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Abstract

Full Text

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TEMPERATURE DEPENDENCE OF THE SURFACE TENSION OF GERMANIUM

(Presented by Academician I. I. Chernyaev, 13 IV 1960)

The development of semiconductor technology has posed the problem of alloying ultra-pure semiconductor materials with negligibly small amounts of impurities and of studying the properties of the resulting alloys as a function of their composition ([1]). The study of the surface tension of such melts is directly connected with the solution of this problem. Quite apart from the theoretical significance of the conclusions regarding the forces and energies of molecular interaction that can be drawn as a result of such studies, the investigation of the surface tension of semiconductor melts is also of purely practical importance in connection with questions of zone melting, the production of single crystals ([2]), wetting of semiconductors by metals ([3]), etc.

Fig. 1. Temperature dependence of the surface tension of germanium

The surface tension (σ) of germanium was first measured by Keck and Van Horn ([2]) by the drop-weight method, i.e., by a method that cannot be regarded as sufficiently well founded theoretically ([4,5]). They found that σ of germanium at its melting temperature is equal to 600 dyn/cm.

Sangster and Carman ([6]), from the shape of a solidified drop, established that σ of germanium near its melting temperature is equal to 632 dyn/cm. However, the method used by the authors of work ([6]) for some metals gives values of σ differing from the true ones by 20–30% ([7]). In addition, these methods exclude the possibility of measuring the surface tension of the melt at different temperatures; therefore, for our measurements of the surface tension of germanium we used the method of maximum pressure in a gas bubble, which is well founded theoretically and raises no doubts. The theory of this method, developed by Cantor ([8]), requires the use of capillaries whose wall thickness at the cut is infinitely small. Such capillaries were made by us from spectrally pure graphite; they had an end face ground down at the end that was lowered into the melt, which made it possible to eliminate the possible influence of the contact angle on the measured value of σ and unambiguously resolved the question of the value of the radius entering into the calculation formula ([9–11]). To carry out the measurements, a sample of single-crystal germanium with a specific resistance of 20 ohm • cm was placed in a graphite crucible, which in turn was placed in a special vacuum furnace having, as its heating element, a cylinder of tantalum sheet through which a high current was passed. Argon, previously purified by bubbling at 300° through molten lithium, was used as the working gas for blowing bubbles. The apparatus allowed measurements to be carried out by Sugden' s method ([12]), i.e., with the aid of two capillaries lowered into the melt to the same···

depth, which eliminated the need to take hydrostatic pressure into account when calculating σ. The maximum pressures in the gas bubbles were measured using a magnetomembrane manometer. Since the capillaries used had diameters up to 4 mm, in calculating the surface tension of germanium we used the effective radii of the capillaries, computed by the method of successive approximations with the aid of Sugdén' s table [(12)]. The density values of molten germanium at different temperatures, needed for calculating σ, were taken by us from [(13)] and extrapolated to 1400°. The accuracy of determining the surface tension under our conditions was 1%, which did not exceed 7 dyn/cm.

The results of our measurements of the temperature dependence of the surface tension of germanium are presented in Table 1 and in Fig. 1. This dependence can be expressed by the following formula

$$\sigma = 621.4 - 0.261\,(t^\circ - 936^\circ), \tag{1}$$

where t° is the temperature in °C, and 936° is the melting temperature of germanium according to Greiner [(14)]. The constants of equation (1) were calculated by us by the method of least squares. It follows from equation (1) that at the melting temperature of germanium its surface tension is equal to 621.4 dyn/cm.

Table 1

Temperature dependence of the surface tension of germanium

Temp., °C	σ_{exp}, dyn/cm	σ_{calc} by (1), dyn/cm	$\Delta\sigma = \sigma_{\text{exp}} - \sigma_{\text{calc}}$, dyn/cm	Temp., °C	σ_{exp}, dyn/cm	σ_{calc} by (1), dyn/cm	$\Delta\sigma = \sigma_{\text{exp}} - \sigma_{\text{calc}}$, dyn/cm
980	609.5	609.9	−0.4	1250	539.8	539.5	+0.3
1045	589.9	593.0	−3.1	1300	526.8	526.5	+0.3
1100	579.9	578.6	+1.3	1355	515.7	512.1	+3.6
1150	564.1	565.6	−1.5	1400	494.2	500.4	−6.2
1225	553.3	547.3	+6.0				

$$\Delta\sigma_{\text{av}} = \pm 2.5$$

This value agrees well with the theoretical value for germanium calculated by Zadumkin [15] on the basis of one variant of the electron-ion polar model of crystal structure and equal to 617 dyn/cm. However, the temperature coefficient of the surface tension of germanium calculated by Zadumkin,

$$\left(\frac{d\sigma}{dT} = -0.054\right),$$

differs strongly from the experimental one,

$$\left(\frac{d\sigma}{dT} = -0.21\right).$$

It is possible that this discrepancy is connected with a change in the structural state of the melt as the temperature is increased, which is not taken into account in Zadumkin' s theory.

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Note: Figure translations are in progress. See original paper for figures.