International Journal of Thermophysics, Vol. 14, No. 5, 1993

Note

A Dynamic Technique for Measuring Normal Spectral Emissivity of Electrically Conducting Solids at High Temperatures with a High-Speed Spatial Scanning Pyrometer

A. Cezairliyan[1] and A. P. Miiller[2]

Received February 24, 1993

A dynamic (subsecond) technique is described for measuring normal spectral emissivity of electrically conducting solids at high temperatures, primarily in the range 1800 K up to near their melting point. The basic method involves resistively heating a tubular specimen from ambient temperature through the temperature range of interest in less than 1 s by passing an electrical current pulse through it, while using a high-speed spatial scanning pyrometer to measure spectral radiance temperatures along a 25-mm length on the specimen. This portion of the specimen includes a small rectangular hole that approximates a blackbody cavity. Measurements of spectral radiance temperature of the specimen surface as well as specimen true temperature enable the determination of the normal spectral emissivity of the surface via Planck's law. The applicability of the technique is demonstrated by measurements performed on molybdenum in the range 1900–2850 K.

KEY WORDS: dynamic technique; high temperature; molybdenum; normal spectral emissivity; scanning pyrometry.

1. INTRODUCTION

Materials research at high temperatures often necessitates noncontact methods, namely, optical pyrometry, for the measurement of specimen temperature. These methods usually involve determining temperature from

[1] Metallurgy Division, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, U.S.A.

[2] Thermophysics Division, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, U.S.A.

0195-928X/93/0900-1109$07.00/0

measurements of spectral radiance from the specimen surface. However, to be reliable, such methods require an accurate knowledge of normal spectral emissivity for the surface of the material under study. Unfortunately, the currently available data on emissivity for many materials at high temperatures are in considerable disagreement, even for pure metallic elements [1].

The present note describes a dynamic technique for measuring normal spectral emissivity of electrically conducting solids that is particularly well suited to measurements at high temperatures. The basic method involves resistively heating a tubular specimen from ambient temperature through the temperature range of interest in less than 1 s by passing an electrical current pulse through it, while using a high-speed spatial scanning pyrometer [2] to measure spectral radiance temperatures along a 25-mm length on the specimen. This portion of the specimen includes a small rectangular hole that approximates a blackbody cavity. The measurements of spectral radiance temperature of the specimen surface as well as specimen true temperature enable the determination of the normal spectral emissivity of the surface via Planck's law. The applicability of the technique is demonstrated by measurements performed on a molybdenum specimen in the temperature range 1900 2850 K.

2. MEASUREMENT SYSTEM

The high-speed measurement system used in the present work consists of a pulse-heating system, a high-speed spatial scanning pyrometer, and a digital storage oscilloscope. The design, construction, and operation of the basic pulse-heating system are described in earlier publications [3, 4].

The high-speed spatial scanning pyrometer is capable of measuring spectral radiance temperatures at approximately 1000 contiguous target points along a 25-mm length on the surface of a rapidly heating specimen. The radiance from the specimen is focused by the pyrometer lens system, through an interference filter (40-nm bandwidth centered at 657 nm), onto the pyrometer detector, which consists of a silicon photodiode array of 1024 elements. Electronics associated with the array consecutively sample the photodiodes every 1 μs, thereby permitting one cycle of measurements (1024 data points), that is, one scan of the target length, to be completed in approximately 1 ms. Details regarding the design, construction, and calibration of the spatial scanning pyrometer, and its use in dynamic experiments, are given in Ref. 2.

The output voltage signal from the scanning pyrometer is recorded by a digital storage oscilloscope capable of storing 16,000 data points with 12-bit resolution. Since the oscilloscope memory is sufficient for the storage

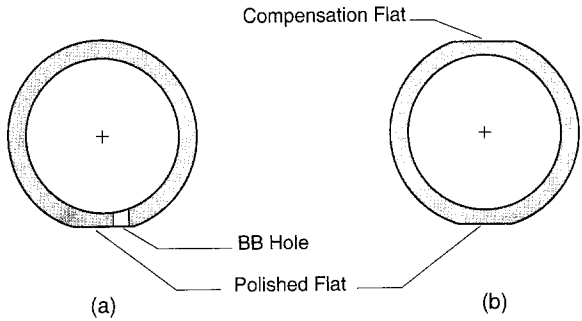

Fig. 1. Cross-sectional views of the tubular specimen (a) in a plane through the "blackbody" hole and (b) in a plane above (or below) the "blackbody" hole.

of only 15 complete scans, a time-delay/gate generator is used to record only results of selected scans so that voltage data from the pyrometer can be sampled over a desired time period. The recorded data are transferred after each experiment to a desktop computer for analyses.

