

On the Use of a Low Current Argon Arc with a MgF_2 -Window as a VUV-Transfer Standard of the Spectral Radiance ($125 \text{ nm} \leq \lambda \leq 335 \text{ nm}$)

D. Einfeld, K. Grützmacher, and D. Stuck

Physikalisch-Technische Bundesanstalt, Institut Berlin

Z. Naturforsch. **34a**, 233–238 (1979); received December 8, 1978

The spectral radiance $L_\lambda(\lambda)$ of a low current argon arc (current: 10 A, power requirement: $\leq 1.5 \text{ kW}$, pressure: 1.2 bar, gas: A) has been calibrated with a relative uncertainty of 5% in the wavelength range between 125 nm and 335 nm by means of the electron synchrotron radiation of DESY (Hamburg, Germany). $L_\lambda(\lambda)$ exceeds generally the spectral radiance of the carbon arc and the commercially available deuterium lamps by more than one order of magnitude. A significant reduction of the transmittance $\tau(\lambda)$ of the MgF_2 -window, inserted for the sealing of the arc chamber has been observed in the entire wavelength range when the low current argon arc has been flanged to a vuv-optical system. The behaviour of the transmission factor of the MgF_2 -window under the influence of increasing times of exposure to arc radiation has been investigated as a function of wavelength. The reduction of the transmission factor of the MgF_2 -window in the uv ($\lambda > 185 \text{ nm}$) is nearly negligible ($< 2\%$ over an operating time of 30 hours) when the arc has been utilized without a connection to a vuv-optical system.

I. Introduction

Measurements in the vuv-spectral region, as required in the fields of astrophysics and plasma-physics, increasingly demand the development and calibration of uv- and vuv-transfer standards of spectral radiance with uncertainties below 10%. Available uv- and vuv-transfer standards (see Fig. 5) of the spectral radiance are: the low-current carbon arc [1, 2], the deuterium lamp [3, 4], a cascade arc (down to 250 nm) [5], and the special version of a cascade arc ("mini-arc") [6].

The spectral radiance of the carbon arc (current: 7.3 amps, voltage: 65 volts) can be approximated for wavelengths above 270 nm by that one of a gray-body radiator [7] (distribution temperature: $T_d = 3830 \text{ K}$, emissivity: $\varepsilon = 0.965$). Below 270 nm the radiation contributed by the arc stream in front of the anode increases significantly and below 235 nm the emitted spectrum is distorted by a number of emission lines. The relative uncertainty of the spectral radiance of the low current carbon arc amounts to 3% in the wavelength region from the air cut-off ($\lambda \sim 185 \text{ nm}$) to 340 nm [2].

Deuterium lamps are used as transfer standards, because they emit a molecular continuum ($165 \text{ nm} \leq \lambda \leq 350 \text{ nm}$), they are cheaply procurable and convenient in their operating conditions. The

spectral radiance of the deuterium lamp increases above $\lambda = 170 \text{ nm}$ with wavelength, attaining a maximum value at $\sim 200 \text{ nm}$, and decreases with further increasing wavelengths. This spectral distribution may lead to lower straylight contributions to the uv-signals in comparison to the low current carbon arc. A disadvantage in the behaviour of the commercially available deuterium lamps is their strongly wavelength dependent decrease of the spectral radiance with increasing time of operation [8]. Specially developed and carefully selected deuterium lamps as used by Key et al. [4] show small alterations of the spectral radiance of less than $-0.05\%/h$ in the entire wavelength range. The relative uncertainty of calibration with respect to the spectral radiance of deuterium lamps amounts to 2% in the wavelength region between 165 nm and 330 nm [3].

