EFFECTS OF A LASER BEAM ON THE DISLOCATION STRUCTURE OF A CRYSTAL

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A laser beam produces a crater on a metal, and the crater area is often very hard (e.g., up to 1500 kg/mm^2 for low-carbon steel), this hardness substantially exceeding any that can be produced by known thermal or mechanical treatments [1].

The hardness is related to the number and distribution of the dislocations. It is considered [2] that dislocations are inherited in phase transitions; further, these can increase the dislocation density.

MATERIALS AND METHODS

We used high-purity NaCl crystals, which were etched (e.g., in alcohol containing a little cadmium) to reveal the dislocations, the etching method of [3] being used, as this enables one to distinguish the large square pits (dislocations produced during growth, which do not move on plastic deformation) from the small square pits (dislocations that move during plastic deformation).

A few tests were also done with tantalum crystals.

The laser was much as described in [4], but differed in certain details. The main parts were as follows: 1) power supply (capacitors), 2) flash tube, 3) ruby crystal. The cavity was formed by two plane mirrors set accurately parallel.

The capacitor was charged by a rectifier and was discharged through the lamp. The range 3800–6100 Å serves to excite the rod, which then emits stimulated radiation in a very short period. The two flash tubes (type IFP-2000) were fed from the power supply, each tube receiving 2000 J.

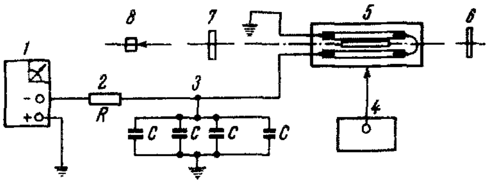

Fig. 1. The laser system.

Figure 1 shows the laser system: 1 is the rectifier, 2 the charging resistor, 3 the capacitor bank (total 2100 μF), 4 the striker, 5 the two-tube light source (IFP-2000 tubes enclosing the ruby rod), 6 a mirror of 99% reflectance, 7 the exit mirror (reflectance 30%), and 8 the specimen. The flash tube and rods are enclosed in a housing with two holes for the beam.

The stored energy is radiated at 6943 Å in a coherent and monochromatic form at very high spectral density (10^6 times solar radiation in the same range). The extremely parallel beam can be reduced by ordinary lenses to a spot of very small size, which gives a very high surface energy density. The intensity at the center of the diffraction pattern is

$$E = \frac{\Phi S}{\lambda^2 f^2},$$

in which Φ is the flux provided by the laser, S is the exit area, λ is the wavelength, and f is the focal length of the optical system. This formula implies E of 10^{12} to 10^{16} W/cm^2, which is greater than the power densities produced in other ways by several orders of magnitude.

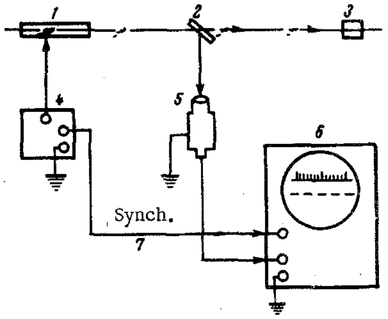

Fig. 2. Apparatus for measuring the intensity as a function of time.

The radiated energy was measured with a thermocouple calorimeter and was found to be 1.5–2 J.

The emerging ray in Fig. 1 is brought to a focus by a lens and strikes the surface at right angles.

The intensity as a function of time was measured with an oscilloscope (Fig. 2): 1 laser, 2 plane-parallel glass plate, 3 specimen, 4 striker, 5 FEU-36 photomultiplier, 6 SI-17 double-beam oscilloscope, 7 time-base synchronization.

The laser beam falls on a plane-parallel glass plate, from which a fraction is reflected to a photomultiplier coupled to the oscilloscope (upper beam), whose lower beam is coupled to a time-mark generator. A typical oscillogram has already been published [1].

