# Recombination radiation on dislocations in silicon

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Recombination radiation connected with dislocations in silicon has been observed for the first time. At $T = 4.2°K$, the dislocation radiation corresponds to a series of lines with energies 0.812, 8.875, 0.934, and 1.000 eV at the maxima.

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It is known that dislocations in silicon can be electrically active and can introduce into the forbidden band local energy levels.[1,2] At the same time, there have been no reports in the literature of recombination radiation in silicon, due to dislocations, as is the case for germanium.[3]

We have performed experiments aimed at observing recombination radiation from dislocations in silicon. We investigated Si samples of $n$ type with $\rho = 7\ \Omega\,\text{cm}$ measuring $24 \times 1.5 \times 1.5$ mm, and with edge orientations $[\bar{1}\bar{2}3]$, $[\bar{5}41]$, and [111], respectively. The dislocations were introduced into the central part of the crystal by four-point flexure at $T = 850\,°C$. The dislocation density in the central part of the samples was $D \gtrsim 4 \times 10^7\ \text{cm}^{-2}$. No dislocations were introduced in the end regions, and the density there was $D \lesssim 6 \times 10^5\ \text{cm}^{-2}$, just as in the undeformed control samples.

The photoluminescence of the crystals immersed in liquid helium was excited with light from a xenon lamp with maximum optical power ~ 50 mW in a beam of 3 mm diam, modulated at a frequency 9 Hz. The radiation was registered through a grating monochromator with cooled photoreceiver of compensated germanium.

The photoluminescence (PL) spectra obtained by exciting different parts of the crystal are shown in Fig. 1. The observed spectrum can be arbitrarily

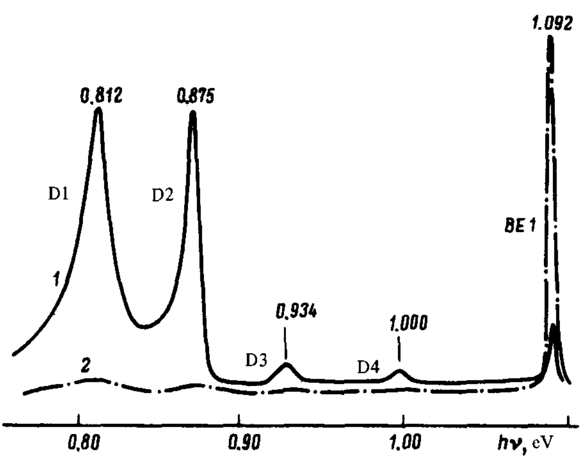


FIG. 1. Photoluminescence spectrum of silicon, $T = 4.2\,°K$: 1—central part, $D \approx 4 \times 10^7\ \text{cm}^{-2}$, 2—end part of the crystal, $D \approx 4 \times 10^5\ \text{cm}^{-2}$.

  

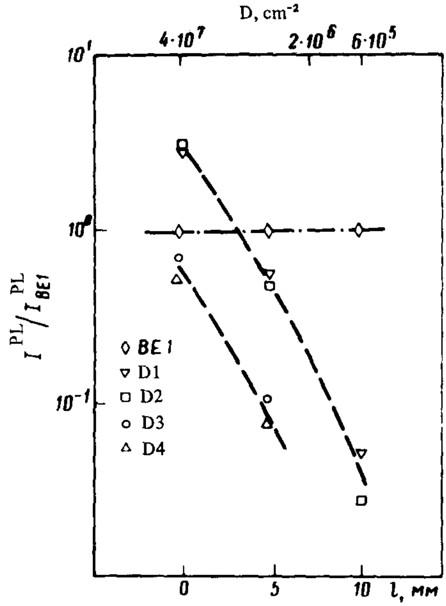


FIG. 2. Normalized intensity of the photoluminescence lines following excitation of crystal regions with different dislocation contents.

livided into two regions—"intrinsic" ($h\nu > 1.02$ eV) and "impurity" ($h\nu < 1.02$ eV). The radiation in the "intrinsic" region has been sufficiently well investigated.[4,5] In our samples it is typical of the end regions of the crystal, with low dislocation density, and is due mainly to annihilation of the excitons and of the many-exciton complexes bound on the phosphorus atoms. The dominant line BE1, with energy 1.092 eV, is determined by the bound exciton, which annihilates with emission of an LO (or TO) phonon.

The intensity of the "intrinsic" radiation decreases as the dislocation-rich central part of the crystal is approached. At the same time, the intensity of the group of lines D1, D2, D3, and D4, with energies 0.812, 8.875, 0.934, and 1.000 eV at the maxima, increases. The most intense lines D1 and D2 differ greatly in shape. The spectral width of the asymmetrical line D2 (at half-height) is $\Delta E_2 = 6.6 \pm 0.5$ meV at $T = 4.2$ °K, whereas the symmetrical D1 line has $\Delta E_1 = 17$ meV and a long-wave wing. Since the photoluminescence intensity ($I^{PL}$) is connected with the lifetime, which in turn may not be the same along the crystal (depending on the dislocation density), we have plotted $I^{PL}$ of all the lines of the spectrum against the distance from the center of the crystal, and normalized the lines to the BE1 line (Fig. 2). As seen from the figure, the entire group of lines D1—D4 drops sharply in intensity when the "dislocation-free" end is approached, and the relative change of the intensity for the entire group of lines is the same. The upper part of the figure shows the reference points at which the dislocation density in the sample was measured.

We note in addition the following singularities of the observed radiation: a) the line D3 correlates with the dislocation level $E_V + 0.27$ eV.[2] b) The lines D1, D2, D3, and D4 are approximately equidistant and the energy distance between them ($62 \pm 3$ meV), corresponds to the energy of the optical phonons in silicon. c) The intensities of the lines D1—D4 are strongly sublinear as functions of the excitation level $g$. As against the linear dependence of the radiation in the BE1 line, the radiation of the indicated lines varies like $I \sim g^{1/n}$, where $n$ ranges from 2 to 3 for the different lines.

The foregoing experimental data indicate that the observed series of photoluminescence lines D1—D4 is directly connected with the presence of dislocations in the crystal.

We note in conclusion that a characteristic dislocation radiation was observed by us also in $p$-type silicon.


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