Cascade arcs operated with argon have been used as uv-standards down to 250 nm by Wende [5]. Recently Bridges and Ott [6] developed a special version of a cascade arc ("mini-arc") sealed with a MgF_2 -window for the application as a transfer standard of the spectral radiance in the spectral range from 115 nm to 350 nm, without the serious limitations of the low current carbon arc and/or the deuterium lamps as mentioned above. The AI-continuum radiation emitted from the cascade arc (including the MgF_2 -window) was calibrated by means of the spectral radiance of the high power hydrogen arc [9] and the blackbody line radiator [10], except at those wavelengths where the transfer

Reprint requests to Dr. D. Stuck, Physikalisch-Technische Bundesanstalt, Institut Berlin, Abbestraße 2–12, D-1000 Berlin 10.

0340-4811 / 79 / 0200-0233 \$ 01.00/0



Dieses Werk wurde im Jahr 2013 vom Verlag Zeitschrift für Naturforschung in Zusammenarbeit mit der Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. digitalisiert und unter folgender Lizenz veröffentlicht: Creative Commons Namensnennung-Keine Bearbeitung 3.0 Deutschland Lizenz.

Zum 01.01.2015 ist eine Anpassung der Lizenzbedingungen (Entfall der Creative Commons Lizenzbedingung „Keine Bearbeitung“) beabsichtigt, um eine Nachnutzung auch im Rahmen zukünftiger wissenschaftlicher Nutzungsformen zu ermöglichen.

This work has been digitalized and published in 2013 by Verlag Zeitschrift für Naturforschung in cooperation with the Max Planck Society for the Advancement of Science under a Creative Commons Attribution-NoDerivs 3.0 Germany License.

On 01.01.2015 it is planned to change the License Conditions (the removal of the Creative Commons License condition "no derivative works"). This is to allow reuse in the area of future scientific usage.

standard emits impurity lines (O I, N I, C I etc.). The relative uncertainty of the spectral radiance $L_\lambda^*(\lambda)$ of the "mini-arc", including the transmittance $\tau(\lambda)$ of the MgF_2 -window, is estimated to be 10% between 115 nm and 140 nm and 5.3% for wavelengths above 140 nm.

The transmittance $\tau(\lambda)$ of the MgF_2 -window changes rapidly under normal vuv-experimental conditions due to possible contamination of hydrocarbons. The spectral radiance $L_\lambda(\lambda)$ of the plasma itself, available by calculating L_λ^* , $(\tau(\lambda))^{-1} = L_\lambda(\lambda)$ is therefore the only quantity without any alterations due to the used vuv-optical system.

The present paper describes the calibration of a low-current argon arc with MgF_2 -window with respect to the spectral radiance $L_\lambda(\lambda)$ of the plasma itself ($125 \text{ nm} \leq \lambda \leq 335 \text{ nm}$). In order to get this quantity careful investigations have been undertaken to determine the wavelength dependent alterations of the transmittance of the MgF_2 -windows as a function of the operating time of the arc, when connected to the vuv-radiometer.

II. Apparatus

II.1. Low Current Argon Arc

A schematic diagram of the argon arc source, developed at the PTB is given in Figure 1. The 45 mm long wall stabilized arc is struck between two thoriated tungsten electrodes (4 mm in diameter) and is constricted by a set of 15 water cooled rectangular copper disks, 2 mm in thickness with a 1.2 mm bore diameter, electrically insulated from each other by silicon rings. In the vicinity of the cathode an additional tungsten pin "T" is used in order to eliminate cathode instabilities from the observed plasma column. The arc chamber can be

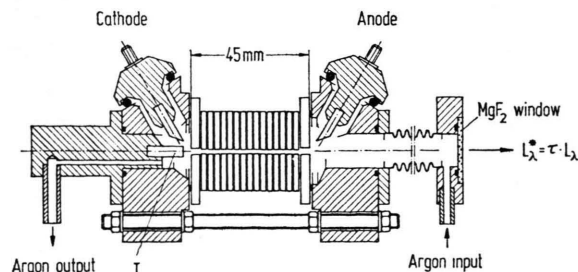


Fig. 1. Schematic drawing of the low current argon arc.

evacuated for ignition under glow discharge conditions (voltage: 600 V). Common operating conditions of the low current argon arc are: current: 10 amps, voltage between both electrodes: 145 V, argon flow rate during operation: $1.5 \text{ cm}^3 \text{ s}^{-1}$, purity: $\geq 99.997\%$, pressure during operation: 1.2 bar. By means of a MgF_2 -window the arc chamber is separated from the vuv-optical system. The gas intake is near the MgF_2 -window, in order to prevent possible contaminations to the window by the discharge, especially by evaporations of the anode material.

