# Change of electric conductivity of semiconductor crystals by passage of a shock wave from a laser pulse

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The kinetics is investigated of the variation induced in the electric conductivity of *p*-Si and *n*- and *p*-Ge filamentary crystals by shock waves produced in the interaction of laser radiation (intensity $10^8$–$10^9$ W/cm$^2$) with absorbing materials located in a transparent condensed medium. The amplitude of the produced shock wave is calculated. A method is developed for protecting the crystals from direct laser radiation and from destruction by the rarefraction wave. It is shown that, irrespective of the type of conductivity, the resistance of the Ge and Si single crystals drops abruptly at the instant of passage of the shock wave. The relaxation time of the process ranges from a few microseconds to tens of microseconds. Residual changes in the conductivity are due to the formation of stable crystal structure defects. The causes of the effect are analyzed.

It was shown in a number of recent studies[1-3] that the passage of the shock wave produced on the surface of a solid crystalline body under the influence of laser radiation produces point defects or dislocations in the solid, depending on irradiation conditions. The temperature stability of the produced defects is determined by their crystallography, density, etc.

It was of interest to trace the kinetics of the production of these defects at the instant of passage of the shock wave. To this end we used filamentary crystals (whiskers) of p and n type germanium and silicon, since they possess the most perfect crystal structure. The resistivity of the p-Si crystals at room temperature was 0.02—0.03 Ω-cm, and that of the n-Ge and p-Ge crystals was 0.4—0.6 Ω-cm.

The shock waves were generated by ruby-laser radiation of pulse duration 50 nsec. To lower the threshold of shock-wave generation and to increase the pressure on the shock-wave front, the crystals were irradiated in optically transparent liquid media (the hydrooptical effect). These media were distilled water for the p-Ge crystals and VM-1 oil for p-Si and n-Ge.

The investigated sample, in the form of a whisker 5—6 mm long, was placed between a quartz substrate and a copper foil, the space between which was filled with epoxy resin in such a way that the distance from the crystal to the foil and to the substrate was approximately 25 μ. The copper foil prevented any undesirable photoeffect from the direct or scattered laser radiation.

When a laser pulse with power density $(2-8) \times 10^8$ W/cm$^2$ was focused on the surface of the foil, a shock wave was generated in the foil, with amplitude on the order of $10^4$ kbar. Before reaching the sample, the shock wave passed through the foil material and the layer of epoxy resin, which had effective impedances $3.2 \times 10^6$ and 3.5 g-cm$^{-2}$ sec$^{-1}$ [4].

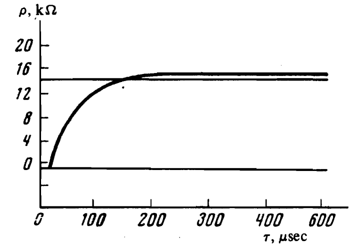
The amplitude of the shock wave produced by the laser radiation can be estimated from the formula

$$P=\left(q\frac{\gamma-1}{\gamma}\frac{\rho_1^*u_1\rho_2^*u_2}{\rho_1^*u_1+\rho_2^*u_2}\right)^{1/2}, \tag{1}$$

where q is the laser radiation power flux density, $\gamma$ is the effective adiabatic exponent of the produced plasma, $\rho_1^*u_1$ and $\rho_2^*u_2$ are the shock impedances of the transparent condensed medium and the absorbing substance, respectively ($\rho^*$ is the density of the substance and u is the velocity of the shock wave). The ratio of the amplitudes $P_2$ and $P_1$ of the transmitted and incident waves on the interface between the two media is given by[4]

$$\frac{P_2}{P_1}=\frac{2}{1+\rho_2^*u_2/\rho_1^*u_1}. \tag{2}$$

Thus, taking reflection from the foil-resin and resin-crystal interfaces into account, the shock-wave amplitude in the sample was $(1.2-4.8) \times 10^3$ atm.



Resistivity of p-Ge whisker crystal during the passage of a shock wave due to a laser radiation pulse.

It was established that at laser radiation densities $(2-8) \times 10^8$ W/cm$^2$ and an irradiation temperature of 290°K, the resistivity of p-Si, p-Ge, and n-Ge decreases at the instant of shock-wave passage. The largest decrease (by several orders of magnitude) of the resistivity was observed for p-Ge. The figure shows an oscillogram of the resistivity of a p-Ge crystal irradiated by a giant laser pulse of energy $4.8 \times 10^8$ W/cm$^2$ (temperature of the medium was 290°K). The upper line marks the initial resistance of the crystal and the lower line marks the zero level. The scanning beam moves from left to right. The change of the resistivity was investigated using a current-generator circuit, so that the voltage drop on the sample was proportional to its resistance and its scale on the oscilloscope screen was equal to 4 kΩ/div (at 10% certified linearity). The accuracy with which the decrease of the resistance was measured was determined by the width of the oscilloscope beam and amounted to ±50 Ω.

As seen from the figure, the resistivity of the p-Ge crystal decreases to zero at the instant of passage of the shock wave (within the limits of the experimental accuracy). The relaxation time of the process for p-Ge amounted to several dozen microseconds.

As shown earlier[1,2], the increase of the resistivity after the passage of a shock wave is due to the appearance of stable crystal-structure defects in the sample. In the case of p-Si and n-Ge, the resistivity decreased to approximately one-half following the passage of the shock wave. The relaxation time for these crystals was several microseconds. Just as in the case of p-Ge, there was no complete restoration of the resistivity of p-Si and n-Ge, owing to the appearance of crystal-structure defects.

Thus, our investigations have shown that the resistivity of perfect Ge and Si single crystals, regardless of the type of conductivity, decreases at the instant of passage of a shock wave generated by laser radiation. This decrease in the resistivity cannot be due to the photoeffect produced by the laser radiation, which, as described above, was excluded. The piezoeffect is eliminated because there was no signal when the supply was turned off.

Nor can the decrease of the resistivity for n-Ge be attributed to the tensoeffect (for p-Ge and p-Si, the tensoeffect leads to an increase of the resistivity), since, given the tensoeffect constant of these crystals, the observed decrease of the resistance could be produced only by an elastic stress that exceeds the strength limit by one order of magnitude. Neither can the observed decrease of the resistivity be due to the heating of the samples, since the temperature dependence of the resistivity of the investigated samples, as shown by control experiments, is of the sign opposite to that observed under exposure to lasers up to temperatures ~500°C (silicon) and ~120°C (germanium).

On the other hand, we have established that such high temperatures are not attained when a laser pulse acts on a pointlike thermocouple under conditions simulating our experiments.

One of the possible explanations of the observed effect is ionization or transformation of the semiconducting crystal to the metallic state during the instant of passage of the shock wave. It is obvious that the large difference between the resistivity decreases of p-Ge and p-Si under the influence of laser radiation can be attributed partially to the difference between the pressures on the shock-wave front, owing to the different impedances of the employed optically-transparent media.

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