3. MEASUREMENTS

The specimen was fabricated from a cylindrical rod of molybdenum (99% pure) by an electroerosion technique into the form of a tube with the following nominal dimensions: length, 75 mm; outside diameter, 6.4 mm; and wall thickness, 0.5 mm. A highly polished (specularly reflecting) flat was fabricated along the length of the tubular specimen for the surface radiance measurements. A small rectangular sighting hole (0.5×1 mm) was fabricated through the wall perpendicular to (and near the middle of) the polished flat so as to approximate a blackbody cavity. The sighting hole was positioned 0.8 mm off center from the tube axis to improve its blackbody quality. In order to compensate for the cross-sectional nonuniformity created by the hole, a portion of the specimen was removed by grinding a "compensation" flat along the length of the tube, excluding the 1-mm length of the hole. Figures 1a and 1b present cross-sectional views of the specimen tube (a) in a plane through the "blackbody" hole and (b) in a plane above (or below) the "blackbody" hole, respectively.

For the pulse-heating experiments, the specimen was mounted vertically between two water-cooled electrodes inside an experiment chamber, which was then evacuated to a pressure of about 1 mPa. The scanning pyrometer was focused, with its 25-mm target length aligned along the polished flat and centered on the "blackbody" hole.

Single-pulse experiments were performed successively through three overlapping temperature ranges, yielding data over a temperature interval of 1900–2850 K. In each experiment, the specimen was rapidly heated from room temperature through the temperature range of interest in less than 1 s by passing an electrical current pulse through it. The duration of the current pulse varied from about 550 to 650 ms, depending on the experiment. Heating rates varied typically from about 3000 to 4000 $K \cdot s^{-1}$. In each experiment, the recorded data from the pyrometer consisted of 15 scans of the target length taken at intervals of about 8 ms during the latter part of the heating period.

The high-speed spatial scanning pyrometer was calibrated against a tungsten-filament standard lamp that, in turn, had been calibrated by the Radiation Physics Division at NIST. The temperatures reported in this note are based on the International Temperature Scale of 1990 (ITS-90) [5].

4. RESULTS

Figure 2 illustrates the spectral radiance temperatures (at 657 nm) as measured by individual photodiodes 150 to 850 of the pyrometer array detector during one scan along the polished flat on the rapidly heating molybdenum specimen. The significantly higher radiance temperatures measured by photodiodes 490–530 are due to the "blackbody" hole. The scatter in the measured temperatures is due primarily to noise from the pyrometer electronics.

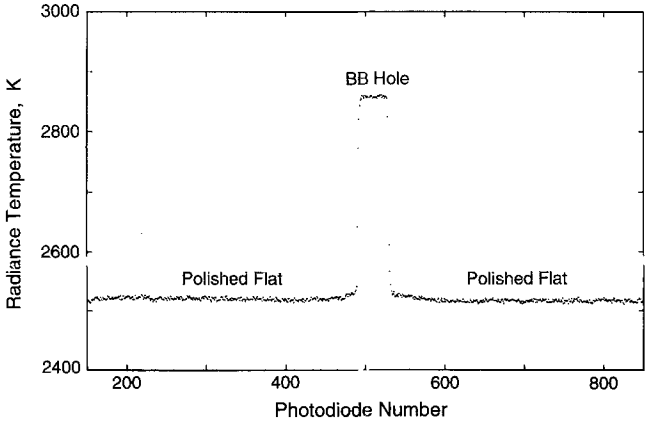

Fig. 2. Spectral radiance temperatures (at 657 nm) as measured by individual photodiodes of the pyrometer array detector during one scan along the polished flat (containing a blackbody hole) on the rapidly heating molybdenum specimen.