The spectral distribution of $L_\lambda(\lambda)$ of the argon continuum radiation is distorted by several impurity lines due to atomic nitrogen, carbon, oxygen and hydrogen and by some weak Ar II lines in the wavelength range below 200 nm [6]. Utilizing Kr instead of Ar in the arc discharge spectral radiance calibrations in the vuv are possible at wavelengths, where the spectral distribution of $L_\lambda(\lambda)$ of the argon continuum radiation is distorted by emission lines. The spectral radiance of the low current argon arc can be varied in a range of about one order of magnitude by changing the operating parameters arc current (5 ... 10 A) and pressure during operation (1 ... 2 bar). These operating parameters are simply adjustable and controllable. Operating the low current argon arc under different conditions its spectral radiance can be adapted to that one of other radiators. In this way linearity problems due to the detection system and scaling difficulties may be avoided.

II.2. Spectro-radiometric Arrangement

The spectral radiance calibration of the low current argon arc was performed by means of the electron synchrotron radiation of DESY (Hamburg, Germany). The radiometer used was especially developed for calibration purposes in the normal incidence spectral range and is described in detail elsewhere [3]. The range of sensitiveness of the radiometer was extended to 105 nm by installation of an EMR photomultiplier (541 G-08-18) with LiF-window. During the spectral radiance calibration photomultipliers with sufficient narrow band spectral sensitivities were used ($105 \text{ nm} \leq \lambda \leq 190 \text{ nm}$: EMR 541 G-08-18, with LiF-window; $145 \text{ nm} \leq \lambda \leq 290 \text{ nm}$: EMR 541 F-05 M-14, with Sapphire-window; $160 \text{ nm} \leq \lambda \leq 335 \text{ nm}$: EMI 6256 S, EMI 9558 QB, with Suprasil-window).

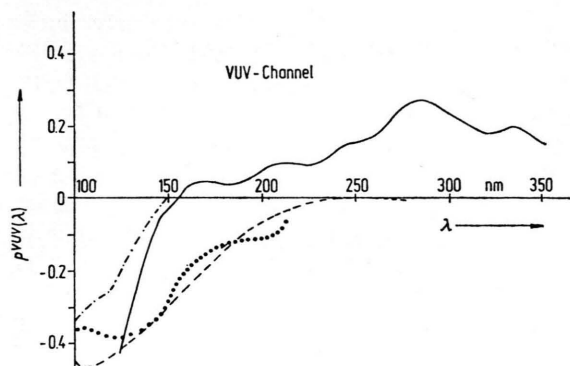


Fig. 2. Degree of polarization produced of the used vuv radiometer versus wavelength and comparison with previous measurements of other authors. -----: Rüsbüldt et al.; -.-.-.-: Ritchie et al.;: Matsui et al.; —: this work.

The polarization behaviour of the vuv-radiometer [3] was investigated additionally in detail in the wavelength range below 165 nm. The degree of polarization produced by the vuv-monochromator is demonstrated in Fig. 2 versus wavelength. The degree of polarization produced by other vuv-monochromators of the same type [11, 12, 13] as in the radiometer used here shows a qualitatively similar behaviour (Figure 2).

III. Results

III.1. Spectral Radiance Calibration

The spectral radiance calibration of the low current argon arc was performed with a spectral bandwidth of $\Delta\lambda \leq 0.6$ nm*.

