Magnetically stimulated acceleration of the change in structure of defects in semiconductors

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A new phenomenon involving the acceleration of the kinetics of photostimulated and injection-stimulated changes in the structure of defects as a result of application of a transverse magnetic field has been observed. The magnetic field of strength $H = 6$–15 kOe was found to accelerate the decomposition of the donor–acceptor pair $(Cr_i^+ B_s^-)^0$ and to lead to the appearance of a new, deep impurity center N_s^- in the p-type Si⟨Cr⟩ and p-type Si⟨Ni⟩ crystals as a result of illumination by a superlow-energy light from the impurity absorption region, and as a result of injection of minority carriers (electrons).

The effect of a strong magnetic field on the kinetics of processes involving a quasichemical change in the structure of defects, including that of deep impurity centers in semiconductors, which occurs as a result of bombardment with different types of radiation and as a result of injection of carriers from contacts, has virtually not been studied, either theoretically or experimentally. In the present letter we present the results of an experimental study of this problem.

We used the deep-level transient-spectroscopy (DLTS) method[1] to study the Schottky barriers in p-type Si⟨Cr⟩ and p-type Si⟨Ni⟩ crystals which were obtained using the method of Refs. 2 and 3. In the p-type Si⟨Cr⟩ samples we found a deep impurity center, $E_1 = E_v + 0.28$ eV, which is due to a donor–acceptor pair

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$(Cr_i^+ B_s^-)^0$ (Refs. 2–4) with a concentration $N_{CrB} \simeq 5 \times 10^{13}$ cm^{-3}. In p-type Si⟨Ni⟩, a deep impurity center attributable to Ni atoms was not observed, as in Refs. 2 and 3. It was shown in Ref. 3 that a donor–acceptor pair $(Cr_i^+ B_s^-)^0$ is formed in the following manner. In the case of high-temperature diffusion of Cr in p-type Si the mobile interstitial Cr_i atoms are pinned by bound lattice-point B_s^- atoms, of which there is a surplus in the original p-type Si ($N_B \simeq 10^{15}$–10^{16} cm^{-3} is the concentration of shallow boron acceptors B_s^-), and form along with them a donor–acceptor pair. During a rapid post-diffusion cooling (quenching), a large fraction of these pairs, not being able to be annealed in time, is "frozen" in the $(Cr_i^+ B_s^-)^0$ state, which is attributable primarily to the Coulomb acceptor component (B_s^-). The vaporization process is described by a reversible quasichemical reaction which proceeds to the right

$$Cr_i^0 + B_s^- \rightleftharpoons (Cr_i^+ B_s^-)^0 + e^-. \qquad (1)$$

The absence of a deep impurity center in a p-type Si⟨Ni⟩ is due[2,3] to the electroneutrality of Ni atoms in p-type Si.

Illumination of the samples by a superlow-energy light from the impurity absorption region, with an energy $h\nu \leqslant 0.65$–0.85 eV, and intensity $I = 10^{15}$–10^{17} photons/cm^2·s, and a dose $D \geqslant 3 \times 10^{19}$ photons/cm^2 at 300–400 K, and subsequently cooling them to a temperature of 77 K at a rate of ~0.3–1.0 K/s, gave rise to a photostimulated change in structure similar to that described in Refs. 2 and 3. In other words, a photostimulated change of structure — the decay of a donor–acceptor pair

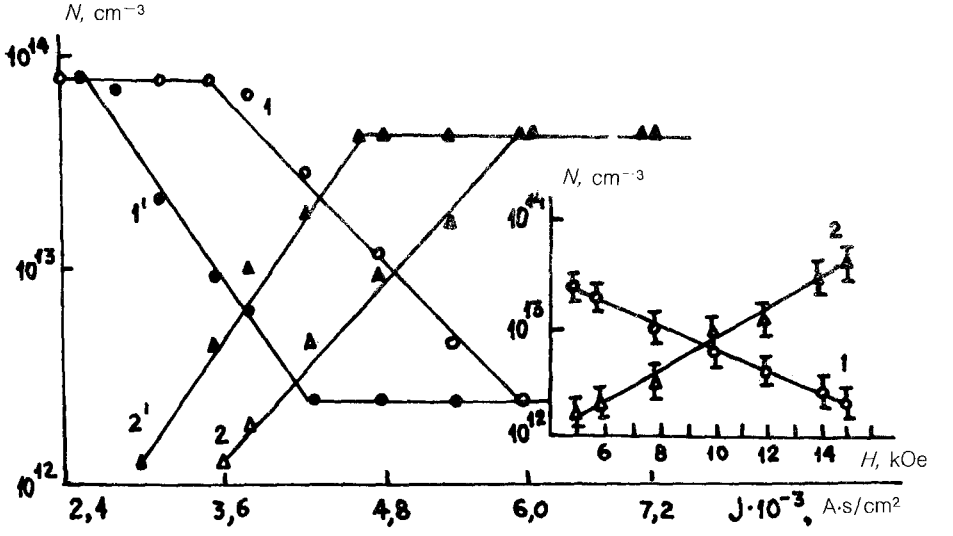

FIG. 1. Dose dependences of the photostimulated change in structure of the deep impurity center E_1 (curves 1 and 1′) and E_2 (curves 2 and 2′) for $I = 10^{16}$ photons/cm^2·s and 350 K. 1 and 2—$H = 0$; 1′ and 2′—$H = 6$ kOe. The inset shows the magneto-photostimulated change in structure versus H for (1) E_1 and (2) E_2. $h\nu = 0.75$ eV.

