.* **16** (1981) 1345.

The growth of b-molybdenum films ($Mo-MoO_2$ composites), made as described in [232, 245], is subjected to thermodynamic and diffusion rate analysis.

269. V. A. WELLS, B. O. SERAPHIN and L. S. RAYMOND, "Solar Energy Converters Fabricated by Chemical Vapor Deposition", in Proceedings of the Conference on Chemical Vapor Deposition, 4th International Conference, Boston, 1973, edited by G. F. Wakefield and J. M. Blocher Jr (Princeton University, Princeton, 1973) p. 512.

A discussion of silicon-based solar absorber stacks and CVD as a method of preparation. Some preliminary results are given.

3.6. Deposition from solution: chemical reactions

(See also [366, 396, 401, 411, 414, 418, 422, 426, 437, 439, 454, 461, 469, 471, 482–3, 510, 524, 527–9].)

270. R. P. ST. AMAND, J. C. WILLIAMS and R. J. FARRAUTO, "Improved Solar Absorber Coatings", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 89.

Films were prepared by decomposition of metallo-organic solutions in air at $500 < \tau < 800°$ C. A film composed of silver, CuO and Rh_2O_3 showed promising results. Hemispherical R and normal emittance were measured before and after thermal ageing in air. Degradation and stabilization of the films is discussed.

271. K. J. CATHRO, "Formation of Nickel-Black Selective Surfaces by a Conversion Coating Process", *Solar Energy Mater.* **5** (1981) 317.

b-nickel was deposited onto zinc-plated steel, galvanized iron, zincated aluminium and Zincalum by chemical conversion. The processes are described in detail. The film composition was studied by chemical analysis and XPS. SSAS with $0.90 < \alpha < 0.94$, $0.08 < \epsilon < 0.15$ and TS for $\tau < 200°$ C in air were produced.

272. A. CHANDRA and P. CHANDRA, "Figures of Merit of Some Solar Selective Coatings", *Thin Solid Films* **67** (1980) L57.

R was measured at $0.5 < \lambda < 10\,\mu m$ for the following coatings: Cu_2S on copper, and CuO_x on copper produced by chemical conversion; a CuO_x layer on aluminium produced by anodizing and chemical conversion; and a sulphide coating on copper-plated aluminium produced by electrodeposition.

273. E. A. CHRISTIE, "Spectrally Selective Blacks for Solar Energy Collection", International Solar Energy Society Conference, Melbourne, March 2–6 1970 (Australian and New Zealand Section of the International Solar Energy Society, Parkville, Victoria, 1970) paper 7/81.

SSAS were prepared on steel by the Ebanol S-30 process and on copper by immersion in a bath containing sodium hydroxide and sodium chlorite. R is given for $0.3 < \lambda < 25\,\mu m$. In addition vee-corrugated black surfaces were studied.

274. D. J. CLOSE, "Flat Plate Solar Absorbers – The Production and Testing of a Selective Surface for

Copper Absorber Plates", CSIRO Report ED 7, June 1962 (Engineering Section, Commonwealth Scientific and Industrial Research Organization, Melbourne, 1962).

SSAS on copper and galvanized iron were produced by a commercial chemical treatment and by b-nickel plating. Copper was treated also in a hydrogen sulphide atmosphere. The best coatings showed $\alpha \approx 0.9$ and $\epsilon = 0.14$.

275. W. C. COCHRAN and J. H. POWERS, "Selective Black Oxide Conversion Coating for Aluminium Solar Collectors", *Aluminium (Düsseldorf)* **54** (1978) 147.

SSAS were prepared by immersion of aluminium sheet in an alkaline solution. Coatings, comprised an $Al-Al_2O_3$ composite, had $\alpha = 0.93$ and $\epsilon(38° C) = 0.35$. Various durability tests were conducted. The degradation mechanisms are discussed.

276. J. R. CULHAM and P. NIESSEN, "Low Cost Solar Selective Chromate Conversion Coatings Applied to Stainless Steel Substrates", *J. Solar Energy Eng. (Trans. ASME)* **102** (1980) 188.

Coatings of b-chrome were produced by immersion of several different SS in an acidic chromate bath at 75° C. An optimum of $\alpha = 0.90$, $\epsilon = 0.12$ and TS for $\tau < 200°$ C in air was reported.

277. R. M. DAVIDSON, S. EKEROT and H. WATANABE, "The Worldwide Development of Stainless Steel Collectors", *Mosaic (J. Molybdenum Metall.)* **3** (1978) 2.

SSAS on SS are reviewed. Data are given for a b-chrome coating produced by immersion of 18 Cr – 2Mo SS in molten sodium dichromate at 425° C.

278. J. DICKSON, "Thin Film Absorber Coatings from Metallo-Organic Solutions", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 359.

Results are given for a "doped" gold surface and for an $Ag-CuO-Rh_2O_3$ film on SS; see [270].

279. P. DRIVER and P. G. McCORMICK, "The Structure and Properties of a Cu Based Selective Surface Formed on an Al–Cu Alloy by Chemical Brightening", in Proceedings of the International Solar Energy Society Congress, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 881.

A coating of CuO was formed on an AlCu alloy by chemical brightening or etching followed by heat treatment at 350° C. It was studied by SEM and X-ray diffraction. $\alpha \approx 0.9$ and $\epsilon \approx 0.2$ are reported.

280. V. M. FOSTER, "Alcoa 655 Selective Surface for Aluminium", in "NESEA 76; Decision Making in Solar Technology", edited by E. Shaw (New England Solar Energy Association, 1976) p. 177.

See [275].

281. S. B. GADGIL, T. THANGARAJ, J. V. IYER, A. K. SHARMA, B. K. GUPTA and O. P. AGNIHOTRI, "Spectrally Selective Copper Sulphide Coatings", *Solar Energy Mater.* **5** (1981) 129.

Films of CuS_x were produced by chemical spray deposition onto heated aluminium. They were studied by TEM and X-ray diffraction. $\alpha = 0.98$, $\epsilon(100° C) = 0.25$ and TS for $\tau < 200°$ C are reported. Cost estimates are given.

282. K. GINDELE, M. KÖHL and M. MAST, "Messtechnische Charakterisierung Selektiver Schichten und ihre Anwendung bei der Optimierung von Kupferoxidabsorber Schichten", in Statusbericht Sonnenenergie, Vol. 1 (VDI-Verlag, Düsseldorf, 1980) p. 241.

Surfaces of CuO_x were produced by chemical oxidation of copper in a solution of NaOH and $K_2S_2O_8$. SEM showed a strong texturing. $\alpha = 0.97$ and $\epsilon(60° C) = 0.11$ are reported.

283. K. GINDELE, M. KÖHL and M. MAST, "Messtechnische Charakterisierung und Optimierung von Selektiver Solarabsorberschichten", *Metalloberfläche* **34** (1980) 516.

See [282].

284. P. K. GOGNA and K. L. CHOPRA, "Selective Black Nickel Coatings on Zinc Surfaces by Chemical Conversion", *Solar Energy* **23** (1979) 405.

b-nickel was deposited onto zincated aluminium, zinc-electroplated aluminium, and galvanized iron surfaces from a chemical bath. The coatings were studied by SEM. Typical results are $\alpha = 0.93$ and $\epsilon = 0.1$. Humidity and outdoor exposure tests were conducted.

285. R. B. GOLDNER and H. M. HASKAL, "Indium–tin-oxide-coated Silicon as a Selective Absorber", *Appl. Opt.* **14** (1975) 2328.

Brief report on indium–tin-oxide films deposited onto silicon by a spray technique. Specular reflectance at 45° incidence angle was measured.

286. F. GRANZIERA, "Coloured Stainless Steel in Solar Energy Collectors", *Met. Australasia* (9) (1977) p. 211.

Brief popular discussion of the properties of coatings obtained by immersion of SS in a bath of chromic and sulphuric acid.

287. B. K. GUPTA, R. THANGARAJ and O. P. AGNIHOTRI, "High Absorptivity Al – PbS Selective Surfaces for Solar Photothermal Conversion", *Solar Energy Mater.* **1** (1979) 481.

PbS was deposited onto aluminium and galvanized iron by spraying a solution of lead acetate and thiourea. $\alpha = 0.93$, $\epsilon(100^\circ\,\mathrm{C}) = 0.21$ and a stagnation temperature of 120° C were measured. The coating degrades under UV irradiation in air.

288. C. M. HACKENBERG, "Nova Chapa Superficialmente Seletiva de Oxido de Cromo–Aluminio", *Rev. Bras. Tecnol.* **10** (1979) 41.

Cr_2O_3 was deposited onto aluminium by a spray method utilizing a solution of $(NH_4)_2Cr_2O_7$. Moderate spectral selectivity and TS for $\tau < 300^\circ$ C are stated.

289. J. HAJDU, "Selektive Überzeuge für Sonnenkollektoren", *Metalloberfläche* **32** (1978) 463.

Commercial SSAS are reviewed. Coatings of CuO_x were produced from alkaline chromate baths. They were studied by SEM and X-ray diffraction. $\alpha \gtrsim 0.9$ and $\epsilon \lesssim 0.3$ are reported. Durability is discussed.

290. J. HAJDU and F. BRINDISI Jr, "Durability and Performance of the Copper Oxide Selective Surface", in Proceedings of American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 29.

See [289].

291. J. B. HAJDU and T. E. SULLIVAN, "Conversion Coatings as Selective Surfaces", in American Electroplaters' Society Second Coatings for Solar Collectors Symposium, St. Louis, October 16–17 1979.

The properties and durability of various conversion coatings are reviewed.

292. H. C. HOTTEL and T. A. UNGER, "The Properties of a Copper-Oxide–Aluminium Selective Black Absorber of Solar Energy", *Solar Energy* **3** (1959) 10.

CuO was deposited on aluminium by spraying a solution of cupric nitrate onto a warm substrate and subsequently heating to $> 170^\circ$ C. Coatings with $\alpha \approx 0.9$ and $\epsilon \approx 0.15$ are reported. The film structure is discussed.

293. H. C. HOTTEL and T. A. UNGER, "Propriétés d'un Absorbeur d'Energie Solaire à Surface Noire Sélective: Aluminium–Oxyde de Cuivre", in Applications Thermiques de l'Energie Solaire dans le Domaine de la Recherche et de l'Industrie; Colloque Internationale du CNRS, Montlouis, June 1958 (Centre Nationale de la Recherche Scientifique, Paris, 1961) p. 523.

See [292].

294. M. G. HUTCHINS, "Selective Coatings on Stainless Steel", *Helios* **4** (1978) 13.

Conversion coatings on SS are briefly discussed.

295. T. ISHIBASHI and K. HORIBE, "Studies on the Selective Absorption Surface on Stainless Steel", in Proceedings of the International Solar Energy Society Congress, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 849.

SSAS were produced by treating SS in a solution of $Na_2Cr_2O_7$ and H_2SO_4 and copper in NaOH and $NaClO_2$. SEM studies were conducted. SS surfaces with $\alpha \approx 0.92$ and low ϵ were obtained. TS was found at $\tau < 180^\circ$ C for copper and at $\tau < 300^\circ$ C for SS. Corrosion tests were performed.

296. C. E. JOHNSON, "Black Electroless Nickel Surface Morphologies with Extremely High Light Absorption Capacity", *Met. Finish.* **78** (7) (1980) 21.

Nickel with different phosphorus contents was deposited onto various substrates by an autocatalytic technique. The coatings were subsequently etched in an oxidizing acid bath, notably HNO_3. SEM showed a dendritic structure. Surfaces with $\alpha > 0.99$ and $\epsilon \approx 0.5$ were obtained.

297. B. KARLSSON and C. G. RIBBING, "Colored Stainless Steel: A New Type of Selective Absorber", *Proc. Soc. Photo-Opt. Instrum. Eng.* **161** (1978) 76.

SSAS were produced by immersion of SS in a solution of chromic and sulphuric acids. They were analysed by AES. Specular reflectance (including high temperature reflectance up to 500° C) was measured on commercial specimens. The best samples had $\alpha = 0.91$, $\epsilon(100° \text{C}) = 0.1$ and TS at $\tau < 200°$ C in air. Degradation mechanisms are discussed.

298. S. N. KUMAR, L. K. MALHOTRA and K. L. CHOPRA, "Low Cost Electroless Nickel Black Coatings for Photothermal Conversion", *Solar Energy Mater.* **3** (1980) 519.

Coatings of b-nickel were produced by autocatalytic deposition at 30° C. They were characterized by SEM, electron diffraction, XPS and AES. Coatings with $0.90 < \alpha < 0.93$, $0.073 < \epsilon(100° \text{C}) < 0.1$ and TS for $\tau < 200°$C in air were obtained. Humidity resistance is discussed.

299. R. C. LANGLEY, "Inorganic Films for Solar Energy Absorption", *Solar Energy* **7** (1963) 155.

Various films obtained by metallo-organic deposition were studied. $R(\lambda)$ is given for a film of "doped" gold.

300. R. C. LANGLEY, "Absorbing and Reflecting Thin Films Deposited by Pyrolysis in Air", in Symposium on the Materials Science Aspects of Thin-Film Systems for Solar Energy Conversion, Tucson, 1974, edited by B. O. Seraphin (University of Arizona, Tucson, 1974) p. 321.

Deposition of films from metallo-organic solutions is reviewed. Results are given for films of "doped" gold.

301. R. S. LINDSTROM, "Selective Surfaces for Copper Solar Absorbers", *INCRA Res. Rep., No. 250* (12) (1977).

A large number of treatments for producing SSAS on copper were tested. These include oxides and sulphides produced by chemical conversion, as well as a b-nickel, b-chrome and several other surfaces produced by electrochemical methods. α and ϵ were estimated and stability tests were conducted.

302. R. S. LINDSTROM, R. L. MERRIAM, E. H. NEWTON and G. CYPHER, "Selective Surfaces for Copper Solar Absorbers", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 113.