This laser was used without Q-switching and showed multipeak operation, each flash lasting about 500 μsec and consisting of 60–80 peaks each lasting 2–3 μsec. There are many factors responsible for this mode of operation [4].

RESULTS

Repeated flashes produced cracks in (100) cube faces and along [100] (cube-edge) directions. Etching in the irradiated area revealed numerous fresh dislocations of deformation origin.

Figure 3 shows the initial dislocation structure at ×450 for a crystal exposed to several flashes. The large square pits correspond to dislocations produced during crystallization; there are hardly any of the small square pits associated with plastic deformation. Figure 4 surveys at ×70 the area exposed to the beam,

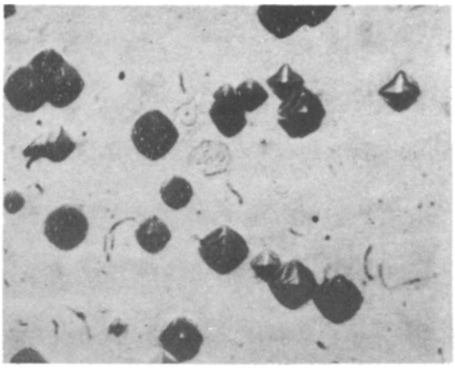

Fig. 3. Dislocation structure of initial crystal, ×450.