A centered circular area of the plasma of 0.9 mm in diameter* was observed in the direction of the arc column (end-on) for the small solid angle of $2.7 \cdot 10^{-5}$ sr. The typical radial variation of the relative spectral radiance in the horizontal direction (y) as well as in the vertical direction (spatial resolution: 0.1 mm) is demonstrated in Fig. 3 for the wavelength range from $\lambda = 180$ nm to 335 nm. To shorter wavelengths a slight decrease of the half-width of the radial distribution has been observed. The spectral radiance $L_\lambda(\lambda)$ of the continuum radiation of the plasma itself, given by $L_\lambda(\lambda) = L_\lambda^*(\lambda) \cdot (\tau(\lambda))^{-1}$ was obtained by measur-

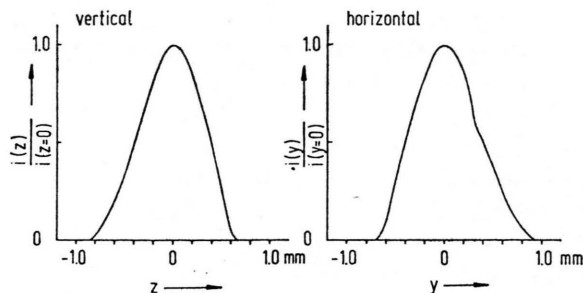


Fig. 3. Radial variation of the relative spectral radiance of the low current argon arc (typical between $180 \text{ nm} \leq \lambda \leq 335 \text{ nm}$) for the horizontal direction (y) and the vertical direction (z), measured with a spatial resolution of 0.1 mm.

ing the quantity $L_\lambda^*(\lambda)$ (including the MgF₂-window) [3] and by measurements of the transmittance $\tau(\lambda)$ of the used MgF₂-window. $\tau(\lambda)$ has been determined by several measurements during the calibration procedure, by inserting the MgF₂-window in a filter wheel in front of the exit slit of the vuv-radiometer, utilizing the electron synchrotron as a light source.

In Fig. 4 $L_\lambda(\lambda)$ is presented versus wavelength in the region between 125 nm and 335 nm, where $L_\lambda(\lambda)$ denotes the mean value, averaged over the centered circular area of the plasma column (0.9 mm in diameter). The spectral radiance attains at $\lambda \sim 130$ nm a minimum value ($L_\lambda(\lambda = 130 \text{ nm}) \sim 6 \cdot 10^{10} \text{ Wm}^{-3} \text{ sr}^{-1}$) and increases continuously with wavelength to values of about $1 \cdot 10^{12} \text{ Wm}^{-3} \text{ sr}^{-1}$ above $\lambda = 320$ nm. Below $\lambda = 130$ nm, the increase of the spectral radiance with decreasing wavelengths results from the superposition of the A-continuum radiation by the line wings of the A-resonance lines

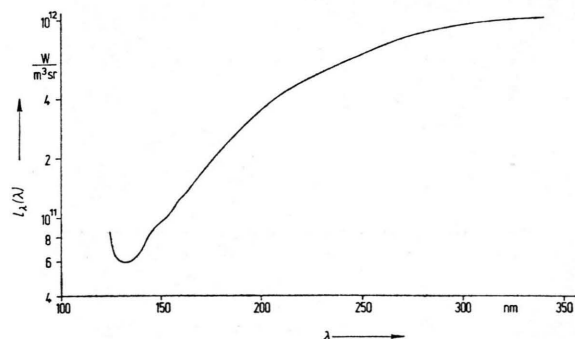


Fig. 4. Spectral radiance of the low current argon arc plasma column versus wavelength. Operating parameters of the arc: $i = 10$ A, $p = 1.2$ bar, gas: argon, bore diameter: 1.2 mm, used bandwidth: $\Delta\lambda \leq 0.6$ nm.

* Bandwidth and the observed circular area of the plasma column are determined by the entrance hole of the used radiometer [3].

($\lambda = 106.7 \text{ nm}$ and $\lambda = 104.8 \text{ nm}$) and from the (impurity) hydrogen line L_α ($\lambda = 121.6 \text{ nm}$).

In comparison with both, low current carbon arc and deuterium lamp, the spectral radiance of the low current argon arc exceeds in part their spectral radiance values of about more than one order of magnitude (Figure 5). The spectral radiance of the NBS "mini-arc" shows nearly the same spectral distribution as the PTB low current argon arc.