Preliminary report on work described in more detail in [301].

303. J. J. MASON and R. BLOWER, "Selective Conversion Coatings on Nickel and Stainless Steel", *J. Phys.* (*Paris*) **42** (1981) C1-231.

The properties of commercial Ni–NiO composite films on nickel (MAXORB) and of coloured SS conversion coatings (SKYSORB) are described. MAXORB has $\alpha = 0.97$, $\epsilon(100° \text{C}) = 0.09$ and TS for 1 h at $\tau < 400°$ C in air. SKYSORB has $\alpha = 0.92$, $0.12 < \epsilon(100° \text{C}) < 0.15$ and TS for 1 h at $\tau < 300°$ C in air. The stability of adhesives for MAXORB foils are reported. SKYSORB-coated SS has excellent formability and can be roll formed, pressed, etc. without loss of optical properties.

304. J. J. MASON and L. G. WHILE, "Maxorb Foil: A Selective Surface for all Substrates", in Energia Solare e Neuve Prospettive, COMPLES Confèrenza Internationale, Milan, September 1979, Vol. 2 (Milan, 1979) p. 159.

See results for MAXORB in [303].

305. J. J. MASON and B. WRIGHT, "Metal Foil Selective Surfaces on Flat-Plate Solar Collectors", in Proceedings of the Second International Solar Forum, Hamburg, July 12–14 1978, Vol. 1 (Hamburg, 1978) p. 337.

See results for MAXORB in [303]; the composition was studied by AES.

306. D. M. MATTOX and R. R. SOWELL, "High Absorptivity Solar Absorber Coatings", *J. Vac. Sci. Technol.* **11** (1974) 793.

Chemical conversion coatings of CuO_x and Cu_2S on copper and of Fe_3O_4 on steel and SS were studied. Vacuum evaporated PbS and a paint consisting of PbS particles in a silicone binder were also prepared. R at $0.4 < \lambda < 2.5\,\mu$m was measured for Cu_2S. T at $0.4 < \lambda < 15\,\mu$m was measured for PbS.

307. S. N. MONTEIRO, A. S. de SOUZA e SILVA, P. E. V. de MIRANDA and W. P. H. LOSCH,

"Revestimentos Seletivos em Chapas Metálicas para Absorção de Energia Solar", *Metalurgia (Brazil)* **34** (1978) 307.

CuO_x surfaces were fabricated by treating aluminium with copper nitrate and also by evaporation of copper in a vacuum of 10^{-2} torr followed by oxidation. R is given for $0.3 < \lambda < 2.5\,\mu m$.

308. J. OHNO, Y. SHINDOH, J. OKA and H. OKADA, "Improvement of Optical Reflectance of Homogeneous Interference Film for Solar Absorber by Texture Control", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1902.

A theoretical study of the design of SSAS is presented. Coatings were produced on SS by immersion in a hot mixture of chromic acid and sulphuric acid. Their composition was studied by ion microanalysis. R is given for $0.3 < \lambda < 10\,\mu m$.

309. K. OKUNO, R. W. MACKEY and J. E. McNUTT, "Chemical Post Treatment of Copper–Zinc Alloy Electrodeposits to Develop Solar Selective Properties", in Proceedings of the 10th World Congress on Metal Finish, Interfinish 80, Kyoto, October 12–17 1980 (Metal Finishing Society of Japan, Tokyo, 1980) p. 199.

310. P. K. C. PILLAI and R. C. AGARWAL, "Preparation and Characterisation of a Spectrally Selective Black Chrome Coating for Solar Energy Applications", *Appl. Energy* 7 (1980) 299.

Coatings of b-chrome were prepared by spraying an aqueous solution of CrO_3 onto chemically brightened aluminium substrates heated to 250 to 300° C. $\alpha = 0.93$, $\epsilon(100^\circ\,C) = 0.16$ and TS for $\tau < 250^\circ$ C in air is reported. A thin polystyrene overcoat prevented degradation under severe humidity conditions.

311. J. H. POWERS, A. G. CRAIG Jr and W. KING, "The ALCOA 655 Selective Surface for Aluminium", in "Sharing the Sun: Solar Technology in the 70's" Vol. 6, edited by K. W. Böer (Winnipeg, Canada, 1976) p. 166.

See [275].

312. G. B. REDDY, V. DUTTA, D. K. PANDYA and K. L. CHOPRA, "Solution Grown PbS/CdS Multilayer Stacks as Selective Absorbers", *Solar Energy Mater.* 5 (1981) 187.

Films of PbS and CdS were deposited by dissociating thiourea in an alkaline solution containing salts of either lead or cadmium. Multilayer coatings were produced on nickel or SS substrates. They were studied by SEM. The best results were $\alpha = 0.92$, $\epsilon(100^\circ\,C) = 0.12$ and TS for $\tau < 200^\circ$ C.

313. J. D. REDMOND, J. D. BAKER and R. M. DAVISON, "A New Selective Black Coating for Solar Collectors", in Solar Diversification, Proceedings of the Meeting of the American Section of the International Solar Energy Society, Denver, August 28–31 1978, Vol. 2, edited by K. W. Böer and G. W. Franks, p. 282.

Coatings of b-chrome were produced on various substrates by immersion in molten sodium dichromate at 420 to 430° C. They were studied by SEM. Typical results are $\alpha = 0.90$ and $\epsilon = 0.15$. A process flow sheet and an economic analysis are presented.

314. E. SALAM and F. DANIELS, "Revêtement Rayonnant de Façon Sélective pour le Chauffage Solaire", in Applications Thermiques de l'Energie Solaire dans le Domaine de la Recherche et de l'Industrie; Colloque Internationale du CNRS, Montlouis, June 1958 (Centre Nationale de la Recherche Scientifique, Paris, 1961) p. 483.

Several kinds of SSAS were studied: chemical conversion coatings of CuS on copper and of MoO_3 on treated aluminium, anodically deposited NiS films on nickel, electrodeposited MnO_2 on SS, and CuO_x produced by thermal oxidation of copper-coated nickel. Results on α, ϵ and TS are given.

315. F. TROMBE, M. FOEX and M. LE PHAT-VINH, "Studies on Selective Surfaces for Air Conditioned Dwellings", in UN Conference on New Sources of Energy, Rome, 1961, Vol. 4 (1961) p. 638.

Results are given for aluminium treated with a $KMnO_4$ solution and for SS oxidized at 600° C. The influence of a grooved substrate was studied.

316. P. VACHET and J. MERCIER, "Use of Certain Al Alloys in the Utilization of Solar Energy", in UN Conference on New Sources of Energy, Rome, 1961, Vol. 4 (1961) 658.

Results for aluminium treated with a $KMnO_4$ solution are included.

317. J. VAIDYANATHA IYER, S. B. GADGIL, A. K. SHARMA, B. K. GUPTA and O. P. AGNIHOTRI, "Cr_2O_3–Cr Composite Selective Absorbers Produced by the Ebonizing Process", *Solar Energy Mater.* **6** (1981) 113.

Coatings of b-chrome were produced on substrates of SS and nickel-plated steel by dipping into sodium dichromate at 425 to 450° C. They were studied by SEM and X-ray diffraction. Coatings on SS had $\alpha \approx 0.92$, $\epsilon = 0.03$ and TS for $\tau < 250°$ C in air.

318. M. VAN DER LEIJ, "Investigation and Perspectives of Iron Oxide, Zinc Conversion Coating, Zinc Oxide, Cobalt Oxide and Tungsten Oxide as Spectral Selective Solar Absorber Surfaces", in Proceedings of the International Solar Energy Society Congress, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 837.

Fe_3O_4 on steel and a zinc chromate coating on zinc were applied by chemical conversion. ZnO on zinc was produced by anodizing, Co_3O_4 was obtained by oxidizing electroplated cobalt at 400° C, and WO_3 was deposited by reactive r.f. sputtering and overcoated by evaporated Al_2O_3. The films were analysed by XPS, X-ray microscanning and nuclear techniques. Hemispherical R was measured for $0.3 < \lambda < 12\,\mu m$. The best samples had $\alpha \gtrsim 0.9$, low ϵ and TS for $\tau < 180°$ C in air.

319. R. K. WILLIAMS, "Ambient-Temperature Conversion Coating of Aluminium for Solar Energy Absorption", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 17.

A moderately selective conversion coating on aluminium, "Aluma Black", was produced by immersion or spraying. Methods to improve the resistance to humidity are discussed.

320. B. WRIGHT and J. J. MASON, "Field Performance of Certain Selective and Neutral Surfaces in Solar Collectors"; in Proceedings of the International Solar Energy Society Congress, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 1080.

See results for MAXORB in [303]. Collector efficiency was studied experimentally.

3.7. Deposition from solution: electrochemical reactions

3.7.1. Black chrome

(See also [216–7, 301–2, 411, 413, 432, 501, 521–5, 543].)

321. A. R. BALAKRISHNAN, K. G. T. HOLLANDS, E. C. SHEWEN and P. NIESSEN, "Optimization Studies on Black Chrome Electroplating Variables for Solar Selective Surfaces", in "Renewable Alternatives" Vol. 1 (Solar Energy Society of Canada, Winnipeg, Canada, 1978) p. 1.1.6.1.

322. C. C. BEATTY and K. RAGHUNATHAN, "Black Chrome Gains Favor as Selective Coating", *Solar Eng. Mag.* 3 (8) (1978) 32.

A popular review on SSAS of b-chrome.

323. J. M. BEHAGHEL, S. BERTHIER, J. LAFAIT and J. RIVORY, "Chromium Black Coatings for Photothermal Conversion of Solar Energy, Part II: Optical Properties", *Solar Energy Mater.* **1** (1979) 201.

Optical measurement techniques are discussed. Hemispherical R for $0.5 < \lambda < 15\,\mu m$ and light scattering were recorded for b-chrome. Films with $\alpha = 0.96$ and $\epsilon(20°\ C) \approx 0.1$ were obtained. Their structure was analysed by SEM. An accompanying paper is [394].

324. A. C. BENNING, "Black Chromium – A Solar Selective Coating", in American Electroplaters' Society Coatings for Solar Collectors Symposium Atlanta, November 9–10 1976, p. 31.

Results are given for the Harshaw b-chrome process applied to nickel, copper and aluminium substrates.

325. A. C. BENNING, "Solar Selective Black Chromium Electrodeposition", in American Electroplaters Society Second Coatings for Solar Collectors Symposium, St. Louis, October 16–17 1979.

Plating, optical properties and durability or b-chrome are reviewed.

326. S. BERTHIER and J. LAFAIT, "Black Chromium Coatings: Experimental and Calculated Optical Properties Using Inhomogeneous Medium Theories", *J. Phys. (Paris)* **40** (1979) 1093.

Coatings of b-chrome were characterized by SEM, XPS and TEM. Measured $R(\lambda)$ was compared with computations based on EMT. The effect of surface roughness was investigated.

327. S. BERTHIER and J. LAFAIT, "Modélisation des Propriétés Optiques des Milieux Inhomogènes à Structure Complexe", *J. Phys. (Paris)* **42** (1981) C1-285.

EMT are reviewed and applied to the optical properties of b-chrome.

328. J. P. BRANCIAROLI and P. G. STUTZMAN, "Black Chrome Plating: Application and Deposit Characteristics of a New Plating Process", *Plating* **56** (1) (1969) 37.

The plating technique is described. The coatings were studied by SEM and chemical analysis. Some data on R for $0.4 < \lambda < 0.7$ μm, chromaticity coordinates and durability are given.

329. K. J. CATHRO, "Black Chrome for Solar Collectors: Deposition from Tetrachromate Baths", *Met. Finish.* **76** (10) (1978) 57.

Films of b-chrome were deposited onto nickel-plated steel. $\alpha = 0.97$, $\epsilon = 0.12$ and TS for $\tau < 150°$ C in air were found. The effect on α and ϵ of altered plating conditions was studied in detail.

330. R. CHANG and W. F. HALL, "On the Correlation Between Optical Properties and Chemical/Metallurgical Constitution of Cr_2O_3/Cr Thin Films", *AIP Conf. Proc.* **40** (1977) 305.

Measured optical properties of b-chrome [390] and of co-sputtered Cr–Cr_2O_3 composites [170] are compared with EMT.

331 G. J. CLARK, Z. E. SWITKOWSKI, R. J. PETTY and J. C. P. HEGGIE, "Analysis of Chrome-Black Solar-Absorber Surfaces", *J. Appl. Phys.* **50** (1979) 4791.

Depth profiles of chromium and oxygen were determined by means of nuclear reactions. The film structure was studied by SEM.

332. G. A. DiBARI and P. P. TURILLON, "Effect of Corrosion on Selectivity of Electrodeposited Black Chromium With and Without Nickel Underlayers", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1917.

α and ϵ were measured before and after corrosion tests including exposure to marine atmosphere.

333. P. M. DRIVER, "What is Black Chrome?", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1887.

Overview of deposition conditions, optical properties, structure, composition and analysis techniques for b-chrome.

334. P. M. DRIVER, "An Electrochemical Approach to the Characterisation of Black Chrome Selective Surfaces", *Solar Energy Mater.* **4** (1981) 179.

Extensive review with many references on b-chrome deposition. A possible degradation mechanism is discussed.

335. P. M. DRIVER, R. W. JONES, C. L. RIDDIFORD and R. J. SIMPSON, "A New Chrome Black Selective Absorbing Surface", *Solar Energy* **19** (1977) 301.

Films of b-chrome were deposited onto copper. They were studied by SEM. $\alpha = 0.92$, $\epsilon(50° C) = 0.08$ and TS for $\tau < 300°$ C in vacuum are reported.

336. P. M. DRIVER and P. G. McCORMICK, Photothermal Degradation of Black Chrome – a Possible Contributing Factor", *J. Phys. (Paris)* **42** (1981) C1-309.

Brief version of [334].

