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ELECTROMECHANICAL EFFECT IN METALS

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We have investigated the plastic deformation of metals under the influence of electric current pulses. Such investigations are of interest from the point of view of both the study of the electromechanical effect (influence of the electrons on the multiplication, motion, and interaction of dislocations) and the study of the jumplike deformation as one of the most characteristic manifestations of the inhomogeneity of plastic shear.

The experiments were made on single crystals of pure zinc (99.998% Zn) and doped zinc (2×10^{-2} % Cd), and on polycrystalline samples of zinc, cadmium tin, lead, and indium with purity not worse than 99.99%. Electric contacts connected to the discharge device were fused into the ends of the samples. Tests for tension and compression at a constant rate of 0.01 cm/min ($\sim$ 0.65%/min) were made with an Instron machine between insulated clamps. The load was determined accurate to 2 g. The samples used in the tension experiments were 15 mm long and 1 mm in diameter. The length and diameter in the compression experiments were 6 and 2.5 mm, respectively.

The employed current pulses had a duration $\sim 10^{-4}$ sec and a strength of 600 - 1800 A in the tension experiments and up to 4800 A in the compression experiments. The average current from pulse to pulse did not exceed 0.3 A. At room temperature, the heat rise of the metal did not exceed 12 - 16°. The samples were cooled with liquid nitrogen.

Figure 1 shows the characteristic tension diagrams of single-crystal zinc. Deformation jumps are seen beyond the elastic region; these increase in magnitude with increasing voltage on the terminals of the discharge source (a bank of electrolytic capacitors). The direction of the deformation jumps and their magnitude indicate an appreciable increment of the plastic deformation at the instant of passage of the current pulse. The places on the diagram at which the tension of the sample has been halted but the current pulses continues to be applied, show only small null jumps after a certain relaxation. The gradual approximately-exponential vanishing of the peaks after the cessation of the tension, and their instantaneous recovery when the tension of the samples is continued, indicate without a doubt that the observed deformation peaks are of dislocation origin.

Anomalously large peaks were observed in the region of the yield point (Fig. 1c). This fact, together with special experiments that have shown that the current pulses have no effect on the elastic part of the deformation curve, offers further evidence of the dislocation nature of the observed phenomenon.