The relative uncertainty of the spectral radiance $\Delta L_\lambda(\lambda)/L_\lambda(\lambda)$ of the plasma itself amounts to 5% and is summed up linearly from the two individual relative uncertainties $\Delta L_\lambda^*/L_\lambda^* = 2.5\%$ [3] and $\Delta\tau(\lambda)/\tau(\lambda) = 2.5\%$. $\tau(\lambda)$ depends sensitively on the operating conditions of the arc and the vuv optical system (spectral radiance distribution, radiant power, vacuum conditions) as discussed in detail in the following Section III.2. Variations of the spectral radiance $L_\lambda(\lambda)$ due to variations of the plasma parameters pressure p and current i ($\Delta p/p = 0.5\%$ leads to $\Delta L_\lambda/L_\lambda \approx 0.5\%$, $1 \text{ bar} \leq p \leq 2 \text{ bar}$ and $\Delta i/i = 0.05\%$ leads to $\Delta L_\lambda/L_\lambda \approx 0.5\%$, $9 \text{ amps} \leq i \leq 10 \text{ amps}$) are small in comparison to the variations of $\tau(\lambda)$ with increasing exposing times to arc radiation of the MgF_2 -window. Taking into account that the use of the low current argon arc as a transfer standard requires a further $\tau(\lambda)$ -determination of the MgF_2 -window during the actual measurements, it is obvious that the relative uncertainty of $L_\lambda^*(\lambda)$ is significantly determined by that one of the transmittance of the MgF_2 -window.

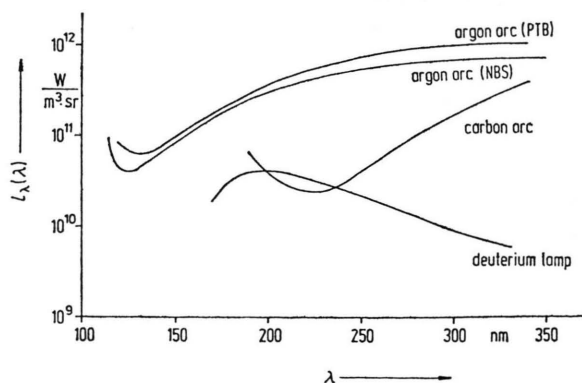


Fig. 5. Comparison of the spectral radiance versus wavelength of different uv- and vuv-transfer standards. Operating parameters: argon arc (PTB): as mentioned in Fig. 4, argon arc (NBS): $i = 50 \text{ A}$, power requirement: 1.5 kW , bore diameter: 3.96 mm ; carbon arc: $i = 7.3 \text{ A}$, $V = 65 \text{ volts}$, deuterium lamp: $i = 300 \text{ mA}$, $V = 85 \text{ volts}$.

In order to confirm the estimated uncertainties of the spectral radiance mentioned above, the low current argon arc has been radiance compared with the carbon arc in the near uv spectral region ($255 \text{ nm} \leq \lambda \leq 335 \text{ nm}$). The optical device used for the latter measurements consists mainly of a 1-m-Czerny-Turner monochromator, that has been operated with a bandwidth of 0.2 nm . An agreement of the spectral radiance values within 6% has been found. This result is consistent with the combined uncertainties of the calibration procedures by synchrotron radiation (5%) and the carbon arc radiation (3%).

Additionally it should be mentioned that the low current argon arc was disassembled and stacked again between several runs. The measured spectral radiance values have been found to be reproduced within the estimated uncertainty limit of 5%.

III.2. Alteration of the Spectral Transmittance of the MgF_2 -Windows, Utilized with the Low Current Argon Arc

The MgF_2 -window* is used in order to separate the arc chamber of the low current argon arc from the vuv-optical system or from the air respectively (when the arc is used only in the uv-optical region; $\lambda > 185 \text{ nm}$). Therefore the spectral radiance of the argon plasma is reduced by the transmittance of the MgF_2 -window. Utilizing the low current argon arc as a transfer standard, the determination of the actual transmittance $\tau(\lambda)$ of the MgF_2 -window is required with sufficient accuracy.