$(Cr_i^+ B_s^-)^0$ and the formation of a new, deep impurity center, Ni_s^- $E_2 = E_v + 0.23$ eV (curves 1 and 2, respectively, in Fig. 1)—occurred in this case.

Similar structural changes in the deep impurity centers, E_1 and E_2, occur even after the injection of electrons of density $J \geqslant 3.6 \times 10^3$ A·s/cm^2 by applying a reverse bias voltage to the samples ($\sim$5–50 V) at temperatures of 250–350 K. The functional dependences of the injection-stimulated structural change in the deep impurity centers E_1 (curve 1) and E_2 (curve 2) are shown in Fig. 2. Note that a new deep impurity center due to Cr does not appear after the photostimulated and injection-stimulated changes in the structure.

The photostimulated and injection-stimulated structural changes were found to accelerate in a transverse magnetic field: The threshold values of D and J at which the disintegration of the donor–acceptor pair $(Cr_i^+ B_s^-)^0$ began and at which the deep impurity centers E_2 appeared at $H = 0$ (curves 1 and 2 in Figs. 1 and 2), decreased appreciably at $H \geqslant 6$ kOe (curves 1′ and 2′ in Figs. 1 and 2); i.e., the photostimulated and injection-stimulated changes in structure required shorter time to complete their process. The curves of the magneto-photostimulated and magneto-injection-stimulated changes in structure (the insets in Figs. 1 and 2, respectively) show that upon application of a magnetic field the kinetics of these processes is accelerated in accordance with an exponential law with increasing value of H.

While the photostimulated and injection-stimulated changes in structure that occur in the absence of a magnetic field are attributable, as was shown in Refs. 2–4, to the decay of the donor–acceptor pair $(Cr_i^+ B_s^-)^0$, as a result of the capture of a

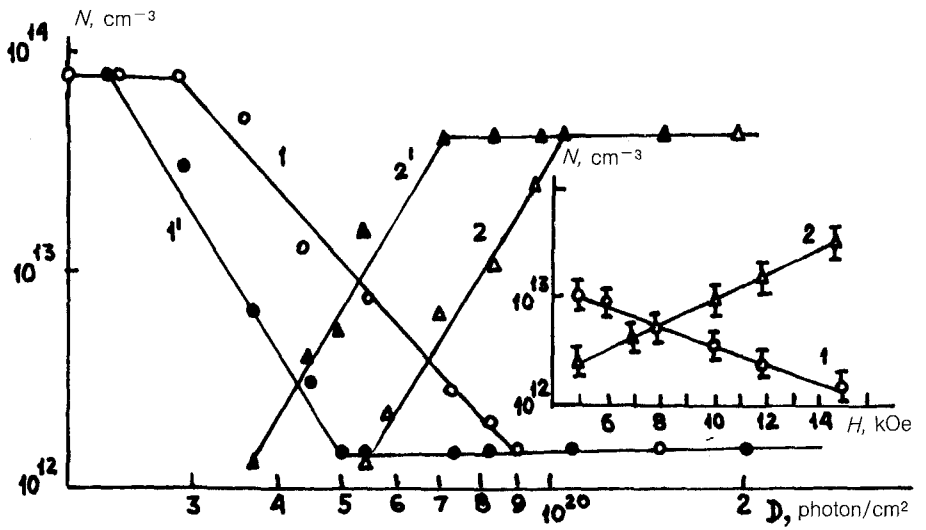

FIG. 2. Injection-stimulated change in structure of a deep impurity center E_1 (curves 1 and 1′) and E_2 (curves 2 and 2′) at 300 K. 1 and 2—$H = 0$; 1′ and 2′—$H = 6$ kOe. The inset shows the magneto-injection-stimulated change in structure versus H for (1) E_1 and (2) E_2.

nonequilibrium electron (photoexcited or injected) in accordance with a quasichemical reaction (1) (the reaction proceeds to the left), and to the charge-exchange of the natural Ni_i^0 atom in accordance with the same reaction

$$Ni_i^0 + e^- \rightarrow Ni_i^- + V \rightarrow Ni_s^- \qquad (2)$$

with the appearance of a deep impurity center E_2 due to the lattice-point Ni_s^- atom, i.e., in accordance with the mechanism for the recombination-stimulated diffusion[5] and the mechanism for the charge exchange of the centers,[6] the photostimulated and injection-stimulated changes that occur upon application of a magnetic field and the acceleration of these processes evidently cannot be trivially interpreted. Two possibilities must, however, be considered: First, the magnetic field affects the motion of the conduction electrons and, secondly, it affects the recombination (or charge exchange) either during the propagation stage of the carrier or at the time it is captured by Cr_i^+ and Ni_i^0 ions. In the first case the magnetic field changes the trajectory of the electron and the mechanisms of its scattering. In the second case a change in the wave function of the electron in the initial state of the capture introduces an H dependence into the integral for the probability of electron capture. Both these possibilities are now being studied. The results will be published in a separate paper.

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