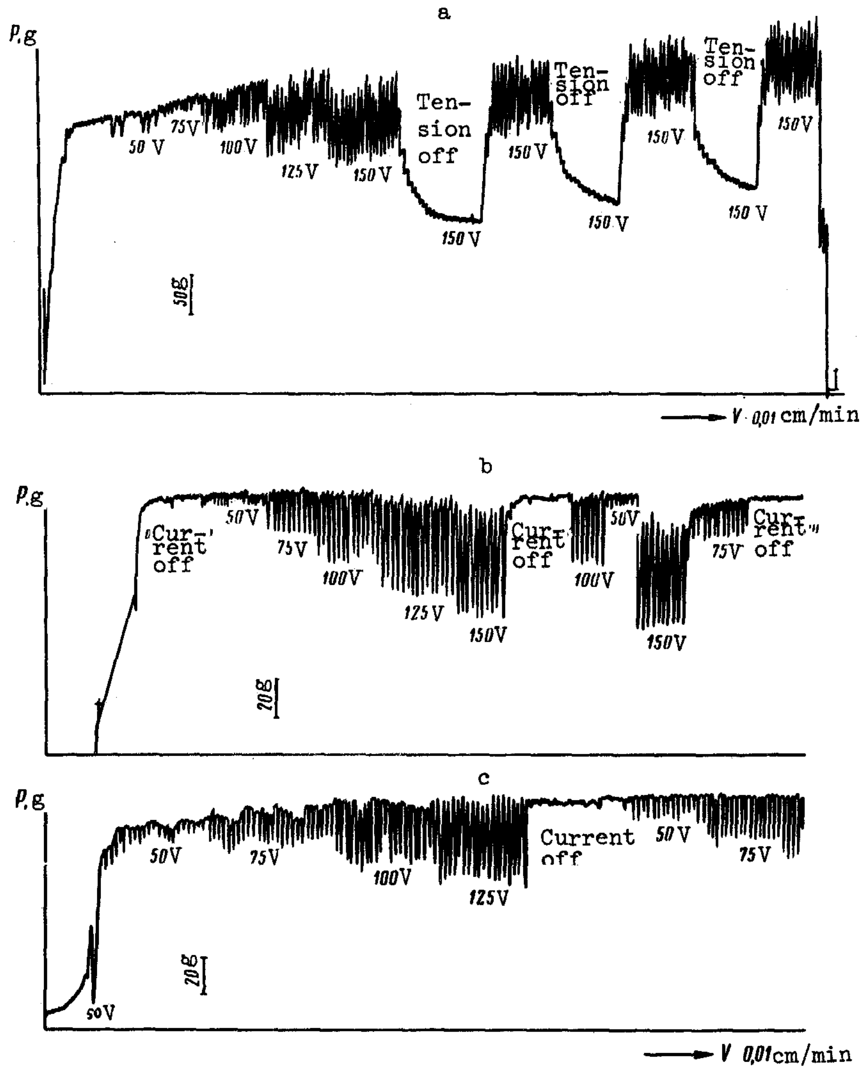

Fig. 1. Tension diagrams of zinc single crystals: a - $\chi_0 = 26°$, b - $\chi_0 = 80°$, and c - $\chi_0 = 66°$, tested by passing current pulses at 78°K (a) and 300°K (b, c).

U,	Zn		Cd		Sn		Pb		In	
V	Δp, g	Δp/p, %	Δp, g	Δp/p, %	Δp, g	Δp/p, %	Δp, g	Δp/p, %	Δp, g	Δp/p, %
50	10–15	0.6	10–12	0.6	–	–	5–7	1	5–7	1,2
75	15–20	0.7	–	–	–	–	–	–	–	–
100	45–50	1,5	15–20	1	12–15	1,8	6–8	1,4	10–15	2
125	40–50	1,8	–	–	18–22	2	–	–	15–20	4
150	55–60	2	20–22	1,2	20–25	3	26–30	5	30–35	5
200	–	–	30–35	1,5	45–50	3,2	35–40	5,7	65–70	8

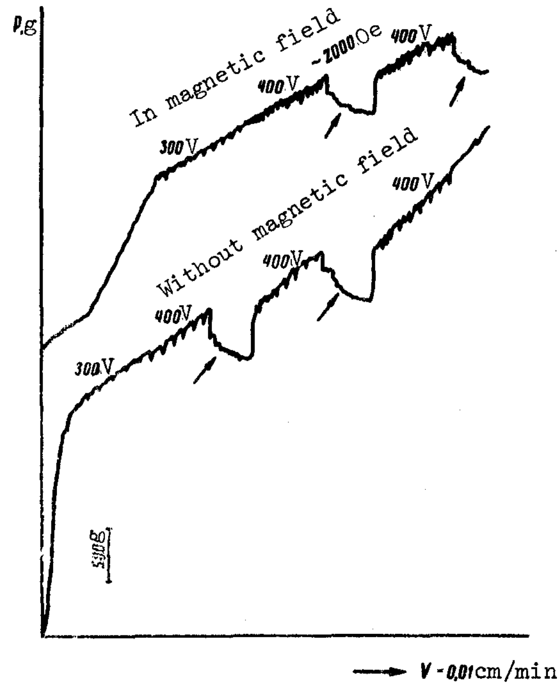

Fig. 2. Compression diagrams of zinc single crystals, $\chi_0 = 45°$, tested with pulsed current at 78°K. The arrows indicate the place where the compression halted.

A study of the influence of the rate of deformation on the magnitude of the deformation jump h as shown that the effect decreases with increasing deformation rate. Examination of the zinc-crystal surface with a microscope revealed no significant changes in the slip-band picture. The distance between the slip bands was 9 - 12μ.