The transmittance of MgF_2 -windows ($1.9 \text{ mm} \dots 2.04 \text{ mm}$ in thickness) are presented in Fig. 6 [6, 15, 16]. The MgF_2 -window used in this work was freshly polished before the transmittance measurements**. The stage of aging of the windows used by the other authors is not accurately known.

Using the low current argon arc as a transfer standard in the uv spectral region above 185 nm in air, i.e. without connection to an evacuated vacuum system the alteration of the transmittance $\tau(\lambda)$ of utilized MgF_2 -window was found to be rather small as a function of exposing times to arc radiation.

* The most attractive feature utilizing the MgF_2 -crystal as window material is the low solubility of water compared with LiF [14].

** Polishing was performed by the manufacturer Halle Nachf., Berlin.

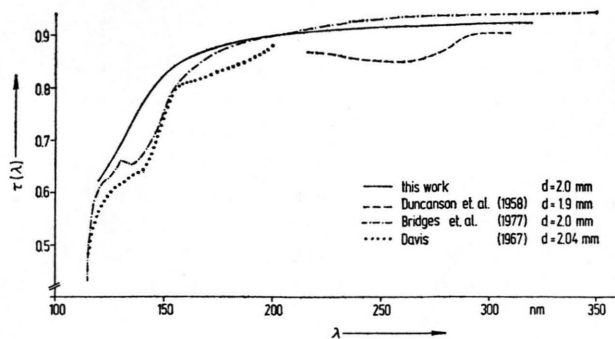


Fig. 6. Transmittance $\tau(\lambda)$ of several MgF_2 -windows versus wavelength (thickness: 1.9 mm ... 2.04 mm), determined by several authors.

In Fig. 7 the spectral transmittance $\tau(\lambda)$ of a freshly polished MgF_2 -window (No. 2) is demonstrated (solid line) in the spectral range between 120 nm and 335 nm. The dots given in Fig. 7 represent additional measurements of $\tau(\lambda)$ obtained after exposing times to arc radiation between 6 h and 30 h at nine wavelengths above 220 nm. A more detailed analysis of the results given in Fig. 7 shows a rather slight tendency downwards with increasing exposure time to arc radiation of less than 2% per 30 h.

However, a significant reduction of the transmittance of the MgF_2 -window has been observed under vuv-experimental conditions at DESY, due to contamination of hydrocarbons. The vacuum of the utilized vuv device is generated by two turbomolecular pumps with a pumping speed of 1000 m^3/h each [3]. The vacuum should be largely free of oil vapour and the pressure during all measurements

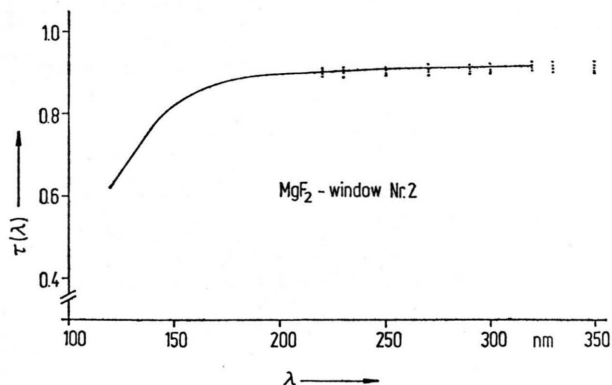


Fig. 7. Transmittance $\tau(\lambda)$ versus wavelength of a freshly polished MgF_2 -window (No. 2) and after different times of exposure to arc radiation (given by dots). The window has been exposed to air on the one side in the latter case.