337. D. M. FELL, L. L. TONGSON, S. V. KRISHNASWAMY, R. MESSIER and I. S. T. TSONG, "Characterization of Commercial Black Chrome Coatings", *J. Vac. Sci. Technol.* **17** (1980) 358.

Three commercial b-chrome coatings were characterized by optical measurements, AES, sputter-induced photon spectrometry and X-ray diffraction.

338. J. GOEBEL, "SOLARONYX, Selektive Beschichtung für Sonnenenergie – Absorber", in Proceedings of the 1st Deutsches Sonnenforum, Hamburg, September 26–28 1977, Vol. 2 (Hamburg, 1977) p. 389.

Harshaw b-chrome was deposited onto steel and aluminium. $\alpha = 0.97$ and $\epsilon = 0.08$ were found. Durability was studied.

339. P. K. GOGNA and K. L. CHOPRA, "Optical and Topographical Properties of Selective Black Chrome", *Thin Solid Films* **63** (1979) 183.

Films were deposited onto various substrates and studied by SEM. $\alpha = 0.94$ and $\epsilon(100^\circ \text{ C}) = 0.14$ are reported.

340. D. P. GRIMMER and R. K. COLLIER, "Black-Chrome Solar-Selective Coatings Electrodeposited on Metallized Glass Tubes", *Solar Energy* **26** (1981) 467.

Films were deposited onto copper-coated tubes. $\alpha = 0.94$, $\epsilon(25^\circ \text{ C}) = 0.98$ and TS for $\tau < 400^\circ$ C in vacuum were observed. Degradation mechanisms are discussed.

341. S. W. HOGG and G. B. SMITH, "The Unusual and Useful Optical Properties of Electroplated Chrome-Black Films", *J. Phys. D: Appl. Phys.* **10** (1977) 1863.

Published $R(\lambda)$ of b-chrome is compared with computations based on EMT.

342. P. H. HOLLOWAY, K. SHANKER, R. B. PETTIT and R. R. SOWELL, "Oxidation of Electrodeposited Black Chrome Selective Solar Absorber Films", *Thin Solid Films* **72** (1980) 121.

Films were studied by AES and XPS both as deposited and after different heat treatments. Results on α and ϵ are given.

343. M. G. HUTCHINS, "Current Advances in the Development of Electrodeposited Black Chrome Solar Absorber Coatings", *Helios* (11) (1979) 6.

Brief review.

344. A. IGNATIEV, "Black Chrome Surface Morphology", in Proceedings of the Department of Energy /DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 197.

Gas evaporated chromium particles and electroplated b-chrome were studied by SEM and XPS.

345. A. IGNATIEV, "The Problems and Promise of Black Chrome as a Selective Surface", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1883.

Extended abstract on the work in [347].

346. A. IGNATIEV, P. O'NEILL, C. DOLAND and G. ZAJAC, "Microstructure Dependence of the Optical Properties of Solar-Absorbing Black Chrome", *Appl. Phys. Lett.* **34** (1979) 42.

Preliminary Report of work described in more detail in [347].

347. A. IGNATIEV, P. O'NEILL and G. ZAJAC, "The Surface Microstructure Optical Properties Relationship in Solar Absorbers: Black Chrome", *Solar Energy Mater.* **1** (1979) 69.

Harshaw b-chrome was deposited onto nickel and studied by SEM and XPS. A structural model was proposed. Measured R for $0.3 < \lambda < 2.5\,\mu$m was compared with computations based on EMT.

348. A. IGNATIEV, P. O'NEILL, G. ZAJAC and C. DOLAND, "The Surface Microstructure – Optical Properties Relationship in Solar Absorbers", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 9.

See [347]; studies on durability and oxidation and a theoretical optimization are reported.

349. O. T. INAL, J. C. MABON and C. V. ROBINO, "Thermal Degradation of Solar Collector Surfaces", *Thin Solid Films* **83** (1981) 399.

b-chrome coatings were produced by electroplating and b-zinc by anodizing zinc sheet. Metal-to-oxide ratios were determined by X-ray analysis and field ion microscopy. Thermal degradation of α and ϵ was associated with an increase of the oxide content.

350. O. T. INAL and A. E. TORMA, "A Field Ion Microscope Study of Black Chrome and Nickel Electroplated Coatings", *Thin Solid Films* **54** (1978) 161.

Nucleation and growth of electroplated nickel on SS and of b-chrome on nickel were investigated by SEM and field ion microscopy.

351. O. T. INAL, M. VALAYAPETRE, L. E. MURR and A. E. TORMA, "Microstructural and Mechanical Property Evaluation of Black-Chrome Coated Solar Collectors – II", *Solar Energy Mater.* **4** (1981) 333.

Coatings of b-chrome were studied by SEM and TEM and a composite structure was found. Optimization of the plating parameters gave $\alpha = 0.98$, $\epsilon(100^\circ \text{ C}) = 0.10$ and TS for $\tau < 400^\circ$ C in air and for $\tau < 500^\circ$ C in an inert atmosphere. Mechanical properties are reported.

352. O. T. INAL and W. YARBROUGH, "A Field Ion Microscope Study of Microstructural Features of Solar Collector Coatings", *Thin Solid Films* **64** (1979) 129.

An extension of the work in [350] is presented.

353. M. C. KEELING, "Optically Thin Diffusion Barriers Enhance the Life of Metal/Metal Oxide Selective Surfaces", in Proceedings of the 1977 Annual Meeting of the American Section of the International Solar Energy Society, Orlando, Florida, Vol. 1, edited by C. Beach and E. Fordyce (American Section of the International Solar Energy Society, Cape Canaveral, Florida, 1977) p. 5.13.

The stability of b-chrome on copper was found to be improved by an intermediate thin nickel layer.

354. M. C. KEELING, R. K. ASHER and R. W. GURTLER, "High Selective Absorbers Utilizing Electrodeposited Black Chrome", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 53.

b-chrome deposited onto thin aluminium-foil had $\alpha = 0.964$ and very low ϵ.

355. J. LAFAIT, J. M. BEHAGHEL and S. BERTHIER, "Le Chrome Noir et la Sélectivité aux Moyennes Températures (100–250° C)", *Rev. Phys. Appl.* **15** (1980) 403.

The efficiency of solar collectors with selective and non-selective coatings is calculated. b-chrome with $\alpha = 0.95$, $\epsilon(250^\circ \text{ C}) \approx 0.25$ and TS for $\tau < 300^\circ$ C in air is reported.

356. J. LAFAIT, S. BERTHIER and J.-M. BEHAGHEL, "Selective Electrodeposited Chromium Black Coatings: Optical Properties, Selectivity Model", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1922.

See [326].

357. C. M. LAMPERT, "Microstructural Characterization of a Black Chrome Solar Selective Absorber", *Proc. Soc. Photo-Opt. Instrum. Eng.* **161** (1978) 84.

b-chrome was plated onto copper and steel and onto nickel-plated copper and steel. The films were characterized by SEM and TEM. $\alpha \approx 0.95$ and low ϵ are reported. A model for the structure is presented.

358. C. M. LAMPERT, "Structure of a Black Chrome Selective Surface", Proceedings of the American Section of the International Solar Energy Society Annual Meeting, Denver, August 28–31 1978, Vol. 2.2, p. 289.

See [357].

359. C. M. LAMPERT, "Thermal Degradation of a Black Chrome Solar Selective Absorber Coating: Short Term", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1892.

TS in air and in vacuum was studied by TEM, SEM, X-ray diffraction and measurement of hemispherical R. A structural transformation precipitating Cr_2O_3 was found below 300 to 400° C.

360. C. M. LAMPERT, "Metallurgical Analysis and High Temperature Degradation of the Black Chrome Solar Selective Absorber", *Thin Solid Films* **72** (1980) 73.

A model for the microstructure of b-chrome is presented. It is based on TEM, SEM, AES, X-ray diffraction and measurements of $R(\lambda)$ before and after heat treatments.

361. C. M. LAMPERT and J. WASHBURN, "Microstructure of a Black Chrome Solar Selective Absorber", *Solar Energy Mater.* **1** (1979) 81.

See [357].

362. C. LAMPERT and J. WASHBURN, "Microstructure and Optical Properties of Black Chrome Before and After Exposure to High Temperatures", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 19.

See [359].

363. C. M. LAMPERT and J. WASHBURN, "Chemical and Structural Characterization of Thermally Degraded Black Chrome", in Proceedings of the American Section of the International Solar Energy Society Annual Meeting, Phoenix, June 2–6 1980.

See [360].

364. J. H. LINDSAY, "Solar Properties of Electrodeposited Nickel Underlayers in Composite Absorber Systems", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 25.

b-chrome was deposited onto various kinds of nickel and Ni–Fe substrates. The effect on α and ϵ was studied.

365. J. A. MANRIQUE and R. SUAREZ, "The Effect of a Black Chrome Selective Surface on the Thermal Performance of a Solar Collector", *Lett. Heat Mass Transf.* 7 (1980) 25.

b-chrome films with $\alpha = 0.97$ and $\epsilon = 0.13$ were produced on nickel-plated SS. The efficiency was calculated for solar collectors with b-chrome was well as nonselective black paint.

366. H. Y. B. MAR, R. E. PETERSON and P. B. ZIMMER, "Low Cost Coatings for Flat Plate Solar Collectors", *Thin Solid Films* **39** (1976) 95.

Reliable results are given for b-chrome, b-nickel, b-iron and some spectrally selective paints. b-nickel had the best optical properties with $\alpha = 0.95$ and $\epsilon(100° \mathrm{C}) = 0.07$. b-chrome showed best TS and corrosion resistance. b-iron had lowest cost among the electroplated coatings. The best paints had $\alpha = 0.90$ and $\epsilon(100° \mathrm{C}) = 0.30$.

367. G. E. McDONALD, "Spectral Reflectance Properties of Black Chrome for Use as a Solar Selective Coating", *Solar Energy* **17** (1975) 119.

b-chrome was plated onto nickel. The structure was studied by SEM. $R(\lambda)$ was measured for $0.4 < \lambda < 15\,\mu\mathrm{m}$. Data are given also for b-nickel.

368. G. E. McDONALD, B. BUZEK and H. CURTIS, "Fundamental Studies in Black Chrome for Solar-Selective Use", in "Sharing the Sun, Solar Technology in the 70's" Vol. 6, edited by K. W. Böer (1976) p. 162.

Brief discussion of the plating conditions for producing SSAS of b-chrome is given.

369. G. E. McDONALD, R. LAUVER and H. CURTIS, "Development of Low-Cost Procedures for Application of Solar-Selective Black Chrome", in "Sharing the Sun, Solar Technology in the 70's" Vol. 6, edited by K. W. Böer (1976) p. 164.

Brief discussion of b-chrome plating onto several different substrates, including nickel foil.

370. S. W. MOORE, "Results Obtained from Black Chrome Production Run on Steel Collectors", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 57.

371. A. MUEHLRATZER, G. P. GOERLER, E. ERBEN and H. ZEILINGER, "Selection of a Black Chrome Bath for Continuous Tube-Plating and the Properties of the Coatings Deposited from It", *Solar Energy* 27 (1981) 115.

b-chrome was plated from various baths onto different nickel undercoatings. The surfaces were investigated by AES and SEM. Optimized coatings had $\alpha \approx 0.96$, normal thermal emittance of 0.09, and TS for $\tau < 300°$ C in air.

372. L. E. MURR, O. T. INAL and M. VALAYAPETRE, "Characterization of Selective Solar Absorber Microstructures: Electron Microscope Studies", *Thin Solid Films* 72 (1980) 111.

b-chrome films were studied by TEM, SEM and electron diffraction. A structural model was formulated. Some results for electrodeposited b-zinc are included.

373. G. E. OLESON, "A Black-Chromium Selective Coating", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 107.

Results are given for b-chrome films deposited onto copper, zincated aluminium, carbon steel and SS.

374. L. PALMITER, D. A. MAGAN, T. WHEELING and B. WADSWORTH, "Results from Heated Direct Gain and Selective Surface Trombe Wall Test Units", in Forging the Solar Transition, Joint Solar Conference, Vancouver (Solar Energy Society of Canada, Winnipeg, 1980) p. 121.

Comparative measurements of the performance of Trombe walls with and without a b-chrome coating are presented.

375. R. B. PETTIT and R. R. SOWELL, "Solar Absorptance and Emittance Properties of Several Solar Coatings", *J. Vac. Sci. Technol.* **13** (1976) 596.

Hemispherical R for $0.5 < \lambda < 2.5\,\mu\text{m}$ and ϵ for $\tau \leqslant 300^\circ$ C were measured for b-chrome on various nickel underlayers, b-nickel on nickel, and for paints consisting of a silicone binder mixed with germanium, silicon or PbS. b-chrome with $\alpha \approx 0.95$, $\epsilon(200^\circ \text{ C}) \approx 0.2$ and TS for $\tau < 300^\circ$ C in air is reported.

376. R. B. PETTIT and R. R. SOWELL, "Recent Developments Regarding Electrodeposited Black Chrome Solar Coatings", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 33.

b-chrome coatings with improved TS were plated from solutions with low Cr^{+3} concentrations. AES studies were performed. $\alpha = 0.98$, $\epsilon(300^\circ \text{ C}) = 0.31$ and TS at $\tau < 350^\circ$ C for long times in air are reported.

377. R. B. PETTIT and R. R. SOWELL, "Thermal Aging Characteristics of Electrodeposited Black Chrome Solar Coating", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1897.

See [376]. Results from TEM and SEM are included.

378. C. PISONI, C. ISETTI, M. BATTUELLO and T. RICOLFI, "Procedures for Obtaining Black Chrome Solar Selective Coatings with Reproducible Radiation Properties", *J. Phys.* (*Paris*) **42** (1981) C1-195.

Films were deposited onto brass, nickel-plated aluminium, and iron. α and ϵ were measured.