The table lists the values of the deformation jumps for polycrystalline samples of zinc, cadmium lead, and indium as a result of the passage of current pulses at 78°K. The listed values are averages of 40 - 50 measurements. The most sensitive to pulsed current loading were lead and indium.

Figure 2 shows a diagram of the compression deformation, from which it is seen that in compression, just as in tension, deformation jumps appear at the instants when the current pulses flow, in a direction that indicates that the crystal is relaxed as a result of the emergence of a large number of dislocation to the surface. The magnitude of the deformation jumps did not change when the sample was deformed in a constant magnetic field (∿ 2000 Oe). It can therefore be concluded that the deformation jumps cannot be the result of magnetic pressure on the simple surface (pinch effect).

In the tension experiments on single-crystal zinc, the deformation jumps equalled 3 - 3.5μ at a current of 1800 A, and 67 - 70μ at 2400 A. When recalculated to the effective slip element <1120> (0001), this corresponds to 10^4 - 10^5 dislocations emerging to the surface of the crystal.

According to a theoretical paper [1], the condition for energy transfer from the electron system to the dislocations is that the electron drift velocity exceed the phase velocity of the elastic dislocation. When the crystals are irradiated in an electron accelerator, this condition is certainly satisfied. The enhancement of plastic shear in zinc crystals, under conditions when the dislocation-motion direction coincided with the direction of electrons injected with the aid of an accelerator, was observed directly in [2]. This condition is not always satisfied in the case of free electrons in a metal. According to estimates, the drift velocity of the electrons in our experiments, was $v = 9.7 \simeq 10$ cm/sec at 50 V on the terminals of our discharge device, and ~ 80 cm/sec at 400 V. According to [3], the velocity of the basal dislocations in zinc is $10^2 - 10^3$ cm/sec. Consequently, the drift velocity of the electron coincided at best case with that of the moving dislocations. It is possible that the interaction of the electrons with the elastic fields of the dislocations caused motion of some hindered dislocations, thus facilitating the work of the dislocation sources.

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FINE STRUCTURE OF CYCLOTRON RESONANCE LINES OF CADMIUM

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An investigation of the cyclotron resonance (CR) on the central section of the lenslike Fermi surface shows that the ordinary CR spectrum obtained at $\vec{H} \perp \vec{J}$ experiences significant changes when the magnetic field $\vec{H}$ is inclined to the surface of the sample. Even an inclination of several minutes of an angle produces on the weak-field side a broad rise that increases with further inclination of $\vec{H}$ (the amplitude of the main lines decreases), leads to a splitting of the resonance lines at $\phi \simeq 1.5 - 2°$, and to total inversion of the CR lines at $\phi \simeq 30°$. In this form, the CR is observed up to $\phi \simeq 30°$ with a strongly decreased amplitude. Another consequence of the inclination of H is the occurrence, at $\phi \gtrsim 1°$, of a series of small oscillations about each of several of the first main CR lines (see the figure). They are periodic in both H and H^{-1}. Their position relative to the magnetic field depends strongly on the angle of inclination, whereas rotation of $\vec{H}$ in the plane of the sample has practically no effect on them. These circumstances, and also the absence of oscillations in a parallel field, apparently make it impossible to attribute them to cyclotron resonance on the orbits of the "monster" with large mass [1]. At a sample thickness 2 mm and a mean free path $\ell \simeq 4.5 \times 10^{-3}$ cm, this structure can likewise not be attributed to excitation of the continuous-spectrum waves observed in [2]. The most probable explanation of the oscillations is excitation of the discrete-spectrum waves predicted in [3], which should lead to a fine structure of the CR lines just in an oblique field. Excitation of field spikes in a metal along a chain of trajectories can occur at either low frequencies ($\omega\tau << 1$) or high ones ($\omega\tau >> 1$). At low frequencies it can be revealed only by the size effect of thin plates, and