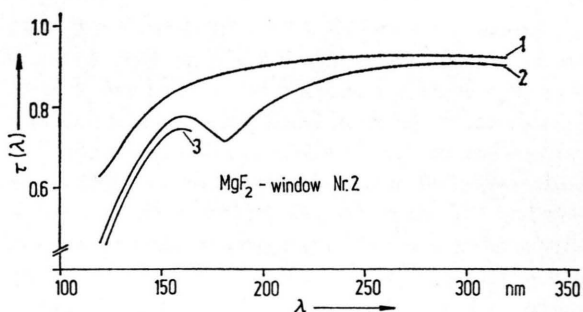


Fig. 8. Transmittance $\tau(\lambda)$ versus wavelength of the MgF_2 -window No. 2 after different times of exposure to arc radiation under vuv optical conditions. (Curve 1: freshly polished window, curve 2: 3 h of exposure time to arc radiation). The window was used as a sealing element between the arc chamber and the vuv optical system.

was always smaller than 10^{-4} Pa. With increasing time of exposure to arc radiation the transmittance of the MgF_2 -window diminishes considerably. In Fig. 8 curve 1 shows again the transmittance $\tau(\lambda)$ versus wavelength of the freshly polished MgF_2 -window (No. 2). The window was then exposed to the arc radiation. The subsequently measured transmittance $\tau(\lambda)$ (Fig. 8) show a rapid decrease in the uv- as well as in the vuv-spectral region.

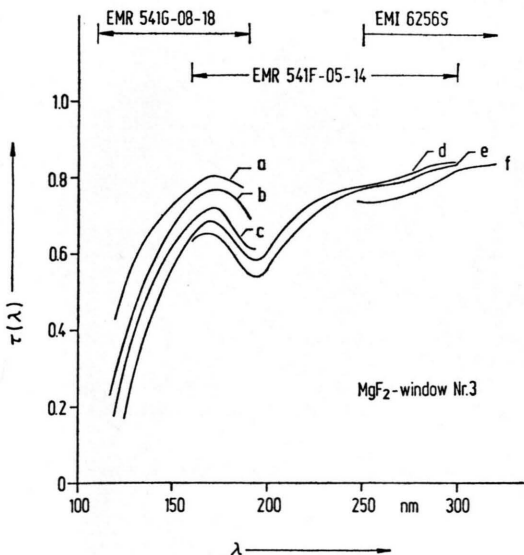


Fig. 9. Transmittance $\tau(\lambda)$ versus wavelength of the MgF_2 -window No. 3 (70 h preexposed to arc radiation and carefully dry-cleaned) for different times of exposure to arc radiation, that were achieved during a complete run of the spectral radiance calibrations in the spectral range $125 \text{ nm} \leq \lambda \leq 320 \text{ nm}$. The sequence of measurements started at curve a and ended at curve f. The time of exposure to arc radiation between two subsequent measurements of $\tau(\lambda)$ amounts to two hours.

Another MgF_2 -window (No. 3) that already had been exposed to arc radiation of more than 70 hours was dry-cleaned carefully before the subsequent measurements (Fig. 9). During the spectral radiance calibration of the low current argon arc in the entire spectral range from 125 nm to 335 nm a number of transmittance $\tau(\lambda)$ determinations of this window have been performed (the sequence of measurements started with curve a and ended with curve f, Figure 9). The time of exposure to arc radiation between two subsequent measurements of $\tau(\lambda)$ amounts to two hours and the wavelength range of the curves given in Fig. 9 corresponds to the spectral sensitivity ranges of the utilized photomultiplier tubes. The transmittance $\tau(\lambda)$ of window No. 3 is in all cases smaller than that one of the freshly polished window (see Fig. 8, curve 1). However, the relative reduction of $\tau(\lambda)$ with increasing time of exposure to arc radiation is comparable to those values found for the freshly polished window (Figure 8). From the measurements shown in Fig. 9 the relative reduction of the transmittance $\Delta\tau(\lambda)/\tau(\lambda)$ (related to the actual value of the transmittance) in percent per hour has been deduced (Figure 10).