379. G. S. S. PRASAD, S. MOHAN and K. I. VASU, "Microstructural Characterisation of an Electrodeposited Black Chromium Surface", *J. Electrochem. Soc. India* **29** (1980) 82.

Films were deposited on galvanized steel and characterized by optical microscopy, SEM and XPS.

380. K. RAGHUNATHAN, "Structure and Composition of Black Chrome", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 49.

381. I. RAJAGOPALAN, W. GRIPPS, N. VASUDEVAN, S. R. RAJAGOPALAN and S. RAMASESHAN, "A New Process for Black Coatings Useful in Harnessing Solar Energy I – A Room Temperature Black Chromium Plating Bath", in Proceedings of the International Solar Energy Society Conference, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 855.

b-chrome was plated from a new bath. Coatings were analysed by X-ray diffraction and diffuse R for $0.3 < \lambda < 2.5\,\mu\text{m}$. Some results are given on TS, corrosion resistance and mechanical properties.

382. M. RAMAKRISHNA RAO, K. I. VASU and I. BALACHANDRA, "Spectral Selective Properties of Black Chrome and Nickel Electrodeposited Coatings for Solar Absorber", in Proceedings of the International Solar Energy Society Conference, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 875.

Spectral R at $0.3 < \lambda < 20\,\mu\text{m}$ was measured for b-chrome and b-nickel on nickel-coated steel and aluminium.

383. H. REISS, "Corrosion Protective Transparent Polymer Layers with low Thermal Emissivity on Selectively Absorbing Surfaces", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1978) p. 1931.

Electroplated b-chrome and b-nickel were overcoated with a thin polymer layer. Its effect on α, ϵ, corrosion resistance and abrasion resistance was studied.

384. H. REISS, "Polymer Layers Protective Against Corrosion and Abrasion, Transparent in the Infrared

and with Low Thermal Emissivity on Electrodeposited Selectively Absorbing Surfaces in Solar Collectors", *Thin Solid Films* **75** (1981) 261.

See [383]; in addition, polymer coated b-cobalt was studied.

385. T. A. REITTER and W. H. GIEDT, "Effect of a Heated Atmosphere on the Emittance of Black Chrome Solar Collector Pipe Surfaces", in Proceedings of the 1980 Annual Meeting of the American Section of the International Solar Energy Society, Phoenix, June 2–6 1980, Vol. 3, edited by G. E. Franta and B. H. Glenn (American Section of the International Solar Energy Society, Cape Canaveral, Florida, 1980) p. 644.

ϵ was measured for $0 < \tau < 300^\circ$ C before and after exposure to heated dry or humid air.

386. T. A. REITTER and W. H. GIEDT, "Apparatus for Total Hemispherical Emittance Measurements of Full-Scale Receiver Pipes from 100 to 300° C", *Solar Energy* **26** (1981) 511.

Results of $\epsilon(\tau)$ for b-chrome are included.

387. C. L. RIDDIFORD, P. M. DRIVER and R. J. SIMPSON, "A New Black Chrome Selective Absorbing Surface", in Solar Heating and Cooling, A National Forum, Miami Beach, December 13–15 1976, edited by T. N. Veziroglu (Clean Energy Research Institute, Coral Gables, Florida, 1976) p. 93.

A preliminary report on the work described in detail in [335].

388. I. T. RITCHIE, S. K. SHARMA, J. VALIGNAT and J. SPITZ, "Thermal Degradation of Chromium Black Solar Selective Absorbers", *Solar Energy Mater.* **2** (1980) 167.

b-chrome coatings were produced as in [394]. Their structure was studied by SEM, TEM and electron diffraction before and after annealing at 350° C. A structural model was formulated and used to compute $R(\lambda)$ from EMT and also for explaining thermal degradation.

389. G. B. SMITH, G. ZAJAC, A. IGNATIEV and J. W. RABALAIS, "Surface Composition of Solar Selective Black Chrome Films as Determined by SIMS", *Surf. Sci.* **114** (1981) 614.

The composition of b-chrome was analysed by SIMS. It is argued that the non-metallic component in the composite film is a hydroxide.

390. R. R. SOWELL and D. M. MATTOX, "Optical Properties and Composition of Electroplated Black Chrome", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 21.

b-chrome on nickel was analysed by hemispherical $R(\lambda)$, $\epsilon(\tau)$, XPS, AES and electron diffraction.

391. R. R. SOWELL and D. M. MATTOX, "Optical Properties and Composition of Electroplated Black Chrome", *Plating Surf. Finish.* **65** (1) (1978) 50.

See [390].

392. R. R. SOWELL and R. B. PETTIT, "Black Chrome Development – Thermal Aging of Electrodeposited Black Chrome", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 183.

393. R. R. SOWELL and R. B. PETTIT, "Influence of Bath Composition on Thermal Stability of Electroplated Black Chrome Solar Coating", *Plating Surf. Finish.* **65** (10) (1978) 42.

See [376].

394. J. SPITZ, T. VAN DANH and A. AUBERT, "Chromium Black Coatings for Photothermal Conversion of Solar Energy Part I: Preparation and Structural Characterization", *Solar Energy Mater.* **1** (1979) 189.

The b-chrome coating process is described in detail. Films were characterized by chemical analysis, SEM, electron diffraction, X-ray diffraction and XPS. Abrasion and corrosion tests were carried out. Films with $\alpha = 0.98$, $\epsilon(150^\circ \text{ C}) = 0.16$ and TS for $\tau < 250^\circ$ C in air are reported.

395. Z. E. SWITKOWSKI, J. C. P. HEGGIE, G. J. CLARK and R. J. PETTY, "Use of Nuclear Techniques in the Characterization of Chrome Black Solar Absorber Surfaces", *Aust. J. Phys.* **32** (1979) 343.

See [331].

396. S. TANEMURA, M. SANDO and T. NOGUCHI, "On the Optical Properties and the Composition of Black Copper and Black Chrome Coating", in Proceedings of the International Solar Energy

Society Conference, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 859.

Electroplated b-chrome and b-copper produced by chemical conversion were studied by measurements of normal R at room temperature and 150° C, hemispherical R for $0.4 < \lambda < 0.7\,\mu\text{m}$, XPS and AES.

397. G. Ya. UMAROV, U. Kh. GAZIEV, Sh. A. FAIZIEV, V. V. LI and V. S. TRUKHOV, "Electrolytic Coatings of 'Black Chromium' Type for Solar Collectors", *Geliotekh.* **15** (5) (1979) 50 (*Appl. Solar Energy* **15** (5) (1979) 44).

    b-chrome was plated onto copper and nickel. Coatings with $0.90 < \alpha < 0.93$ and $\epsilon \approx 0.1$ were obtained.

398. M. VALAYAPETRE, O. T. INAL, L. E. MURR, A. E. TORMA and A. ROSENTHAL, "Microstructural and Mechanical Property Evaluation of Black-Chrome Coated Solar Collectors", *Solar Energy Mater.* **2** (1980) 177.

    b-chrome was deposited onto nickel-plated steel. The plating parameters were optimized. The coatings were studied by SEM, replica TEM, adhesion measurements and optical measurements.

399. J. VALIGNAT, J. SPITZ and I. T. RITCHIE, "La Dépôt Électrolytique de Chrome Noir: Caractérisation et Stabilité Thermique", *Rev. Phys. Appl.* **15** (1980) 397.

    The b-chrome deposition process is described. The coatings were studied by SEM. Measured R for $0.3 < \lambda < 2.5\,\mu\text{m}$ was compared with calculations based on EMT with the purpose of identifying the degradation mechanisms. See also [388].

400. J. VULETIN, M. BOSANAC, F. MARČELJA and P. KULIŠIČ, "Temperature Dependence of Selective Properties for Black Chromium Solar Absorbers", in Second International Solar Forum, Hamburg, July 12–14 1978, Vol. 1 (COMPLES/DGS, 1978) p. 359.

    The effect of thermal treatments on $R(\lambda)$ and coating structure was studied.

401. J. VULETIN, P. KULIŠIČ and M. BOSANAC, "Selective Absorbing Coatings", *J. Phys. (Paris)* **42** (1981) C1-191.

    R for $0.3 < \lambda < 15\,\mu\text{m}$ is given for electroplated b-chrome on nickel and for CuO_x prepared by chemical conversion.

402. T. VURGUN, "Selective Surface Coating with Black Chrome", in Solar Energy International Progress, Proceedings of the International Symposium–Workshop on Solar Energy, Cairo, Egypt, June 16–22 1978, Vol. 1, edited by T. N. Veziroglu (Pergamon, New York, 1980) p. 536.

    The influence of changed plating parameters on the optical properties of b-chrome on nickel-plated steel was studied.

403. B. WINDOW, I. T. RITCHIE and K. CATHRO, "Selective Electroplated Chromium Blacks", *Appl. Opt.* **17** (1978) 2637.

    The deposition procedure is described. The b-chrome films were studied by optical microscopy and surface profiling. Hemispherical R was measured for $0.4 < \lambda < 2.5\,\mu\text{m}$ and compared with EMT calculations for films with graded composition.

404. B. WINDOW, I. T. RITCHIE and K. CATHRO, "A Study of Selective Electroplated Chrome Blacks", *Thin Solid Films* **57** (1979) 309.

    See [403].

405. G. ZAJAC and A. IGNATIEV, "Relationship of Optical Degradation to Surface Morphology Changes in Solar Absorbers", *J. Vac. Sci. Technol.* **16** (1979) 233.

    The effect of heat treatment in air on b-chrome was studied by measurement of $R(\lambda)$ for $0.3 < \lambda < 2.5\,\mu\text{m}$, SEM and AES.

406. G. ZAJAC and A. IGNATIEV, "High Temperature Optical and Structural Degradation of Black Chrome Coatings", *Solar Energy Mater.* **2** (1979/1980) 239.

    See [405]; the effect of heat treatment in high vacuum was also studied.

407. G. ZAJAC, A. IGNATIEV and G. B. SMITH, "Photodesorption Studies of CO and CO_2 from the Solar Absorber Black Chrome", *J. Vac. Sci. Technol.* **18** (1981) 379.

    The main photodesorbing species from b-chrome was found to be CO_2 at $\tau = 300°$ C and atmospheric pressure.

408. G. ZAJAC, G. B. SMITH and A. IGNATIEV, "Refinement of Solar Absorbing Black Chrome Microstructure and Its Relationship to Optical Degradation Mechanisms", *J. Appl. Phys.* **51** (1980) 5544.

   b-chrome was investigated by SEM, AES, XPS, thermal desorption studies and $R(\lambda)$ for $0.3 < \lambda < 2.5\,\mu$m. The data obtained by these techniques were used to construct a model of the composite microstructure, from which optical properties and thermal degradation were explained. Cf. [347].

3.7.2. Other electroplated coatings

(See also [216–7, 272, 274, 301–2, 314, 318, 350–1, 366–7, 372, 375, 382–4, 440, 449–51, 456, 461, 463, 466–7, 488, 521–3, 525].)

409. C. V. BISHOP and R. DARGIS, "Electroplated Coatings for Solar Thermal Collectors", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 109.

   General considerations on SSAS, their manufacturing, etc. are given. Preliminary results are discussed for electroplated tin.

410. P. J. BLIEK, R. DELEUIL, F. PAPINI and M. PAPINI, "Étude et Préparation de Surfaces Rugeuses Destinées à la Conversion Photothermique de l'Energie Solaire", *J. Phys. (Paris)* **42** (1981) C1-105.

   Rough lead and $CuNi_x$ surfaces were obtained by electrodeposition. They were analysed by SEM. α and angular dependent emittance are reported.

411. J. T. BORZONI, "Comparison of Three Solar Selective Absorber Coatings", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 89.

   Studies were made of b-nickel on nickel-plated steel; b-chrome on steel, galvanized steel, nickel-plated steel and copper; and b-iron on steel. The b-iron was produced both by chemical conversion and thermal oxidation; an organic overcoat was used to improve its performance. $R(\lambda)$, α, ϵ and durability are reported. The purpose of the study was to make valid comparisons of different solar coatings.

412. J. C. BOWEN and F. SCHMIDT, "Semiconductor Lead Dioxide Plating as Applied to Solar Collectors", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10, 1976, p. 121.

   Oxygen deficient PbO_2 was produced by electroplating. The chemical bath is described. $0.98 < \alpha < 0.995$ is reported.

413. P. BRAUN, G. BETZ, W. FÄRBER and G. K. WEHNER, "Characterization of Selective Solar Absorber Coatings", in Proceedings of the Seventh International Vacuum Congress and Third International Conference on Solid Surfaces, Vienna, September 12–16 1977, Vol. 2, edited by R. Dobrozemsky, F. Rüdenauer, F. P. Viehböck and A. Breth (R. Dobrozemsky, F. Rüdenauer, F. P. Viehböck and A. Breth, Vienna, 1977) p. 1825.

   Films of b-nickel and b-chrome were studied by AES before and after heat treatments. α and ϵ are given.

414. F. BROSSA and M. AIROLA, "Superfici Selettive per Collettori Solari", *La Metallurgia Italiana* **71** (1979) 438.

   R was determined at $1 < \lambda < 12\,\mu$m for electroplated b-nickel, CuO_x on copper produced by chemical conversion, chromate coating on zinc produced by chemical conversion, and selenide and telluride coatings on SS obtained by anodization. TS was investigated.

415. G. GERLAGH, J. MELSE and J. VAN RUTER, "Black Cobalt as Selective Black Coating for Solar Collectors", in Proceedings of the Tenth World Congress on Metal Finishing, Interfinish 80, Kyoto, October 12–17 1980 (Metal Finishing Society of Japan, Tokyo, 1980) p. 187.

416. R. B. GILLETTE, "Selectively Emissive Materials for Solar Heat Absorbers", *Solar Energy* **4** (1960) 24.

   CoO_x films were produced by anodization of cobalt-plated nickel and copper, and $CrNi_xV_y$ alloy films were prepared by electroplating. CoO_x had $\alpha = 0.93$ and $\epsilon = 0.24$. $CrNi_xV_y$ had $\alpha = 0.94$ and $\epsilon = 0.40$. TS is discussed.