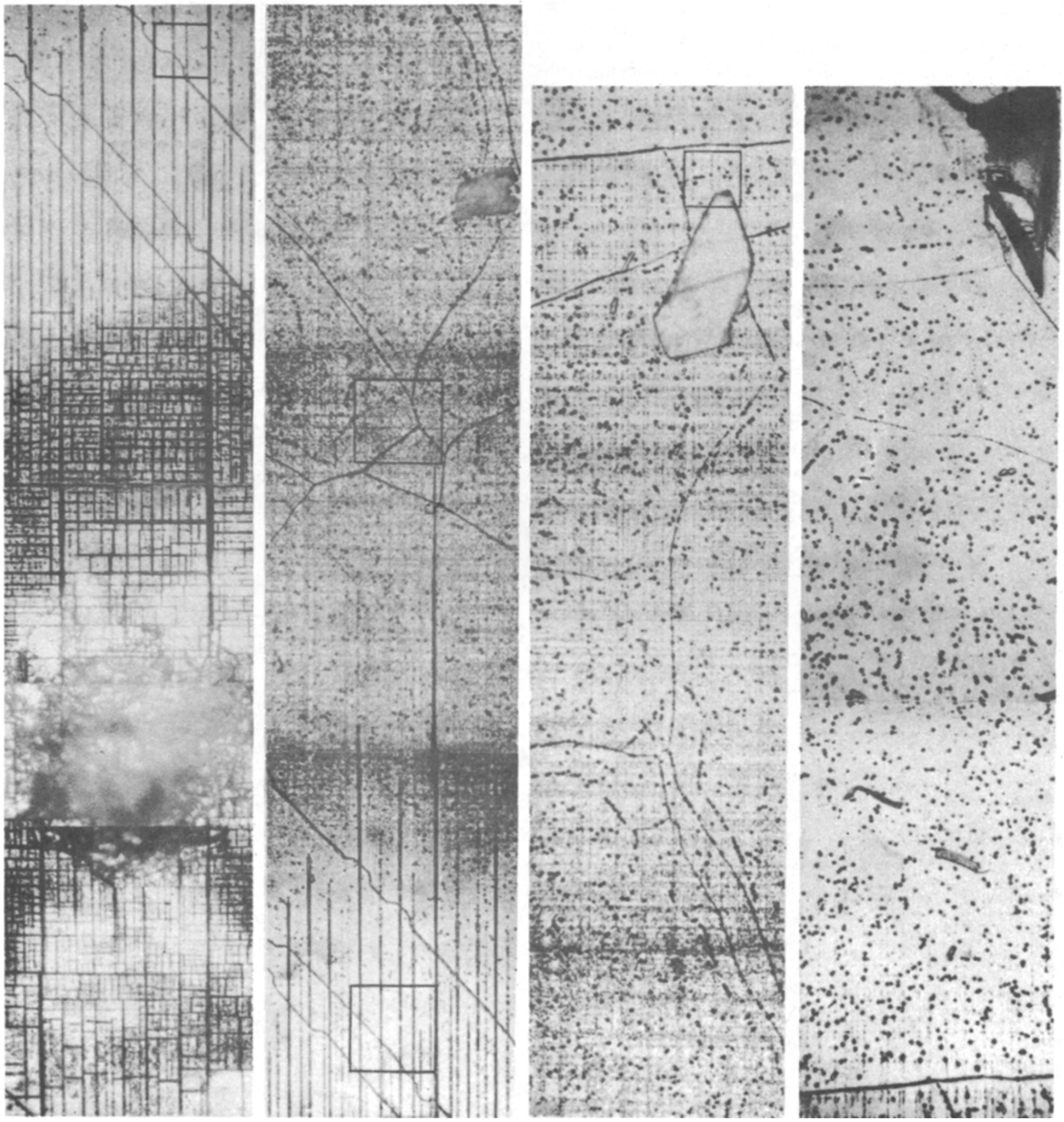

Fig. 4. Area of rocksalt crystal affected by laser beam, ×70. The areas enclosed by the rectangle are shown in other figures at higher magnification.

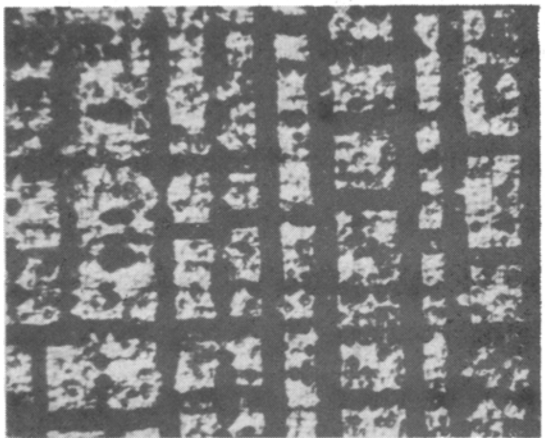

Fig. 5. Part of zone 2, with much fracturing and many dislocations, ×450.

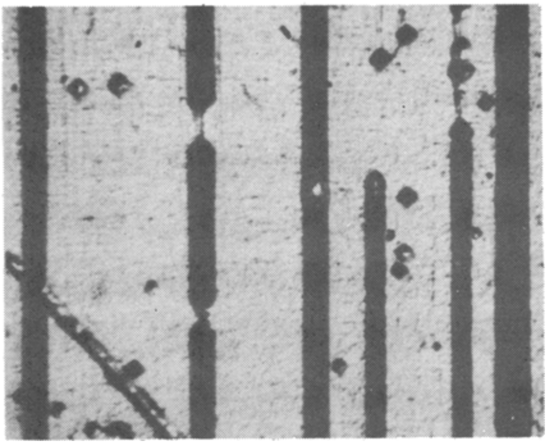

Fig. 6. Part of zone 3, ×450.