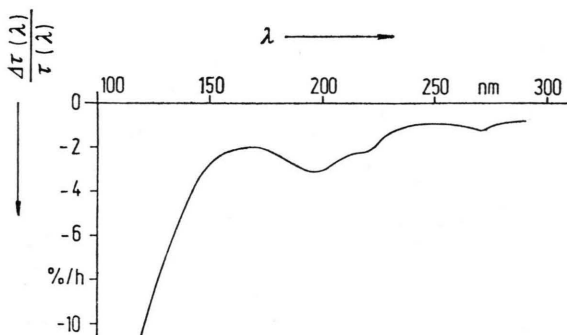


Fig. 10. The relative reduction of the transmittance of a MgF_2 -window (No. 3) in %/h versus wavelength.

IV. Conclusion

The results of the transmittance $\tau(\lambda)$ measurements given in this paper demonstrate the serious problems due to the wavelength dependent reduction of the transmittance of the MgF_2 -windows when these windows are used in connection with an intense vuv radiation source, particularly by utilizing the argon arc as a vuv transfer standard. The relative reduction of the transmittance of the MgF_2 -windows is a characteristic of both, the utilized vuv optical system and the operating conditions of the light source, here of the low current argon arc. Users of the low current argon arc as a transfer standard of spectral radiance are therefore forced to determine the actual transmittance of each utilized MgF_2 -window during the radiance measurements. The relative uncertainty of the actual transmittance determination achieved by the user has to be summed to the uncertainty of the spectral radiance ($\Delta L_\lambda/L_\lambda = 5\%$) of the arc plasma.

The accuracy of the spectral radiance calibration of the low current argon arc achieved in this work is limited by using a conventional synchrotron accelerator and a transfer standard source with a MgF_2 -window as a vacuum sealing element. Significant improvements in the accuracy are only likely to be possible with the much more stable conditions of a storage ring source and by using a differential pumping system to get a windowless connection of the low current argon arc to the vacuum system which eliminates the uncertainties of the transmittance determination. But the convenience in handling the low current argon arc as a transfer standard would be further complicated.

Acknowledgements

Two of the authors (D. E. and D. St.) are grateful to the staff of the DESY group F 41 for their support during the work at Hamburg.

- [1] H. Magdeburg and U. Schley, *Z. angew. Phys.* **20**, 465 (1966).
- [2] D. Einfeld and D. Stuck, *Z. Naturforsch.* **33a**, 502 (1978).
- [3] D. Einfeld, D. Stuck, and B. Wende, *Metrologia* **14**, 111 (1978).
- [4] P. J. Key and T. W. Ward, *Metrologia* **14**, 17 (1978).
- [5] B. Wende, *Optik* **25**, 284 (1967).
- [6] J. M. Bridges and W. R. Ott, *Appl. Opt.* **16**, 367 (1977).
- [7] J. P. Mehlretter, Thesis, University Heidelberg (1962).
- [8] D. Einfeld and D. Stuck, *Opt. Comm.* **19**, 297 (1976).
- [9] W. R. Ott, K. Behringer, and G. Gieres, *Appl. Opt.* **14**, 2121 (1975).
- [10] W. R. Ott, P. Fieffe-Prevost, and W. L. Wiese, *Appl. Opt.* **12**, 1618 (1973).
- [11] R. H. Ritchie, E. J. Arakawa, J. J. Cowan, and N. N. Hamm, *Phys. Rev. Letters* **21**, 1530 (1968).
- [12] A. Matsui and W. C. Walker, *J. Opt. Soc. Amer.* **60**, 64 (1970).
- [13] D. Rüböldt and K. Thimm, *Nucl. Instrum.* **116**, 125 (1974).
- [14] J. A. R. Samson, *Techniques of Vacuum Ultraviolet Spectroscopy*, John Wiley, New York 1967.
- [15] A. Duncanson and R. W. H. Stevenson, *Proc. Phys. Soc. London* **72**, 1001 (1958).
- [16] D. L. Steinmetz, W. G. Philipps, M. Wirick, and F. F. Forbes, *Appl. Opt.* **6**, 1001 (1967).