417. P. K. GOGNA and K. L. CHOPRA, "Structure-Dependent Thermal and Optical Properties of Black Nickel Coatings", *Thin Solid Films* **57** (1979) 299.

b-nickel coatings were deposited onto galvanized iron and studied by SEM. $\alpha = 0.94$ and $\epsilon(100^\circ \text{ C}) = 0.09$ are given. Some results on TS are included.

418. P. K. GOGNA, K. L. CHOPRA and S. C. MULLICK, "Photothermal Performance of Selective Black Nickel Coatings", *Energy Research* **4** (1980) 317.

Films of b-nickel were prepared on galvanised steel by electroplating and chemical conversion. α, ϵ and TS are reported. Collector tests were performed.

419. P. K. GOGNA, D. K. PANDYA and K. L. CHOPRA, "Selective Coatings for Solar Energy Conversion", in Proceedings of the International Solar Energy Society Congress, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 842.

See [417].

420. G. P. GÖRLER, "Einige Messungen an Selektiv Absorbierenden Oberflächen für Niedertemperatur-Solarkollektoren", *Deutsche Luft-u Raumfahrt Forsch. Ber.* **77-23** (1977) p. 49.

Electroplated b-nickel was studied in detail and the optical properties were optimised. The effect on the efficiency of solar collectors was investigated by calculations.

421. J. HARRIS, H. TABOR and H. WEINBERGER, "Surfaces of Controlled Spectral Absorptance", in "Symposium on Thermal Radiation of Solids", edited by S. Katzoff, NASA SP-55 (NASA, Washington, 1965) p. 525.

Normal $R(\lambda)$ of two-layer and three-layer b-nickel films was measured.

422. J. HORNER and J. GREENE, "Solar Selective Properties of Some Plated Coatings", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 125.

Studies were made of several coatings deposited onto nickel- or zinc-plated steel or onto aluminium. NiO_x was prepared by thermal oxidation or by proprietory processes. A sulphide coating on nickel was obtained by oxidizing and immersion in a sodium sulphide solution. b-nickel was produced by electroplating. α, ϵ and visible colour are given in tables.

423. M. M. KOLTUN, V. P. MOLCHANOVA, F. R. YUPPETS and I. P. GAVRILOVA, "Investigation of the Characteristics of Electrochemical Coatings for Solar-Radiation Collectors", *Geliotekh.* **15** (6) (1979) 84 (*Appl. Solar Energy* **15** (6) (1979) 82).

Multilayer b-nickel coatings were studied and the possibility of obtaining grading by continuously changing the current density was considered. Multilayer films have good selectivity and $0.97 < \alpha < 0.98$.

424. J. H. LIN and R. E. PETERSON, "Improved Black Nickel Coatings For Flat Plate Collectors", *Proc. Soc. Photo-Opt. Instrum. Eng.* **85** (1977) 62.

Coatings with improved humidity resistance were plated from a new b-nickel batch. They were studied by AES. $\alpha = 0.92$ and $\epsilon(100^\circ \text{ C}) < 0.1$ is reported. The influence of different deposition conditions on the film properties was investigated.

425. E. M. LUSHIKU and K. R. O'SHEA, "Ellipsometry in the Study of Selective Radiation-Absorbing Surfaces", *Solar Energy* **19** (1977) 271.

Optical constants of b-nickel were measured by ellipsometry. R was calculated for $0.4 < \lambda < 4\,\mu\text{m}$ from these data.

426. G. McDONALD, "A Preliminary Study of a Solar Selective Coating System Using a Black Cobalt Oxide for High Temperature Solar Collectors", *Thin Solid Films* **72** (1980) 83.

Co_3O_4 was deposited onto silver or gold by thermal decomposition of cobalt nitride or by electrodeposition. Surfaces with $\alpha > 0.9$, $\epsilon \approx 0.2$ and TS at $\tau < 650^\circ$ C for long times in air were obtained.

427. R. E. PETERSON and J. W. RAMSEY, "Thin-Film Coatings in Solar-Thermal Power Systems", *J. Vac. Sci. Technol.* **12** (1975) 174.

A short review is given of SSAS. Electroplated b-nickel had $\alpha = 0.96$, $\epsilon(100^\circ \text{ C}) = 0.07$ and TS for $\tau < 200^\circ$ C. Evaporated $Al_2O_3/Mo/Al_2O_3$ multilayer coatings showed TS for $\tau < 930^\circ$ C in air. Several durability tests were performed.

428. P. K. C. PILLAI and P. K. SAXENA, "Techniques of Selected Coating", in Proceedings of the International Solar Energy Society Congress, New Delhi, India, January 16–21 1978, Vol. 2, edited by F. de Winter and M. Cox (Pergamon, New York, 1978) p. 1085.

b-CoMg$_x$ and b-copper were electrodeposited onto aluminium. $R(\lambda)$ is reported.

429. S. R. RAJAGOPALAN, K. S. INDIRA and K. S. G. DOSS, "An Explanation for the Black Colour of 'Black Nickel' ", *J. Electroanal. Chem.* **10** (1965) 465.

The optical properties of b-nickel are compared qualitatively with EMT.

430. R. S. SILO and P. A. MLADINIC, "Informe Technico sobre Fabricacion de Colectores Solares", *Scientio* (*Chile*) **34** (1967) 26.

Results are given on electroplated b-nickel deposited onto zinc-coated iron. Collector tests were performed.

431. R. S. SILO and P. A. MLADINIC, "Solar Heaters Using Selective Surfaces", *Geliotekh.* **5** (5) (1969) 28 (*Appl. Solar Energy* **5** (5) (1969) 18).

See [430].

432. G. B. SMITH and A. IGNATIEV, "The Relative Merits of Black Cobalt and Black Chrome as High Temperature Selective Absorbers", *Solar Energy Mater.* **2** (1980) 461.

Nickel substrates were coated with electroplated CoS$_x$ or CoO$_x$, and with CoO$_x$ produced by thermal oxidation of electrodeposited cobalt-metal. The film structure was studied by SEM. CoO$_x$ surfaces with $\alpha = 0.98$, $\epsilon < 0.2$ and TS for $\tau < 420°$ C in air were obtained. CoS$_x$ was less durable. CoO$_x$ had poor adherence to Ni. The results for CoO$_x$ are compared to those for b-chrome.

433. G. B. SMITH and A. IGNATIEV, "Black Chromium–Molybdenum: A New Stable Solar Absorber", *Solar Energy Mater.* **4** (1981) 119.

Electrodeposition of b-CrMo$_x$ is discussed. The coatings were studied by SEM, AES and XPS. $\alpha = 0.95$, low ϵ and TS for $\tau < 425°$ C in air are reported.

434. G. B. SMITH, A. IGNATIEV and G. ZAJAC, "Solar Selective Black Cobalt: Preparation, Structure and Thermal Stability", *J. Appl. Phys.* **51** (1980) 4186.

See [432]; the film composition was studied also by AES and XPS.

435. B. SPINNER, M. DAGUENET and G. MAURIN, "Préparation de Surfaces Sélectives Chaudes pour la Captation du Rayonnement Solaire par Dépot Cathodique de Cobalt", *J. Chim. Phys.* **75** (1978) 1105.

Textured cobalt surfaces were obtained by electrodeposition. $\alpha = 0.93$ and $\epsilon = 0.05$ are stated.

436. R. K. SWARTMAN and K. S. LAM, "A Preliminary Investigation of Selective Properties of Lead Sulphide on Copper", in Forging the Solar Transition, Joint Solar Conference, Vancouver, 1980 (Solar Energy Society of Canada, Winnipeg, 1980) p. 495.

Optical properties of electrodeposited PbS are given.

437. H. TABOR, J. HARRIS, H. WEINBERGER and D. DORON, "Further Studies on Selective Black Coatings", in UN Conference on New Sources of Energy, Rome, 1961, Vol. 4, p. 618.

Results are given for electroplated b-nickel and for CuO$_x$ on aluminium produced by chemical treatment. α, ϵ and film composition were studied.

438. S. UEDA, T. ABE, M. INAGAKI and T. SHIKATA, "Properties of Electrodeposited Black Alloy Coatings for Solar Heat Collectors", in Proceedings of the Tenth World Congress on Metal Finishing, Interfinish 80, Kyoto, October 12–17 1980 (Metal Finishing Society of Japan, Tokyo, 1980) p. 192.

Electroplated MoNi$_x$Sn$_y$ coatings had $\alpha = 0.92$ and $\epsilon = 0.06$.

439. R. E. VAN DE LEEST, B. VAN DER WERF and G. KRIJL, "The Stabilization of Black Nickel Against a Humid Environment", *Solar Energy* **26** (1981) 551.

The corrosion resistance of b-nickel was improved by overcoating it with a thin CrO$_x$ layer deposited by chemical or electrochemical methods.

3.7.3. Anodization

(See also [121, 242, 259, 272, 301–2, 314, 318, 349, 414, 416, 527–9].)

440. J. AMBLARD, M. FROELICHER, G. BLONDEAU, J. LAFAIT, J. M. BEHAGHEL and R. HERRERA, "Rough Nickel Selective Coatings Obtained by Electrochemical Processes", *J. Phys. (Paris)* **42** (1981) C1-147.

Textured nickel surfaces were obtained by electroplating and antireflected by a thin NiO layer produced by anodic oxidation. SEM studies were performed. The best surfaces had $\alpha \approx 0.95$, $\epsilon(100^\circ \mathrm{C}) = 0.16$ and TS for $\tau < 300^\circ$ C. Measured $R(\lambda)$ was compared with a theoretical model for the optical properties of rough surfaces.

441. Å. ANDERSSON, O. HUNDERI and C. G. GRANQVIST, "Nickel Pigmented Anodic Aluminum Oxide for Selective Absorption of Solar Energy", *J. Appl. Phys.* **51** (1980) 754.

SSAS were produced by electrolytic colouring of anodized aluminium sheet. The coatings were characterized by SEM, AES and atomic absorption analysis; they were found to consist of fine nickel particles in an Al_2O_3 matrix. $\alpha = 0.96$, $\epsilon(65^\circ \mathrm{C}) = 0.20$, TS for $\tau < 300^\circ$ C in air and good corrosion resistance were found. Measured $R(\lambda)$ was explained quantitatively from EMT. Coatings of this kind are produced on an industrial scale.

442. L. ARIÈS, J. P. BONINO, R. BENAVENTE, A. LAAOUINI and J. P. TRAVERSE, "Élaboration d'Absorbeurs Sélectifs de l'Énergie Solaire à Partir d'Acier Inoxydable", *J. Phys. (Paris)* **42** (1981) C1-213.

SS was anodized in an acid solution with additions of sulphides. The surfaces were studied by SEM and SIMS. $\alpha \gtrsim 0.9$, $\epsilon \lesssim 0.2$ and TS for $\tau < 300^\circ$ C in air are reported.

443. C. G. GRANQVIST, "Optical Properties of Integrally Colored Anodic Oxide Films on Aluminium", *J. Appl. Phys.* **51** (1980) 3359.

Published optical properties of integrally coloured anodized aluminium are compared with EMT.

444. C. G. GRANQVIST, Å. ANDERSSON and O. HUNDERI, "Spectrally Selective Surfaces of Ni-Pigmented Anodic Al_2O_3", *Appl. Phys. Lett.* **35** (1979) 268.

A preliminary report on the work described in detail in [441].

445. C. G. GRANVIST, Å. ANDERSSON and O. HUNDERI, "Nickel Pigmented Anodic Aluminium Oxide for Selective Absorption Solar Energy", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1955.

See [441].

446. C. HOMHUAL, O. T. INAL, L. E. MURR, A. E. TORMA and I. GÜNDILER, "Microstructural and Mechanical Property Evaluation of Zinc Oxide Coated Solar Collectors", *Solar Energy Mater.* **4** (1981) 309.

Coatings of b-zinc were produced by anodic oxidation of zinc in an alkaline bath. The fabrication procedure is described in detail. The coatings were studied by SEM and TEM and found to be composed of zinc particles in ZnO. The best results were $\alpha \approx 0.98$, $\epsilon(100^\circ \mathrm{C}) \approx 0.11$ and short time TS for $\tau < 200^\circ$ C. Mechanical properties were studied.

447. O. T. INAL and A. E. TORMA, "Nucleation and Growth Characteristics of Zinc Oxide Overgrowths", *Thin Solid Films* **72** (1980) 89.

Electrodeposited zinc metal and b-zinc produced by anodic oxidation were studied by SEM and field ion microscopy.

448. H. S. POTDAR, N. PAVASKAR, A. MITRA and A. P. B. SINHA, "Solar Selective Copper-Black Layers by an Anodic Oxidation Process", *Solar Energy Mater.* **4** (1981) 291.

Coatings of b-copper were produced by anodic oxidation of copper in an alkaline solution. The films were studied by X-ray diffraction, SEM and XPS; they were found to be $CuO{-}Cu_2O$ composites. $\alpha \approx 0.95$ and moderately low ϵ are given.

449. W. SCHERBER and G. DIETRICH, "Selektive Schichten für Solarabsorber aus Aluminium und Stahl", in 1st Deutsches Sonnenforum, Hamburg, September 26–28 1977, Vol. 2, p. 375.

Results are given for "SOLAROX" and "SOLARTEX" SSAS. Data are given on α, ϵ and TS. See also [450].

450. W. SCHERBER, W. EDLER and B. SCHRÖDER, "Selektive Schichten für Aluminium- und

Stahlabsorber", in "Statusbericht Sonnenenergie", Vol. 1 (VDI-Verlag, Düsseldorf, 1980) p. 211.

