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ON THE CORE STRUCTURE AND MOBILITY OF DISLOCATIONS
IN SILICON UNDER HIGH STRESS

H. ALEXANDER and K. WESSEL

ABT. FUR METALLPHYSIK IM II. PHYS. INST. DER UNIV. KÖLN, R.F.A.

Résumé. — Le changement de la dissociation des dislocations vis et des dislocations à 60° par une contrainte élevée, indique que la mobilité d'une dislocation partielle est déterminée non seulement par son caractère mais aussi par sa position devant ou derrière la faute d'empilement.

Abstract. — From the change of the splitting width of pure screw and 60° dislocations under a high shear stress it is concluded that the mobility of a partial dislocation depends as well on its character as on its position before or behind the stacking fault.

The velocity of dislocations in crystals with diamond structure depends nearly linearly on stress but exponentially on temperature. So it becomes possible to freeze in dislocations in a state which is the equilibrium state at a high temperature under an external and/or internal stress. Because of the high Peierls potential the dislocations stay in this — now metastable — state when the stress is released after cooling down to room temperature. This was used in the case of germanium to investigate the distribution and curvature of dislocations in the various stages of the stress strain curve [1]. In the work to be reported here it is used to examine the influence of an external stress on the dissociation width of single dislocations. Such experiments were suggested by J. Friedel [2] in order to improve the determination of the stacking fault energy of metals from the dissociation width. In the case of metals, however, as well the application of a high stress to a thin foil in the electron microscope as the pinning of partial dislocations before thinning should be very difficult tasks.

Dislocations in crystals with diamond and sphalerite structure are split into two Shockley partials. Calculating the ratio $F_1/F_2$ of the forces working in the glide plane on the leading and on the trailing partial, respectively, one finds the standard triangle of crystal orientations to be divided into two regions (Fig. 1). For uniaxial compression $F_2 > F_1$ in the larger part; the opposite holds in the smaller region. Indexing the primary glide system $(1\overline{1}1)$ [011] and the compression axis $a = \langle hkl \rangle$ one gets

$$F_1/F_2 = \frac{h + k - 2l}{h + k + 2l}.$$ 

Our first experiments [3] were done with $a = [213]$, i.e. $F_1/F_2 = 5/7$. After a slight predeformation at 750 °C the crystal were put under shear stresses between 15 and 35.3 kp/mm² at 420 °C and then relieved of the stress. In the electron microscope those crystals exhibit only long straight dislocations parallel to $(110)$, i.e. pure screw and 60° dislocations. All dislocations are dissociated and contain intrinsic stacking fault ribbons in all cases which we analysed. As expected the width $d$ of the stacking fault ribbon is changed by the applied stress. But only one of the two classes of 60° dislocations (« PU », parallel to [101]) is narrowed corresponding to $F_1/F_2 < 1$. Screw dislocations and the second class of 60° dislocations (« PK » [110]) in contrast are widened. (The scatter of the measured values $d$ is remarkable, especially for screws.) The observation of widened dislocations leads one to assume that the lattice friction working on the two partials will not be the same. If we think in terms of mobilities $\mu$ an easy calculation [3] results in

$$d/d_0 = \left[ 1 + \frac{1}{2\gamma} \left( F_2 - F_1 - \frac{1 - \alpha}{1 + \alpha} b\tau \right) \right]^{-1}$$

($\gamma = $ stacking fault energy, $d_0 = d(\tau = 0)$, $\alpha = \mu_2/\mu_1$; $F_1 + F_2 = b\tau$).

$F_1/F_2 = \alpha_0$ is a critical value separating a widening effect of the stress for $\alpha > \alpha_0$ from a narrowing one ($\alpha < \alpha_0$). The three types of dislocations being differently influenced shows that $\alpha$ cannot be the same for all three. Furtheron it is not sufficient to accept a difference between the mobilities of a 30° partial and a 90° partial: the screw dislocation consists of two 30° partials, but is widened in by far the most cases. Taking into account all those observations we conclude that the mobility of a partial dislocation depends on its character as well on its position before

Fig. 1. — Lines of constant ratio $F_1/F_2$ in the standard triangle of orientations. The numbers give $F_1/F_2$ for compression. + [2, 1, 3] $\alpha [2, 1, 11]$.
or behind the stacking fault. So we get an order of mobilities [3]:

$$\mu_{30t} < \mu_{30l} < \mu_{90l} \leq \mu_{90t}$$

(t: trailing; l = leading).

An interesting consequence of this statement concerns the two classes of 60° dislocations: the mobility of PU with the order of partials (30°, 90°) should be larger than that of PK (90°, 30°). This in fact is a well known [4, 5] but never explained observation. Under the conditions of our standard experiment we find as representative values:

$$\alpha_{\text{screw}} = 0.4; \quad \alpha_{\text{PU}} = 3; \quad \alpha_{\text{PK}} = 0.2.$$

From these numbers and $\gamma = 51 \text{ erg/cm}^2$ [6] one expects an infinite width dissociation for applied shear stresses of 100 kp/mm² (screws) and 53 kp/mm² (PK). As these stresses are difficult to handle we changed the orientation to [2, 1, 111], where $F_z - F_3 = (1/6) b \tau$ instead of $(-1/6) b \tau$ at [2, 1, 3]. Here $\tau = 31.8 \text{ kp/mm}^2$ should be sufficient fully to separate the partials of PK. In fact we found dissociations as wide as several µm (Fig. 2). Further experiments will show if the $\alpha$ values characteristic for the three dislocation types depend on the climb forces which are different in the two orientations.

**Fig. 2.** — Dissociated dislocations in the primary glide plane of a silicon crystal compressed parallel to [2, 1, 111]. (Stacking fault contrast.) $\tau = 35 \text{ kp/mm}^2$, $T = 420^\circ \text{C}$, $t = 31.6 \text{ min}.$

**References**