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INFLUENCE OF ELECTRIC-CURRENT PULSES ON THE OPERATION OF SOURCES OF TWINNING DISLOCATIONS IN BISMUTH SINGLE CRYSTALS

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The influence of electric-current pulses on the operation of different sources of twinning dislocations is discussed. It is established that an electric current stimulates it and decreases the critical stresses needed for the onset of generation of dislocation loops.

The detection of the influence of electric-current pulses on the macroscopic plasticity of different metals [1] has suggested a significant role for conduction electrons in the motion of dislocations. The increase in the velocity of plastic flow upon passage of current pulses through a deformable metal is explained by the increased mobility of dislocations due to electron-dislocation interaction [2].

In [3, 5] a consideration was given to the influence of current pulses on crystal twinning along with slip, which is one of the main types of plastic deformation of crystals. However, despite a great amount of experimental works along this line, till now the generally adopted physical mechanism of electroplastic deformation of metals does not exist. In connection with this it is of interest to consider the mechanisms of action of a pulsed electric current on dislocation processes. In particular, the present work is aimed at investigation of operation of twinning dislocations since these sources are responsible for the process of dislocation generation and in many respects for plastic deformation of crystals.

Experimental Procedure. Single crystals of bismuth were grown from a raw material with a purity of 99.999% by the Bridgeman method. The initial density of dislocations was determined by the method of selective etching and amounted to 10^5 cm^{-2} for base dislocations and 10^3 cm^{-2} for pyramidal dislocations.

Samples with dimensions of $4 \times 5 \times 10$ mm were cut from $5 \times 10 \times 50$ mm single crystals along the cleavage plane (111).

The freshly cleaved surface (111) of bismuth single crystals was deformed by a concentrated load, namely, a Vickers diamond pyramid of the standard PMT-3 microhardness gauge. The load on the identer was varied from 0.05 to 0.3 N. Simultaneously with surface deformation a pulse of an electric current with a density of up to 600 A/mm^2, and a duration of 10^{-5} sec was passed through the crystal. As a result of the deformation, an ensemble of wedge twins appeared around the indentation, the number of which was controlled in the course of the investigation.

Results and Analysis of the Influence of Electric-Current Pulses on the Operation of Sources of Twinning Dislocations. Around an indentation of the PMT-3 device 6-8 wedge twins of the type $\{110\}\langle 001\rangle$ appear, as a rule, on the crystallographic plane (111) of a bismuth single crystal, which are developed in three crystallographic directions. As experimental results obtained in the present work showed, in the load range investigated the mean number N of twins appearing in the region deformed by the diamond pyramid practically does not depend on the indenter load and is determined by the density j of the electric current passed through the sample. It was established that an increase in the current density entails a proportional increase in the number of twins occurring at the indentation (see Fig. 1).

Measurement of the diagonal dimensions of a Vickers pyramid impression made on the surface of a deformable crystal, with and without electric-current pulses passed through it during the action of the concentrated

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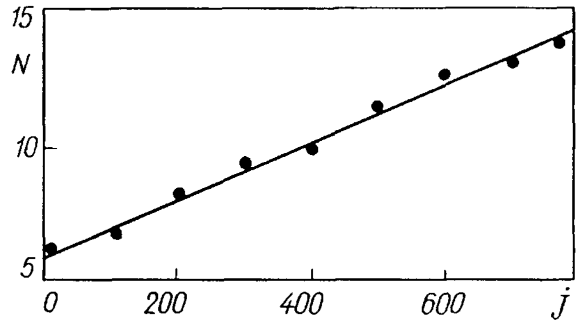

Fig. 1. Mean number N of twins appearing at an identation on a cleaved crystallographic plane (111) of a bismuth single crystal as a function of the electric current j (A/mm^2) passed through the deformable sample.

load, revealed a 1.2–1.5-fold decrease in the microhardness of the crystals under conditions of excitation of their electron subsystem by an external electric field.

The increase in the number of twins appearing at the indentation of the diamond pyramid indenter on the surface (111) of a bismuth single crystal, with electric-current pulses passed through the latter, is attributable to an increase in the number of "working" sources of twinning dislocations stimulated by the current pulses. Now we will consider the mechanism of the influence of electric-current pulses on the operation of sources of twinning dislocations.

As sources of twinning dislocations, Franck and Reed sources [6] and aggregations of perfect dislocations [7] that belong to the slip system belonging to the planes {111} in bismuth single crystals manifest themselves.

The critical stress needed for initiation of a dislocation loop by a Franck and Reed source is determined by the relation [8]

$$\tau_{cr} = \frac{\alpha b G}{l}, \tag{1}$$

where G is the shear modulus; b is the Burgers vector; l is the source size; α is a constant.

As is seen from Eq. (1), τ_{cr} depends on G, which is determined by the elasticity characteristics of the material. Electric-current pulses passed through a crystal cause, as shown in [9] and detected in the present work on the microhardness decrease of a material upon passage of a current through it, a change in the plasticity and elasticity properties of the surface layer toward a decrease in G. The change in the elasticity characteristics of the crystal will influence the value of the critical stresses required for initiation of dislocations, in particular, in our case it will decrease the critical stresses for initiation of dislocation loops. A decrease in τ_{cr} will entail, obviously, an increase in the number of "working" sources of twinning dislocations and, consequently, an increase in the number of twins appearing at an indentation.

From relation (1) it also follows that with a decrease in G, sources with a smaller l than in the case of the absence of an electric current will begin to generate dislocations. This will be manifested in the fact that the number of twins of small length at an indentation increases, which was observed experimentally in the present work.

As was noted in [7], aggregations of perfect dislocations (in bismuth single crystals they are mainly dislocations of the planes {111}) can also serve as sources of twinning dislocations. Usually they occur either at stoppers or at the intersection of the planes {111} (Lomer–Cottrell barriers). The stresses in such an aggregation are proportional to the number n of dislocations forming it:

$$\tau = n\tau^{d}, \tag{2}$$

where τ^{d} is the stresses caused by an individual dislocation.

For the onset of twinning initiated by such a source stresses must appear in the dislocation aggregation under consideration that exceed some threshold value established by the Schmidt factor. This is provided by the presence of a certain number of dislocations in the aggregation.

Electric-current pulses passed through a bismuth crystal stimulate slip, and to a greater degree than twinning does, since the Burgers vector of the perfect dislocations implementing the slip is larger than that of the partial twinning Schockly dislocations. This provides the possibility of increasing the number of dislocations in the aggregations by increasing the stresses caused by them and, consequently, the number of dislocation sources under consideration. We note that a pulsating current can favor a decrease in the number of such sources of twinning dislocations by decreasing the magnitude of the energy required for a dislocation to overcome the barriers preventing its motion. As such barriers, stoppers most often manifest themselves. But this is most pronounced at higher current densities than those under consideration. The fact that perfect dislocations easily overcome the barriers can be responsible for the threshold character of the electroplastic effect in the process of twinning observed in [10].

A twinning boundary can also serve as a source of twinning dislocations. This is manifested in so-called branching of twins [4], which consists in formation of wedge twins at twinning boundaries rather than at a concentrator of external stresses. Enhancement of the process of branching of twins upon passage of current pulses through the crystal is indicative of stimulation of this type of sources of twinning dislocations.

Thus, for the first time consideration is given to the stimulating action of a pulsating electric current on different types of sources of twinning dislocations.

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