The "SOLAROX" selective surface was produced by anodization and metal impregnation of aluminium. A textured surface called "SOLARTEX" was produced by a galvanic treatment of nickel or chromium. SEM studies were performed. $0.94 \lesssim \bar{\alpha} < 0.96$ and $0.12 < \epsilon(100^\circ\,\mathrm{C}) < 0.18$ are reported.

451. S. TSUDA and Y. ASANO, "Spectrale Eigenschappen van Zwart Nikkel op Aluminium voor Gebruik als Selectief Zonnepaneel", *Belg.-Ned. Tijdschr. Oppervlaktetech. Met.* **22** (1978) 33.

Electroplated b-nickel on nickel substrates and nickel impregnated anodized aluminium were studied by electron probe microanalysis and X-ray analysis. The best results were $\alpha = 0.91$ and $\epsilon(100^\circ\,\mathrm{C}) = 0.09$.

452. H. UCHINO, S. ASO, S. HOZUMI, H. TOKUMASU and Y. YOSHIOKA, "Selective Surfaces of Color-Anodized Aluminium for Solar Collectors", *Matsushita Electr. Ind. Natl. Tech. Rep.* **25** (1979) 994.

Anodic coatings on aluminium were impregnated with nickel, copper and cobalt. The films were characterized by SEM, electron diffraction, AES and chemical analysis. The effect of different deposition parameters on α and ϵ was studied. The best results were $\alpha = 0.96$ and $\epsilon\,(25^\circ\,\mathrm{C}) = 0.11$.

453. M. VAN DER LEIJ, "The Possibility of Black Zinc Oxide as Spectrally Selective Coating for Low Temperature Solar Collectors", *J. Electrochem. Soc.* **125** (1978) 1361.

b-zinc was produced by anodic oxidation of zinc. The films had $\alpha \approx 0.95$, low ϵ and TS for $\tau < 180^\circ$ C. Ageing under UV irradiation was studied.

454. J. L. WOODS, "Anodic Coatings on Aluminium as Solar Selective Surfaces", in American Electroplaters' Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 117.

Results are given for moderately selective anodic coatings on aluminium and for one conversion coating on aluminium.

3.8. Thermal oxidation

(See also [122, 154–5, 307, 314–5, 318, 411, 422, 432, 434, 524].)

455. A. AVELINE and I. R. BONILLA, "Spectrally Selective Surfaces of Curpous Oxide (Cu_2O)", *Solar Energy Mater.* **5** (1981) 221.

Stoichiometric and nonstoichiometric Cu_2O films were obtained by thermal oxidation of copper in air. Hemispherical R and T were measured for $0.45 < \lambda < 2.5\,\mu$m.

456. R. C. BIRKEBAK, J. P. HARTNETT and E. R. G. ECKERT, "Measurement of Radiation Properties of Solid Materials", in "Progress in International Research on Thermodynamics and Transport Properties, ASME Second Symposium on Thermophysical Properties", edited by J. F. Masi and D. H. Tsai (Academic, New York, 1962) p. 563.

α and $\epsilon(\tau)$ are given for porous SS, electroplated cobalt on platinum, CuO_x on silver prepared by thermal oxidation, and for coatings produced by thermal oxidation of cobalt-alloys. Radiation measurement techniques are reviewed.

457. R. J. BLATTNER, A. J. BRAUNDMEIER Jr and C. A. EVANS Jr, "Evaluation of Calcium Fluoride Diffusion Barriers in CuO/Ag High Temperature Solar Absorbers", *J. Electrochem. Soc.* **124** (1977) C290.

See [458]; thermally evaporated CaF_2 was used as a diffusion barrier between the silver and the CuO. TS was found for $\tau < 500^\circ$ C in air.

458. R. J. BLATTNER, C. A. EVANS Jr and A. J. BRAUNDMEIER Jr, "Mechanism of High-Temperature Instability of CuO–Ag Thin-Film Solar Absorbers", *J. Vac. Sci. Technol.* **14** (1977) 1132.

CuO films on silver were obtained by thermal oxidation of copper. The films were studied by AES, SEM and energy dispersive X-ray analysis. $R(\lambda)$, measured for $0.4 < \lambda < 15\,\mu$m, showed spectral selectivity. TS was studied and a model for oxidation and degradation was formulated.

459. Ph. DEMONT, H. TRAN NGUYEN and J. F. SACADURA, "Influence de l'Oxydation et de la Rugosité sur les Caractéristiques Radiatives des Aciers Inoxydables", *J. Phys. (Paris)* 42 (1981) C1-161.

Optical constants of unoxidized and oxidized SS were determined for $0.3 < \lambda < 11\ \mu m$. The influence of oxidation temperature and surface roughness was studied.

460. D. L. DOUGLASS and R. B. PETTIT, "The Selective Solar Absorptance of In Situ-Grown Oxide Films on Metals", *Solar Energy Mater.* **4** (1981) 383.

Various metals were thermally oxidized in air, oxygen or water vapour. Hemispherical R for $0.5 < \lambda < 2.5\ \mu m$ and normal emittance were measured for NiO on nickel, TiO_2 on titanium, FeO_x on iron, Cr_2O_3 on chromium, ZrO_2 on Zircaloy-2, FeO_x on Kovar, Fe_2O_3 on SS, Al_2O_3 on Kanthal and Cu + 6.2 wt% Al, and Cu_2O on Cu + 6.2 wt% Al, Cu + 5 wt% Al, and Cu + 30 wt% Ni. TS is discussed.

461. D. K. EDWARDS, J. T. GIER, K. E. NELSON and R. D. RODDICK, "Spectral and Directional Thermal Radiation Characteristics of Selective Surfaces for Solar Collectors", *Solar Energy* **6** (1962) 1.

Hemispherical and normal R were measured for thermally oxidized titanium, chromium and SS; chemically converted copper and SS; b-nickel on nickel and of silicon on aluminium with and without an SiO_2 antireflecting film. α and ϵ are given.

462. A. A. FATTAKHOV, Sh. A. FAIZIEV, U. Kh. GAZIEV and V. S. TRUKHOV, "Influence of Heat Treatment on Solar Energy Collector Optical Properties", *Geliotekh.* **13** (6) (1977) 50 (*Appl. Solar Energy* **13** (6) (1977) 38).

SS was mechanically ground and subsequently heat treated in moist hydrogen to form an oxide layer on the surface. Typical results are $\alpha = 0.9$ and $\epsilon = 0.3$.

463. A. KELLER, "Selective Surfaces of Aluminium Foils", in International Solar Energy Society Conference, Melbourne, March 2–6 1970 (Australian and New Zealand Section of the International Solar Energy Society, Parkville, Australia, 1970) paper 7/16.

Aluminium foils were coated by thermally oxidized copper films or electroplated b-nickel. The best data were $\alpha = 0.97$ and $\epsilon(50°\ C) = 0.07$.

464. A. KELLER, "Selective Surfaces of Copper Foils", in Congrès Internationale de Soleil au Service de l'Homme, Paris, France, 1973, p. 1.

Oxidation of copper was studied. α, ϵ and TS are stated.

465. P. KOKOROPOULOS and M. V. EVANS, "Infrared Spectral Emissivities of Cobalt-Oxide and Nickel-Oxide Films", *Solar Energy* **8** (1964) 69.

Moderately low ϵ was measured for NiO and CoO_x on platinum at $\tau < 1080°\ C$.

466. P. KOKOROPOULOS, E. SALAM and F. DANIELS, "Selective Radiation Coatings. Preparation and High Temperature Stability", *Solar Energy* **3** (1959) 19.

CuO and Co_3O_4 coatings on nickel, silver and platinum were obtained by thermal oxidation in air of electroplated copper and cobalt layers. SSAS with good TS were formed. Co_3O_4 on platinum had TS for $\tau < 1000°\ C$.

467. W. KRUIDHOF and M. VAN DER LEIJ, "Cobalt Oxide as a Spectrally Selective Material for Use in Solar Collectors", *Solar Energy Mater.* **2** (1979) 69.

CoO films were formed by thermal oxidation of electroplated cobalt on nickel substrates. A mixture of CoO and Fe_2O_3 was obtained by thermal oxidation when iron sulphate was added to the electroplating bath. The films were characterized by SEM, AES, XPS and other techniques. The best mixed oxide coatings showed $\alpha = 0.95$, $\epsilon(100°\ C) = 0.11$ and TS for $\tau < 300°\ C$ in air.

468. K. D. MASTERSON, "Absorber Surfaces For High Temperature Alloys", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 167.

Low hemispherical R was measured at $0.3 < \lambda < 0.9\ \mu m$ for thermally oxidized Inconel, Incoloy and Croloy alloys, and for Inconel and Croloy coated with Pyromark high temperature paint.

469. V. C. SHARMA, "A Comparison of Thermal Performance of Austenitic Stainless Steel Solar Absorber Plates Coloured by Chemical and Thermal Oxidation Techniques", *Energy* **6** (1981) 133.

Two SS oxides were compared in a stagnation τ test under solar radiation.

470. V. C. SHARMA and M. G. HUTCHINS, "Fabrication of Spectrally Selective Surfaces by Thermal Treatment of Austenitic Stainless Steel AISI 321", *Solar Energy* **23** (1979) 89.

Oxidized austenitic SS had $\alpha \approx 0.9$ and low ϵ.

471. V. C. SHARMA and M. G. HUTCHINS, "Radiative Selectivity and the Oxidation of Stainless Steel", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1940.

Various SS were thermally oxidized and their spectral selectivity was compared to that of chemically oxidized SS. Hemispherical R for $0.3 < \lambda < 2.5\ \mu$m, α, ϵ and AES data are reported.

472. P. TINCOLINI, C. FRANCESCHINI and A. PAPINI, "Contributo allo Studio delle Proprietà Radianti delle Superficie Selective", *Termotecnica* **33** (1979) 2.

ϵ was estimated for polished and rough copper surfaces with and without a thermally grown oxide.

473. R. D. TOBIN, "Absorptive Coatings Evaluation for Solar Tower Receiver Application", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 75.

α and normal emittance were measured for various moderately selective or non-selective surfaces on Incoloy 800 alloy. They include thermally oxidized rough and smooth alloy surfaces; plasma sprayed cobalt + tungsten carbide, cobalt + chromium carbide, and ferrite layers; and two high-τ stable paints. Artificial ageing tests were performed.

3.9. Paints

(See also [306, 366, 375, 468, 473, 495, 525].)

474. V. K. AGARWAL and D. C. LARSON, "Selective Coatings of the Black Pigment F6331", in Proceedings of the 1980 Annual Meeting of the American Section of the International Solar Energy Society, Phoenix, Vol. 3.2, edited by G. E. Franta and B. H. Glenn, p. 1121.

Selective paints are reviewed. Paints with pigment of Fe–Mn–Cu oxide in silicon binder were applied to aluminium foil by dip coating or spraying. A 1 μm thick layer showed $\alpha = 0.85$ and $\epsilon = 0.25$. These results were fitted to a theoretical model.

475. O. C. BALDONADO and C. R. SCHMITT, "Advanced Solar Collector Concepts Using Carbon", in Proceedings of the 1981 Annual Meeting of the American Section of the International Solar Energy Society, Vol. 4.1 (American Section of the International Solar Energy Society, Cape Canaveral, 1981) p. 235.

Spectrally selective paints, consisting of carbon particles in a binder, are described.

476. R. BÄR, "Selectivity of Absorber Coatings", in Proceedings of the 2nd Meeting of the Deutsche Gesellschaft für Sonnenenergie, Fellbach, October 1976, edited by U. Bossel (DGS, München, 1976).

Results for black varnish coatings are included.

477. R. BÄR, "Lacke zur Beschichtung von Absorbern von Sonnenkollektoren", *Farbe. u. Lack* **85** (1979) 930.

Steel plates were coated with paint containing a soot pigment. The most selective sample had $\alpha = 0.8$ and $\epsilon = 0.3$.

478. E. FARBER, "Selective Surfaces and Solar Absorbers", *Solar Energy* **3** (1959) 9.

479. E. A. FARBER, C. A. MORRISON, J. T. PYTLINSKI, H. A. INGLEY and H. A. CLARK, "Solar Characteristics of New Absorptive Coatings Used on Solar Collectors", in Proceedings of the Institute of Environmental Science, 21st Annual Technology Meeting, Anaheim, April 14–16 1975, Vol. 1, (Mount Prospect, 1975) p. 194.

Results are given for paints with FeO_x pigment.

480. J. M. GALLAS and M. EISNER, "Melanin Pigmented Solar Absorbing Surfaces", in Proceedings of the 1980 Annual Meeting of the American Section of the International Solar Energy Society, Phoenix, edited by G. E. Franta and B. H. Glenn, Vol. 3.2, p. 1118.

The properties of melanin, a black biopolymer pigment, were studied. Scanty optical data are given.

481. B. K. GUPTA, F. K. TIWARI, O. P. AGNIHOTRI and S. S. MATHUR, "A New Approach to Low Cost Large Area Selective Surfaces for Photothermal Conversion", *Int. J. Energy Res.* **3** (1979) 371.

Selective paints were prepared by coating zinc powder with CuO, CuS or PbS + CuS and mixing the coated particles in a silicone binder. The paint was then applied to aluminium, copper or galvanized iron by brush painting or spraying. 20 to 30 μm thick layers had, typically, $\alpha = 0.95$ and $\epsilon = 0.5$. Stagnation temperature under solar irradiation was measured.

482. B. K. GUPTA, F. K. TIWARI, O. P. AGNIHOTRI, S. S. MATHUR and R. THANGARAJ, "Black Zn-dust Pigmented Solar Selective Coatings for Solar Photothermal Conversion", in Miami International Conference on Alternative Energy Sources, Miami Beach, 1979 (Clean Energy Research Institute, Coral Gables, Florida, 1979) p. 210.

See [481]; PbS deposited onto aluminium by chemical spraying was investigated.

483. B. K. GUPTA, F. K. TIWARI, R. THANGARAJ, S. S. MATHUR and O. P. AGNIHOTRI, "Absorptance and Emittance Measurements on AlPbS and Zn Dust Selective Surfaces", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1945.