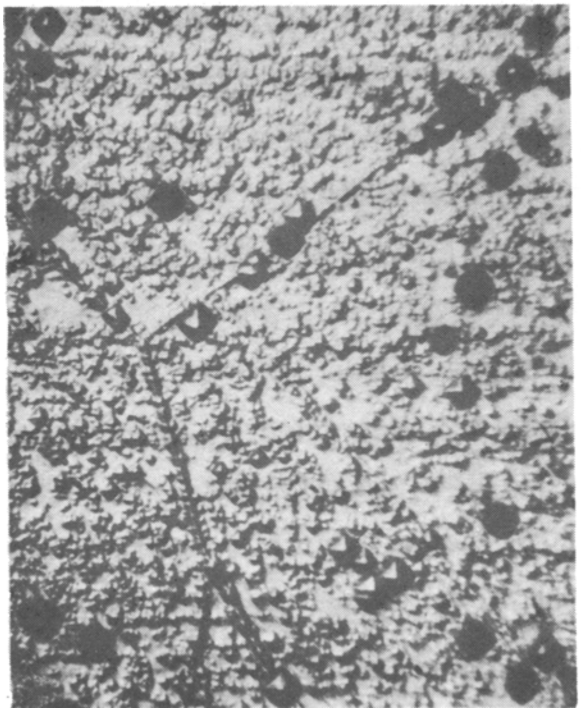

Fig. 7. Part of zone 4, ×450.

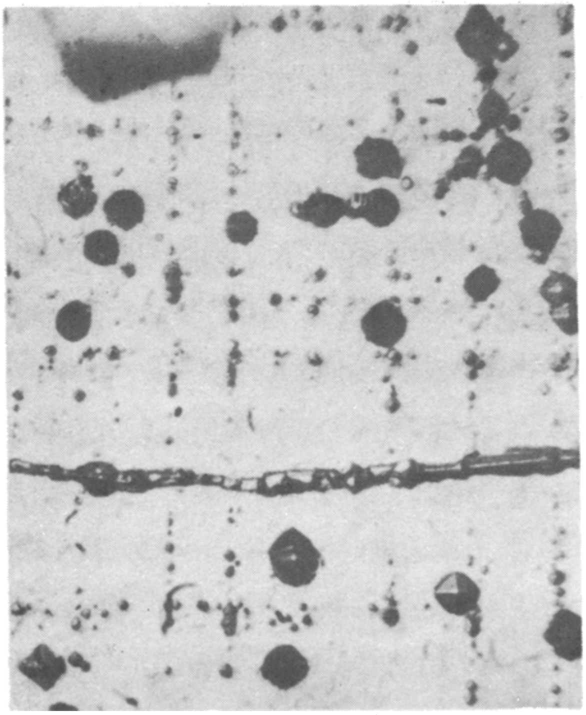

Fig. 8. Part of zone 5, ×450.

the lower edge being parallel to [100]. The beam has produced a polycrystalline area (zone 1) where the crystals are of very small size. The adjacent zone contains many cracks and dislocations irregularly distributed around the site; the distribution of the number of dislocations resembles the pattern of internal stress revealed by polarized light after localized deformation. This zone 2 is shown in more detail in Fig. 5 at ×450. The next zone (zone 3) has fewer cracks and dislocations (Fig. 6), the large cracks ending in characteristic points of angle 90°. It is difficult to judge the deformation dislocations, since these are scarcely revealed, but the rough structure between the cracks is very different from that of the smooth areas between dislocations in the initial material, and it may be that the roughness is due to a large number of unresolved dislocations.

Zone 4 has no cracks, but there are many randomly placed fresh dislocations (Fig. 7), which appear unrelated to any definite crystallographic direction.

Zone 4 passes gradually into zone 5, in which the dislocations lie along [100], i.e., along the directions in which the cracks propagate. The number of deformation dislocations decreases away from the crater, but Fig. 8 shows that the dislocation rows retain their orientation to the end. The beam produces effects over a diameter of about 7 mm, which is several times larger than the zone affected in a polycrystalline metal such as iron or steel [1].

Slow cracking of rocksalt (as by a slowly moving wedge) produces only one crack, which moves in steps and produces dislocations only where it stops. Hardly any deformation dislocations are seen on the surface perpendicular to the indentor, which produces rows of dislocations along the (110) planes, or at 45° to the direction of the dislocations produced by the laser. The dislocations in the (110) planes are edge dislocations.

Rapid cooling produces cracks resembling those produced by the laser beam. Lower cooling rates produce numerous randomly placed dislocations, i.e., as for the laser. High-temperature deformation by an indentor produces dislocations along (100) planes [5]. The effects produced by laser flashes may thus be ascribed to the thermal effect.

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