For each scan, radiance temperatures of the polished flat, as measured by 300 photodiodes on each side of the blackbody hole, were averaged and the mean was taken as the spectral radiance temperature of the molybdenum specimen. Similarly, radiance temperatures associated with the blackbody hole were averaged and the mean was taken as the specimen true temperature, after making corrections for departure of the specimen from true blackbody conditions [6] and for the light-scattering effect of the pyrometer optics [2].

The normal spectral emissivity (at 657 nm) of molybdenum was determined via Planck's law from the values determined for true temperature and spectral radiance temperature of the specimen during each scan. Our results for the normal spectral emissivity of polished molybdenum in three overlapping temperature ranges are presented in Fig. 3. As may be seen, the emissivity of molybdenum is essentially a linear function of temperature in the temperature interval (1900–2850 K) of our measurements. The standard deviation of a given measurement of emissivity from a fitted linear function of temperature (dashed line) is less than 0.5%. An extrapolation (about 40 K) of the linear function to the melting point of molybdenum (2893 K [7]) yields a value of 0.343. This value is somewhat higher (about 2%) than the value (0.335) obtained at the melting point in earlier measurements of the melting-point radiance temperatures of molybdenum [8]. This difference is not unexpected since the surface of polished (solid) molybdenum is not likely to be as smooth as that of molten (liquid) molybdenum and therefore it should have a higher emissivity.

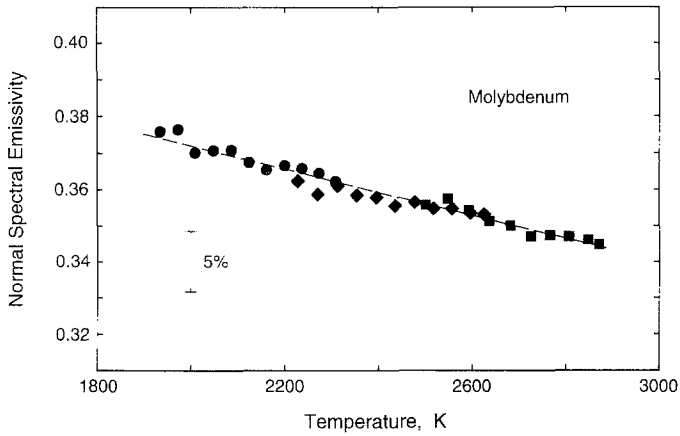

Fig. 3. Results for the normal spectral emissivity of polished molybdenum determined from measurements in three overlapping temperature ranges (indicated by different symbols). The dashed line represents the best linear fit to the data.

5. CONCLUDING REMARKS

The dynamic technique described herein for measuring normal spectral emissivity of electrically conducting solids is particularly well suited to measurements at high temperatures. The technique utilizes measurements at multiple target points and therefore minimizes uncertainties associated with single-target methods such as those arising from local surface defects, temperature gradients, etc. In addition, the present technique significantly reduces measurement noise by averaging the data from multiple target points.

ACKNOWLEDGMENT

This work was supported by the Microgravity Science and Applications Division of NASA.

REFERENCES

1. Y. S. Touloukian and D. P. DeWitt, *Thermophysical Properties of Matter: Thermal Radiative Properties, Vol. 7* (IFI/Plenum, New York, 1970).
2. A. Cezairliyan, R. F. Chang, G. M. Foley, and A. P. Miiller, *Rev. Sci. Instrum.* **64**:1584 (1993).
3. A. Cezairliyan, *J. Res. Natl. Bur. Stand. (U.S.)* **75C**:7 (1971).
4. A. Cezairliyan, M. S. Morse, H. A. Berman, and C. W. Beckett, *J. Res. Natl. Bur. Stand. (U.S.)* **74A**:65 (1970).
5. H. Preston-Thomas, *Metrologia* **27**:3 (1990); *Metrologia* **27**:107 (1990).
6. J. C. De Vos, *Physica* **20**:669 (1954).
7. A. Cezairliyan, M. S. Morse, and C. W. Beckett, *Rev. Int. Hautes Temp. Refract.* **7**:382 (1970).
8. A. P. Miiller and A. Cezairliyan, in *Temperature: Its Measurement and Control in Science and Industry, Vol. 6, Part 2*, J. F. Schooley, ed. (AIP, New York, 1992), p. 769.

Printed in Belgium
Verantwoordelijke uitgever:
Hubert Van Maele
Altenastraat 20 – B-8310 St.-Kruis