See [481].

484. S. LÖFVING, "A Paint for Selective Solar Absorbers", *Solar Energy Mater.* **5** (1981) 103.

A paint consisting of polyurethanealkyd lacquer pigmented with soot was sprayed onto aluminium. A 0.7 μm thick layer had $\alpha \approx 0.9$ and $\epsilon(100^\circ \text{ C}) \approx 0.3$. Durability and adhesion were tested.

485. L. K. MALHOTRA, K. CHIDAMBARAM and K. L. CHOPRA, "Partly Selective Black Paint Coatings", *Int. J. Energy Research* **5** (1981) 393.

Thin layers of commercially available black paints were applied to aluminium and galvanized iron by spraying or dip-coating techniques. The best results were $\alpha = 0.87$ and $\epsilon = 0.39$. SEM studies and durability tests are reported.

486. V. D. McGINNISS, "Coatings for Solar Thermal Collector Applications", in American Electroplaters' Society Second Coatings for Solar Collectors Symposium, St. Louis, October 16–17 1979.

A list of polymeric binders is given. Material selection and durability tests for black and transparent coatings are discussed.

487. W. D. McKELVEY and P. B. ZIMMER, "Low-Cost High-Performance Solar Selective Paint Coatings", in 11th National SAMPE Technology Conference, New Horizons – Materials and Processes for the Eighties, Boston, November 13–15 1979 (Society for the Advancement of Materials and Process Engineering, Azusa, USA, 1979) p. 453.

A paint consisting of a transition-metal pigment in a silicone binder was constructed. A 1 μm thick layer was applied to aluminium foil by spraying or dip-coating. The best results were $\alpha \approx 0.90$ and $\epsilon(100^\circ \text{ C}) \approx 0.1$. A thickness-insensitive paint was made by admixture of aluminium flake. It was capable of giving $\alpha \approx 0.9$ and $\epsilon(100^\circ \text{ C}) \approx 0.3$. Durability tests were performed. Cost estimates are given.

488. A. C. MEYERS III, "Paint Coatings as Selective Surfaces for Solar Collectors", in Solar Diversification, Proceedings of the Meeting of the American Section of the International Solar Energy Society, Denver, August 1978, Vol. 2.2, edited by K. W. Böer and G. E. Franks, p. 304.

Basic principles of solar selectivity are reviewed. $R(\lambda)$ for two black paints are compared with results for electroplated b-nickel and for galvanized iron.

489. C. S. MOORE, T. S. ASHLEY III and H. A. BLUM, "Analytical and Experimental Treatment of a Spray-on Selective Coating: Application to Collector Design", in "Sharing the Sun, Solar Technology in the 70's" Vol. 6, edited by K. W. Böer (Winnipeg, Canada, 1976) p. 187.

A FeO_x-pigmented paint was sprayed onto aluminium, steel or galvanized steel. Typical data are $\alpha \approx 0.9$ and $\epsilon \approx 0.3$. The results are discussed in terms of radiative transfer theory.

490. C. R. SCHMITT, J. M. SCHREYER, J. M. GOOGIN and H. D. WHITEHEAD, "Solar Selective Carbon Coatings", *Carbon* **15** (1977) 432.

Various carbon-pigmented coatings were prepared by spraying, etc. Tests of stagnation temperature and collector efficiency were carried out.

491. A. J. TORTORELLO and R. E. WOLF, “Outgassing Studies of Some Solar Absorber Coatings”, in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 59.

    Non-selective and moderately selective paints were heat treated. Their weight loss was measured, and fogging and discolouration of collector cover plates was studied.

492. R. W. WARREN, “Solar Selective Surfaces Made of Semiconductor Powders”, in Proceedings of the ASME Winter Annual Meeting, New York, November 17–22 1974, paper 75-WA/HT-13.

    Hemispherical R was measured at $0.4 < \lambda < 2\,\mu\text{m}$ for ground silicon powders and for a paint with silicon pigment. The practical usefulness of these types of SSAS is discussed.

493. D. A. WILLIAMS, T. A. LAPPIN and J. A. DUFFIE, “Selective Radiation Properties of Particulate Coatings”, *Trans. ASME* (*J. Eng. Power*) **85** (1963) 213.

    PbS particles were produced by precipitation from a solution and applied to aluminium by settling. These particles were also mixed with a silicone binder and applied by spraying. Particle sizes were determined by TEM. Hemispherical R was measured at $0.4 < \lambda < 15\,\mu\text{m}$ and α and ϵ were estimated. The optical properties were discussed in terms of EMT.

494. J. A. YTTERHUS, “Performance of a Mildly-Selective Coating from the Caldwell Chemical Coatings Corporation”, in American Electroplaters’ Society Coatings for Solar Collectors Symposium, Atlanta, November 9–10 1976, p. 43.

    A black paint was applied by spraying and heat treated at $350 < \tau < 400°$ C.

3.10. Enamels

(See also [525].)

495. M. ALIKHODZHAEVA, L. V. GUDKOV and A. V. SHEKLEIN, “Selective Coatings for Solar Energy Receivers”, *Geliotekh.* **1** (6) (1965) 17 (*Appl. Solar Energy* **1** (6) (1965) 19).

496. C. BELLECCI, A. BONNANO, M. CONTI, L. LA ROTONDA and R. VISENTIN, “Double-Layer Selective Coating, High-Temperature Resistant for the Conversion of Solar Energy into Heat”, *Nuovo Cimerto C* **1** (1978) 488.

    A black enamel was coated with SnO_2. $0.85 < \alpha < 0.90$, $0.25 < \epsilon < 0.35$ and TS for $\tau < 300°$ C were reported.

497. R. B. BENNETT and P. M. STEPHAN, “The Future of Glass Coatings for Solar Collectors”, in American Electroplaters’ Society Second Coatings for Solar Collectors Symposium, St. Louis, October 16–17 1979.

    A review is given of porcelain enamels, special glasses and plasma sprayed materials as applied to SSAS.

498. J. DE JONG, “Zonnewarmte Collectoren en de Glasindustrie”, *Klei en Keramiek* **8** (1975) 142.

    Various SSAS are reviewed; among them is black enamel with and without an overcoat of In_2O_3 or SnO_2.

499. J. DE JONG and M. F. A. HOENS, “Emaillierte Sonnenkollektoren”, *Mitteilungen des Vereins Deutscher Emailfachleute* **26** (1) (1978) 1.

    The use of enamels in solar collectors is discussed. Hemispherical R was measured at $0.2 < \lambda < 10\,\mu\text{m}$ for various coloured enamels and SnO_2-coated enamels.

500. J. DE JONG and M. F. A. HOENS, “Porcelain Enamelled Solar Collectors”, *Vitr. Enameller* **29** (4) (1978) 63.

    See [499].

501. W. JOSEPH, “Sonnenkollektoren, ein neues Einsatzgebiet für Email?”, *Mitteilungen des Vereins Deutscher Emailfachleute* **25** (5) (1977) 53.

    Enamel coatings are discussed and compared with electroplated b-chrome through a stagnation τ-test.

502. F. SIMONIS, M. VAN DER LEIJ and C. J. HOOGENDOORN, “Physics of Doped Tin Dioxide

Films for Spectral-Selective Surfaces", *Solar Energy Mater.* **1** (1979) 221.

SnO_2 coatings doped with fluorine or antimony were sprayed onto hot vitreous substrates. Normal R, electrical conductivity and Hall coefficient were measured, and the results were interpreted in terms of a free-electron model. $\alpha = 0.92$, $\epsilon = 0.15$ and TS for $\tau < 400°$ C in vacuum or air were reported.

503. F. SIMONIS, "Tinoxide als Spectraal-Selectieve Laag op Email", *Klei en Keramiek* **29** (1979) 130.
See [502].

3.11. Miscellaneous experimental results

(See also [182, 226, 473, 497].)

504. G. ABOUCHACRA, G. CHASSAGNE and A. DELMAS, "Matériaux Absorbants Sélectifs Obtenus par Implantation Ionique", *J. Phys.* (*Paris*) **42** (1981) C1-327.
Ion implanted materials consisting of Na–MgO and Au–MgO were studied by optical measurements, TEM, RBS and SIMS. The optical data were interpreted in terms of EMT.

505. C. P. BUTLER, R. J. JENKINS and W. J. PARKER, "Surfaces for Solar Spacecraft Power", *Solar Energy* **8** (1964) 2.
High α and moderately low ϵ were measured at $200 < \tau < 800°$ C for plasma sprayed coatings of Co–CrC_x composite, Co–WC composite, microcrystalline tungsten, and granular molybdenum.

506. V. CHANG and P. BOLSAITIS, "A Study of Two Binary Eutectic Aluminium Alloys as Selective Absorbers for Solar Photothermal Conversion", *Solar Energy Mater.* **4** (1980) 89.
Surface roughness was produced on Al + 6 at% Ni and Al + 33 at% Cu alloys by etching in NaOH. The structure was studied by SEM. Typical results are $\alpha = 0.8$ and $\epsilon = 0.4$.

507. G. CHASSAGNE, A. DELMAS and M. TREILLEUX, "Ion Implated Materials as Selective Absorbers for Photothermal Solar Energy Conversion", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1950.
Na–MgO films were studied by TEM and optical measurements; cf. [504].

508. SEUNG-AM CHO, R. FOOKES and C. A. GARRIS, "Efficiency of Ceramic Absorber Coatings for Solar-Thermal Conversion", *Ceram. Int.* **7** (1981) 8.
α was measured for copper, 14 different oxides, a sulphur mineral, hematite and pulverized laterite on copper substrates.

509. S. EBISAWA, "Evaluation of Durability of Solar Selective Absorbers and Transparent Filters", *Bull. Electrotechn. Lab.* (*Tokyo*) **44** (1980) 121.

510. G. B. HOTCHKISS, F. F. SIMON and L. C. BURMEISTER, "Spectral Effects on Direct Insolation Absorptance of Five Collector Coatings", *Trans. ASME* (*J. Solar Energy Eng.*) **102** (1980) 226.
Hemispherical R was measured at $0.3 < \lambda < 2.2\,\mu$m for b-chrome, b-nickel, CuO_x, b-zinc (chromate or chloride conversion coatings). α was calculated.

511. T. F. IRVINE Jr, J. P. HARTNETT and E. R. G. ECKERT, "Solar Collector Surfaces with Wavelength Selective Radiation Characteristics", *Solar Energy* **2** (1958) 12; **3** (1959) 38 (Erratum).
α and ϵ were measured for two porous surfaces.

512. M. D. KUDRYASHOVA, "Mechanical Treatment of Collector Surfaces in Solar Installations Leading to Improved Selectivity of Optical Properties", *Geliotekh.* **5** (5) (1969) 36 (*Appl. Solar Energy* **5** (5) (1969) 24).
A copper plate was polished with powders of different grades. Moderately high α and low ϵ were measured for surfaces with different roughnesses.

513. S. LÖFVING, "Hemispherical Emittance of Rough Metal Surfaces", *Appl. Phys. Lett.* **36** (1980) 632.
Rough metal surfaces showed enhanced ϵ. This was explained in terms of surface plasmons.

514. G. MALLET, "Absorbeurs Solaires de Synthèse", *Techniques de l'Energie* **35** (4) (1980) 28.

515. D. R. McKENZIE and J. J. ZYBERT, "Optimization of Solar Selectivity in Colloidally Produced Solar Selective Coatings", *Thin Solid Films* **85** (1981) 191.
Coatings were produced on glass slides with evaporated copper films by repeated withdrawals

from a bath containing dispersed colloidal carbon and SiO_2. Typical results are $\alpha \approx 0.9$ and $\epsilon(80^\circ C) \approx 0.1$.

516. D. F. PAUL and R. W. GUMBS, "Solar Energy Collector Coatings from Cyclopolymers of Butadiene and Acrylonitrile", *J. Appl. Polym. Sci.* **12** (1977) 959.

   Aluminium panels were coated by pouring solutions of the polymers over them. After air drying they were heated in an oven. Moderate spectral selectivity was found.

517. T. RAJ and G. K. WEHNER, "Composition Profiling of Solar Coating Materials", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 163.

   Optical properties were measured for several moderately selective materials; cone-covered copper, plasma-sprayed CrO_x, and stacked razor blades. Cr_2O_3 diffusion barriers, were studied by AES.

518. T. SANTALA, "Intermetallic Absorption Surface-Material Systems for Collectors Plates", in Proceedings of the Workshop on Solar Collectors for Heating and Cooling of Buildings, New York, November 1974 (University of Maryland, College Park, 1975) p. 233.

   Textured surfaces were formed on composites of Al–Ni, aluminium-steel, and aluminium-SS. They were studied by SEM. The best results were $\alpha = 0.94$ and $\epsilon = 0.30$ (for $NiAl_3$).

519. J. M. SCHREYER, R. A. HAYS, C. R. SCHMITT and D. FARWELL, "Plasma-Sprayed Coatings for Very High Temperature Solar Absorbers", in American Electroplaters' Second Coatings for Solar Collectors Symposium, St. Louis, October 16–17 1979.

   See [520].

520 J. M. SCHREYER, C. R. SCHMITT, R. A. HAYS and D. FARWELL, "Stability of Plasma-Sprayed Coatings Tested at White Sands Solar Facility", *Solar Energy* **25** (1980) 179.

   Stagnation τ and durability were tested on plasma-sprayed Cr_2O_3, V, Fe_2O_3, TaC, TiB_2, WC, ErB_{12} and YB_6 coatings on steel or tantalum. YB_6, ErB_{12} and Cr_2O_3 showed best TS.

521. D. E. SOULE, "Directional Absorptance Spectrocalometric Measurement and Spectral Profile Parametrization of Solar Absorbers at Elevated Temperatures", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by J. P. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 173.

