TEMPERATURE DEPENDENCE OF THE MICROHARDNESS OF BERYLLIUM SINGLE CRYSTALS AND Be—Cu ALLOYS

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The hardness of beryllium has been investigated many times [1-9], although there are no data on the temperature and concentration dependences of this characteristic.* Useful data on the anisotropy of the strength and ductility characteristics can be obtained from the variation of the microhardness with temperature and impurity concentration. Of particular interest is the microhardness of crystals along the c axis. Data on the plastic deformation of beryllium crystals with compression along the c axis are contradictory [10], and therefore the variation of the microhardness with temperature and impurity concentration in combination with data on the mechanical properties should yield significant information on the embrittlement of beryllium.

An investigation of the microhardness of pure beryllium and alloyed beryllium should also answer the question of whether the strong anisotropy of this characteristic is associated with the presence of impurities or is due to the nature of the beryllium crystal lattice.

We measured the microhardness of beryllium single crystals of high purity (99.995% Be, residual resistivity $R_{\text{room}}/R_{4.2K} \approx 1000$) and crystals of alloys (solid solutions) of beryllium with copper (0.23 and 1.34 at. % Cu).

The microhardness was measured along two perpendicular faces of the crystals — (0001) and (10\bar{1}0) — oriented with an accuracy of a few tens of minutes. The measurements were made with the PMT-3 apparatus equipped with a device for cooling and heating of the sample in the temperature range of 77-550°K, and with the PMTN apparatus [11] with a device for cooling in the temperature range of 20-300°K. The results are given in the form of temperature dependences $H_p$ vs $T$ (Fig. 1). Figure 1 also shows the temperature dependence of the anisotropy coefficient — the ratio of the hardness in plane (10\bar{1}0) to the hardness in basal plane (0001) [$H_p(10\bar{1}0)/H_p(0001)$].

With increasing temperatures the microhardness decreases on both planes, although the temperature and concentration dependences show several anomalies. First, the microhardness $H_p(0001)$ of Be + 1.34 at.% Cu in the temperature range of 77-300°K is less dependent on temperature than the microhardness of pure Be or the Be + 0.23 at.% Cu alloy. Second, the microhardness is lower on both faces of this alloy at low temperatures than for the Be single crystal or the alloy of Be + 0.23 at.% Cu. Third, at temperatures above 400° the microhardness $H_p(0001)$ does not depend on the concentration, while $H_p(10\bar{1}0)$ increases with the concentration throughout the temperature range investigated. Only at 20 and 77°K is $H_p(10\bar{1}0)$ somewhat lower for Be + 1.34 at.% Cu than for Be + 0.23 at.% Cu and pure beryllium.

As for the anisotropy, the general tendency is for it to decrease with increasing temperatures and increasing concentrations of copper. For the alloy of Be + 1.34 at.% Cu at 500°K and higher there is almost no anisotropy of the hardness. It should be noted that for pure beryllium crystals the value of $H_p(0001)$ is two and a half times higher than $H_p(10\bar{1}0)$ in this temperature range. For beryllium single

* Tsuya [2] measured the microhardness of Be—Cu alloys, but his data refer to a single facet (11\bar{2}0) of the crystals, with tests made at room temperature.

crystals the microhardness is highest along the \( c \) axis, reaching 900 kg/mm\(^2\), while for the alloy of Be + 0.23 at. \% Cu it approaches 1200 kg/mm\(^2\) at 20°K. Considering the strong temperature dependence of \( H_p(0001) \), one can assume that the microhardness of pure beryllium extrapolated to 0°K also reaches 1000 kg/mm\(^2\). Such high values of the microhardness are characteristic of crystals with homopolar bonds, but they have still not been fixed for metallic crystals.

The nature of the temperature and concentration dependences of the microhardness can be explained by combined analysis of our results and data on the plastic deformation of beryllium single crystals [10].

As is known, the hardness of materials is characterized by their ability to resist elastic and plastic deformation, and also their resistance to brittle fracture. This is a complex characteristic depending on the elasticity and strength of the material. Although the physical nature of the microhardness is complex and still not clear, in many investigations (see the bibliography in [12, 13]) the microhardness has been associated with crystallographic factors — the type of crystal structure, the lattice constant, the character and anisotropy of bonding forces, valency, etc. Despite the empirical character of these relationships, detailed studies of several crystals have shown a clear relationship between the microhardness and the characteristics of the crystal and electronic structure [12, 13].

Let us consider our data in relation to data obtained previously on the electronic structure, the character of bonding forces, and plastic properties of beryllium [10, 14].

Figure 2 shows a section of the crystal lattice of beryllium in plane (10\( \bar{1} \)0). It should show two types of atomic bonds — parallel to the \( a \) axis (1) and inclined to the plane of the diagram, connecting atoms in the neighboring basal planes (2).

From an analysis of the electronic structure and bonding forces in beryllium [14] one can conclude that the atomic bonds are directional in character in the basal plane (bonds of type 1) and metallic in the directions of atoms in neighboring basal planes (type 2). Therefore Peierls forces for basal slip are very weak in beryllium, since bonds of type 2 operate in this case, while Peierls stresses for pyramidal slip, when bonds of type 1 are broken, are very high [14].

When the indenter is pressed into face (10\( \bar{1} \)0) the prevailing types of deformation are basal and prismatic slip. In both cases the critical shear stress is small, while the activation energy of easy basal slip is 0.5 eV [15].

When the indenter is pressed into face (0001) the resistance to plastic deformation increases sharply; in this case the predominant type of deformation will be pyramidal slip, for which the critical shear stresses are so high that noticeable plastic deformation is usually preceded by fracture with compression of the crystal along the \( c \) axis. Due to the high spherical tensor of compression and the high