A MODULATION METHOD OF STUDYING THERMAL EXPANSION

Ya. A. Kraftmakher and I. M. Cheremisina

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A modulation method of studying the thermal expansion of metals at high temperatures has been developed. This method consists in determining the amplitude of the oscillations in the length of the specimen associated with periodic oscillations of its temperature about a mean value. Thus, the coefficient of thermal expansion is measured directly. The thermal expansion of tungsten has been studied at 1300-2300°K. In this region the coefficient of thermal expansion of tungsten is described by the equation

$$\alpha = 4.1 \cdot 10^{-6} + 10^{-9} T \text{ deg}^{-1} .$$

At present, the thermal expansion of solids is studied by determining the length or volume of the specimens at different temperatures, the coefficient of thermal expansion being found as a result of differentiating the relations thus obtained [1-3]. This method can give good results only if the coefficient of thermal expansion does not vary much with temperature. A serious source of interference is high-termperature creep, which distorts the results of the measurements. Therefore, in order to study thermal expansion it is most convenient to use not the measured value of the total length of the specimen, but the changes in length associated with changes in temperature. This is the basis of the modulation method described below, which makes it possible to obtain high sensitivity to changes in the coefficient of thermal expansion. In certain cases, for example, in connection with the formation of vacancies in the crystal lattice of solids or phase transitions of the second kind, the relative increase in the length or volume of the specimen is small, whereas the coefficient of thermal expansion changes appreciably. Therefore, the method of direct measurement of the coefficient of thermal expansion has important advantages as far as the study of these phenomena is concerned.

The modulation method consists in the following. A wire specimen is heated with alternating current or current containing a constant and a variable component. As a result the temperature of the specimen oscillates about a mean value and this, in turn, produces periodic changes in length. The specimen is clamped at one end and stretched at the other by a load or spring. With the aid of an optical system the unclamped end of the specimen is projected onto a slit in front of the cathode of a photomultiplier. Fluctuations in the length of the specimen correspond to periodic changes in the illumination of the photocathode, so that the output voltage of the photomultiplier has a variable component. From the magnitude of this voltage one can determine the amplitude of the oscillations in the length of the specimen. The measuring circuit is calibrated under static conditions by adjusting the position of the photomultiplier. The amplitude of the temperature oscillations depends on the amplitude of the power supply oscillations and on the specific heat of the specimen. It can be determined from the oscillations of the electrical resistance of the specimen using the compensation circuit previously employed for measuring specific heats in [4]. The changes in the temperature of the specimen can also be determined from the oscillations of its luminosity [5, 6]. If the specific heat of the specimen is known, the amplitude of its temperature oscillations can easily be calculated.

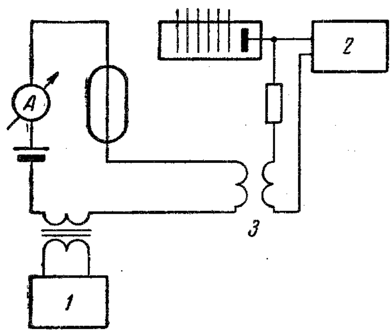

Fig. 1

Thus, when the modulation method is used, the coefficient of thermal expansion is determined directly. If the specimen is heated with alternating current, the formula for calculating the coefficient of thermal expansion has the form

$$\alpha = \frac{2mc\omega V}{lPK\, dV_0/dn} .$$

Here l, m, c are the length, mass, and specific heat of the specimen; P and ω are the power and frequency of the alternating current supplied to specimen, K is the magnification of the optical system, V is the amplitude of the variable component of the photomultiplier output voltage, and n is the displacement of the photomultiplier.

The phase shift between the oscillations of the power supplied to the specimen and the temperature of the specimen is assumed to be close to 90°, which is realized in practice even at low specimen temperature modulation frequencies [4].

When the specimen is supplied with current containing a constant and a variable component (the variable component is considerably smaller than the constant component), the coefficient of thermal expansion is calculated from the formula

$$\alpha = \frac{mc\omega V}{2lKi_0UdV_0/dn}.$$

Here i_0 is the constant component of the current supplied to the specimen, U is the amplitude of the variable component of the voltage across the specimen. In this case the coefficient of thermal expansion can be measured using a compensation circuit balanced independently of the amplitude of the specimen temperature oscillations. Such a circuit is shown in Fig. 1, where 1 is a low-frequency oscillator, 2 is a selective amplifier, and 3 is a mutual inductance box. A compensation circuit using a selective amplifier or the method of synchronous detection makes it possible to measure the coefficient of thermal expansion even at very small specimen temperature modulation amplitudes.

Using the modulation method, we studied the thermal expansion of tungsten in the temperature range 1300-2300°K. The measurements were made on specimens 0.05 mm in diameter. The specimens were heated with a current containing a constant and a variable component. The temperature modulation frequency was 60 cps. The amplitude of the specimen temperature oscillations was 3-4° and was determined from the oscillations of the electrical resistance of the specimen [4]. The magnification of the optical system was 80. A type FEU-17A photomultiplier was employed. The sensitivity of the circuit was 0.5 V/μ.

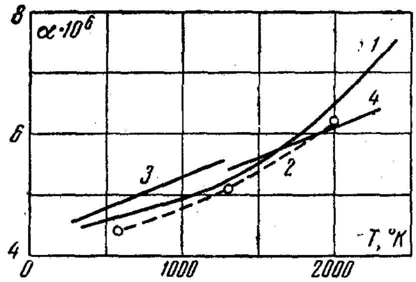

Fig. 2

The amplitude of the oscillations in specimen length was about 0.5 μ, so that the output voltage of the circuit was about 250 mV. During calibration the displacement of the photomultiplier was determined using a dial-type indicator.

In the temperature range 1300-2300°K the results of our measurements are described by the equation

$$\alpha = 4.1 \cdot 10^{-6} + 10^{-9} T \ \deg^{-1}.$$

They are in good agreement with the existing data [7-9]. The results of measurements of the coefficient of thermal expansion of tungsten at high temperatures are shown in Fig. 2, where the curves 1, 2, 3 correspond to references [7], [8], [9], and curve 4 to the results of our measurements. At higher temperatures an additional increase in the coefficient of thermal expansion may be expected owing to the formation of vacancies in the crystal lattice of tungsten [10].

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