   Published $R(\lambda)$ of several SSAS were, arbitrarily, fitted to a five-parameter function.

522. D. E. SOULE, J. H. SCHNITZMEYER and W. R. McKIE, "Fermi Function Model Absorption Profile for Solar-Thermal Conversion", in "Sharing the Sun, Solar Technology in the 70's" Vol. 5, edited by K. W. Böer (American Section of the International Solar Energy Society, Cape Canaveral, 1976) p. 310.

   See [521].

523. D. E. SOULE and D. N. SMITH, "Infrared Spectral Emittance Profiles of Spectrally Selective Solar Absorbing Layers at Elevated Temperatures", *Appl. Opt.* **16** (1977) 2818.

   See [521].

524. M. VAN DER LEIJ and C. J. HOOGENDOORN, "Influence of the Direct Spectral Solar Distribution on the Normal Total Absorptivity of Spectral Selective Surfaces", *Solar Energy* **19** (1977) 575.

   α is reported for b-chrome produced by electroplating, CuO and Fe_3O_4 produced by chemical conversion, and CoO_x produced by thermal oxidation.

525. D. WAKSMAN, E. STREED and A. DAWSON, "The Influence of Environment Exposure on Solar Collectors and Their Materials", in Proceedings of the 1980 Annual Meeting of the American Section of the International Solar Energy Society, Phoenix, June 2–6 1980, edited by G. E. Franta and B. H. Glenn (American Section of the International Energy Society, Cape Canaveral, 1976).

   Results of various durability tests on SSAS are reported.

526. G. K. WEHNER, "Surface Film Analysis and Profiling Techniques", in Proceedings of the Department of Energy/DST Thermal Power Systems Workshop on Selective Absorber Coatings, Golden, Colorado, December 6–8 1977, edited by P. Call (Solar Energy Research Institute, Golden, Colorado, 1978) p. 165.

AES was used to study Cr_2O_3 diffusion barriers on SS and sputtered Al_2O_3–Mo–Al_2O_3 coatings.

527. S. YAMAGUCHI, "Structure of the Sunshine Absorbent", *J. Colloid Interf. Sci.* **51** (1975) 550.

Coatings of CuO_x on copper were produced by chemical oxidation in $NaClO_2$. Coatings of spongy b-platinum were produced by hydrothermal decomposition of K_2PtCl_4. The surfaces were studied by electron diffraction. A black surface was obtained by anodizing an AlSi alloy.

528. S. YAMAGUCHI, "Structural Study of the Sunlight Absorber", *J. Electrochem. Soc.* **123** (1976) 1586.

See [527]; coatings of spinel-type FeO_x were produced by oxidation of SS in $Na_2Cr_2O_7$.

529. S. YAMAGUCHI, "Comparison of a Planckian Black Body with Solar Radiation Absorbers", *Z. Phys. Chem. (Leipzig)* **257** (1976) 1057.

See [527].

530. J. J. ZYBERT and D. R. McKENZIE, "Colloidally Deposited High-Temperature Solar Selective Surfaces", *Appl. Opt.* **20** (1981) 4051.

See [515]; TEM studies are reported.

3.12. Selected theoretical works

(See also [12, 75–5, 85–6, 97–8, 108, 132, 134, 145–6, 148, 150–1, 198, 213, 308, 326–7, 330, 341, 347, 356, 388, 399, 441, 443, 489, 493, 502–3, 513].)

531. L. C. BOTTEN and I. T. RITCHIE, "Improvements in the Design of Solar Selective Thin Film Absorbers", *Opt. Commun.* **22** (1977) 421.

Calculations are presented on the effect of surface roughness and refractive index grading on the spectral selectivity.

532. G. D. CODY and R. B. STEPHENS, "Optical Properties of a Microscopically Textured Surface", *AIP Conf. Proc.* **40** (1978) 225.

EMT is used for treating surface roughness on a scale $<\lambda$. Methods of calculation and comparisons with experimental data are discussed.

533. F. DEMICHELIS and G. RUSSO, "Cavity-type Surfaces for Solar Collectors", *Appl. Phys.* **18** (1979) 307.

Calculations were performed for cylindrical and truncated cones as SSAS.

534. A. DONNADIEU and B. O. SERAPHIN, "Optical Performance of Absorber-Reflector Combinations for Photothermal Solar Energy Conversion", *J. Opt. Soc. Amer.* **68** (1978) 292.

Calculated results on $R(\lambda)$, α and ϵ are given for antireflected silicon and Si–Ge surfaces on metal reflectors. The optical performance was optimized by computations.

535. C. G. GRANQVIST, "Coatings of Ultrafine Chromium Particles: Efficient Selective Absorbers of Solar Energy", *Phys. Scripta* **16** (1977)163.

Calculated absorptance spectra are shown for films composed of small chromium particles.

536. C. G. GRANQVIST, "Spectrally Selective Surfaces with Coatings Comprised of Ultrafine Metal Particles", in Proceedings of the International Symposium on Solar Thermal Power Stations, Cologne, April 11–13 1978 (Deutsche Forschungs- und Versuchs-anstalt für Luft- und Raumfahrt, Cologne, 1978) paper 11.

See [134, 539].

537. C. G. GRANQVIST, "Photothermal Conversion of Solar Energy by Gold Cermet Coatings: Applicability of the Bruggeman Effective Medium Theory", *J. Appl. Phys.* **50** (1979) 2916.

Published optical constants for Au–MgO, Au–Al_2O_3 and Au–MgF_2 composite films are compared with EMT.

538. C. G. GRANQVIST and O. HUNDERI, "Selective Absorption of Solar Energy in Granular Metals: The Role of Particle Shape", *Appl. Phys. Lett.* **32** (1978) 798.

A preliminary report on the work described in [539].

539. C. G. GRANQVIST and O. HUNDERI, "Selective Absorption of Solar Energy in Ultrafine Metal Particles: Model Calculations", *J. Appl. Phys.* **50** (1979) 1058.

Detailed EMT computations are presented of the spectral selectivity of chromium–dielectric

composite coatings on metal backings. The roles of particle shape and orientation and nonhomogeneous particles were studied.

540. K. G. T. HOLLANDS, "Directional Selectivity, Emittance and Absorptance Properties of Vee Corrugated Specular Surfaces", *Solar Energy* **7** (1963) 108.

α and ϵ were investigated for ideal directionally selective surfaces and for real vee corrugated surfaces. The acceptance angle was optimized.

541. H. C. HOTTEL, A. F. SAROFIM and E. J. FAHIMIAN, "The Role of Scatter in Determining the Radiative Properties of Surfaces", *Solar Energy* **11** (1967) 2.

The theory for the efficiency of solar collectors and for the scattering of light from inhomogeneous particulate media are reviewed and calculated results are given. The scattering theory was compared with measurements on polyvinyl toluene, carbon-black and aluminium microspheres.

542. O. HUNDERI and C. G. GRANQVIST, "Selective Absorption of Solar Energy in Chromium Particles: Model Calculations", *Thin Solid Films* **57** (1979) 303.

See [539].

543. A. IGNATIEV, "The Optical Properties—Microstructure Relationship in Particulate Media: Optical Tailoring of Solar Absorbers", in "Solar Materials Science", edited by L. E. Murr (Academic, New York, 1980) p. 151.

A theoretical model, based on EMT for spheroidal particles, is reviewed and compared with experimental data for b-chrome. An optimization of the spectrally selective property of a particulate coating was carried out. Cf. [145, 347].

544. G. A. NIKLASSON and C. G. GRANQVIST, "Photothermal Conversion with Cermet Films: Implications of the Bounds on the Effective Dielectric Function", *Solar Energy Mater.* **5** (1981) 173.

The theory of the bounds on the effective dielectric function for composite media is reviewed. Calculations of $R(\lambda)$ for various values within these bounds demonstrate the influence of the microstructure on the spectral selectivity.

545. G. A. NIKLASSON, C. G. GRANQVIST and O. HUNDERI, "Effective Medium Models for the Optical Properties of Inhomogeneous Materials", *Appl. Opt.* **20** (1981) 26.

Two EMT are derived from basic principles. The size limits for validity of these theories are given.

546. P. O'NEILL, A. IGNATIEV and C. DOLAND, "The Structural Composition and Its Influence on the Optical Properties of Gold Black", *AIP Conf. Proc.* **40** (1978) 288.

See [145].

547. R. PETIT, "Sur l'Étude Électromagnétique de l'Absorption de la Lumiere par les Surfaces Rugueuses", *J. Phys.* (*Paris*) **42** (1981) C1-43.

Finitely-conducting gratings and crossed gratings were studied theoretically as a simple model for corrugated surfaces.

548. I. T. RITCHIE and B. WINDOW, "Applications of Thin Graded-Index Films to Solar Absorbers", *Appl. Opt.* **16** (1977) 1438.

Solar absorptance in uniform interference films and in graded-index films are discussed theoretically and studied by computation.

549. A. J. SIEVERS, "The Emissivity of Metals", in "Solar Materials Science", edited by L. E. Murr (Academic, New York, 1980) p. 229.

See [59, 562].

550. A. J. SIEVERS, "Fundamental Limits to the Spectral Selectivity of Composite Materials", in "Solar Materials Science", edited by L. E. Murr (Academic, New York, 1980) p. 255.

See [59, 562].

551. A. J. SIEVERS, D. M. TROTTER, R. A. BUHRMAN and H. G. CRAIGHEAD, "Spectral Selectivity of Composite Media", in Sun II, Proceedings of the International Solar Energy Society Congress, Atlanta, May 1979, Vol. 3, edited by K. W. Böer and B. H. Glenn (Pergamon, New York, 1979) p. 1878.

See [59, 562].

552. M. SIKKENS, "Physical Background of Spectral Selectivity", *Solar Energy Mater.* **5** (1981) 55.

The physical mechanisms that contribute to spectral selectivity are exposed clearly.

553. G. B. SMITH, "The Scope of Effective-Medium Theory for Fine Metal Particle Solar Absorbers", *Appl. Phys. Lett.* **35** (1979) 668.

    Size limits for the validity of EMT are derived; cf. also [545].

554. R. B. STEPHENS and G. D. CODY, "Optical Reflectance and Transmission of a Textured Surface", *Thin Solid Films* **45** (1977) 19.

    See [532].

555. R. B. STEPHENS and G. D. CODY, "Inhomogeneous Surfaces as Selective Solar Absorbers", in Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receivers, Boulder, January 24–25 1979, edited by P. J. Call (Solar Energy Research Institute, Golden, Colorado, 1979) p. 125.

    See [532].

556. R. B. STEPHENS and G. D. CODY, "Inhomogeneous Surfaces as Selective Solar Absorbers", *Solar Energy Mater.* **1** (1979) 397.

    See [532].

557. H. TABOR, "Selective Surfaces", *Solar Energy* **6** (1962) 112.

    General comments are given on the importance of obtaining α and ϵ as a function of τ.

558. I. S. TAHA, M. A. DARWISH and M. M. ELSAYED, "Theoretical Study of Absorbed Solar Energy in Multi-Layer Absorber Coating for Receivers of Solar Concentrators: Part I. Radiation Transfer Analysis", in "Fundamentals and Applications of Solar Energy – Part II, edited by I. H. Farag and S. S. Melsheimer, *AIChE Symp. Series* **77** (210) (1981) 27.

    A theoretical analysis is given of a SSAS comprising a thin semiconductor layer, covered by two thin absorbing layers, laid on silver.

559. B. S. THORNTON and Q. M. TRAN, "Optimum Design of Wideband Selective Absorbers with Provision for Specified Included Layers", *Solar Energy* **20** (1978) 371.

    A general technique for designing SSAS by use of effective surface impedance matching is discussed.

560. D. M. TROTTER Jr, H. G. CRAIGHEAD and A. J. SIEVERS, "Design of Selective Surfaces for Solar Energy Collection", *Solar Energy Mater.* **1** (1979) 63.

    Calculations are presented of α and ϵ for a dielectric film on a metal substrate and for graded SSAS. The optimal grading profile is discussed.

561. D. M. TROTTER Jr and A. J. SIEVERS, "Thermal Emissivity of Selective Surfaces – New Lower Limits", *Appl. Phys. Lett.* **35** (1979) 374.

    Preliminary report on the work in [562].

562. D. M. TROTTER Jr and A. J. SIEVERS, "Spectral Selectivity of High-Temperature Solar Absorbers", *Appl. Opt.* **19** (1980) 711.

    Extensive paper in which calculated α and ϵ are given for various model surfaces. Studies were made of bare metal substrates and metals coated with a homogeneous dielectric layer, an ideal SSAS, and a graded-index layer. Limits on $\epsilon(\tau)$ are discussed.

563. B. WINDOW, D. McKENZIE and G. HARDING, "Selective Absorber Design", *Solar Energy Mater.* **2** (1980) 395.

    Calculations were performed for graded-index composite SSAS. The parameters required for optimum performance were investigated.

564. A. WIRGIN, "Sur l'Absorption Sélective du Rayonnement Solaire par un Tandem Métal-Diélectrique à Interfaces Rugeuses", *Comptes Rendues Acad. Sci. (Paris)* **292** (1981) 945.

    The effects on α of roughness at the air–dielectric and dielectric–metal interfaces were studied.

565. A. WIRGIN, "Sur la Résponse Spectrale de Certaines Surfaces Texturées", *J. Phys. (Paris)* **42** (1981) C1-57.

    A simple model for rough periodic surfaces was developed and applied to gratings whose period is less than the minimal wavelength of the solar spectrum.

Appendix I: author index for 1955–1981

5. Appendix II: coatings index for 1955–1981

Includes references to review articles [1–78] only when these contain otherwise unpublished material, and to theoretical papers [531–565] only when these contain explicit comparisons with experimental data. The symbol (t) given after the materials designation implies that texture is essential for governing the optical properties. Particulate gas evaporated coatings are listed according to M–air, where M is the metal. Paints are listed according to P–binder, where P is the pigment material.

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