Photomagnetic effects in semiconductors induced by local illumination

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It is shown that closed electric currents and magnetic fields can be generated in an inhomogeneous semiconductor upon local exposure to light in the region of intrinsic absorption or in a homogeneous semiconductor in the presence of an external magnetic field.

1. Let us consider a semiconductor with a subsurface inhomogeneity of the potential well (a *p-n* junction, a heterojunction, doping nonuniformity, a structural defect, etc.). Let us consider, for example, a *p-n* junction placed parallel to the surface at a depth d on the order of the diffusion length L of the carriers. The electrons and holes generated by the light beam (of radius a) diffuse over a distance $\approx L$ and, after reaching the barrier of the *p-n* junction, are split up by its field. A nonequilibrium potential difference $V(\mathbf{r})$, where $\mathbf{r}$ is a coordinate directed in the junction plane, develops across the barrier. The high conductivity of the p and n layers causes the potential difference to decrease from the center of the exciting beam much slower than the carrier concentration. As a result, a current which is produced by the light-induced bias of the *p-n* junction in the transmission direction appears in the peripheral parts of

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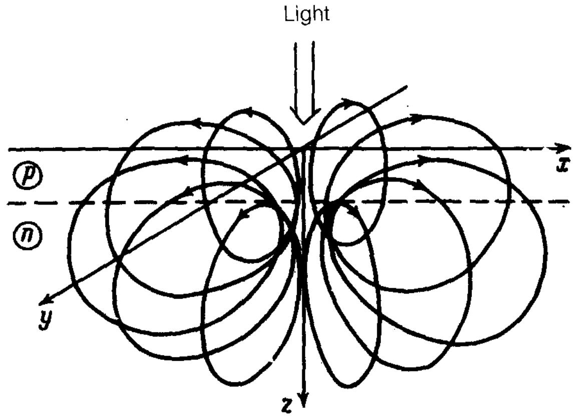

FIG. 1. The current configuration induced by light in a sample with a p-n junction.

the structure, while a nonequilibrium-carrier photocurrent which flows in the opposite direction predominates in the central part ($\approx L$). We thus have a toroidal distribution of the current (Fig. 1), which is described by the equation div $\mathbf{j} = 0$, where $\mathbf{j}$ is the current which has an electron component and a hole component.

The uniqueness of the problem is that the nonequilibrium electrons and holes are formed not only during their direct injection by the light but also as a result of the flow of current through the barrier. A solution of this problem for the surface absorption of light and for a Gaussian distribution of the light beam intensity gives a distribution of $\mathbf{j}$ such as that shown in Fig. 1. The plot of the normal component of j_z through p-n junction vs r is shown in Fig. 2: the maximum value of j_z is in the central part:

$$j_z \approx \frac{qP(1 + d/L)}{2\pi h\nu d^2(\sigma + 1)} e^{-d/L},$$

where P is the power of the light beam, $h\nu$ is the photon energy, $\sigma = SL/D_n$, S is the surface recombination rate, and D_n is the coefficient of electron diffusion. With increasing distance from the beam center j_z decreases as exp $(-r/L)$, changes sign at a distance $r_0 \gg L$, and continues to decrease as r^{-5},

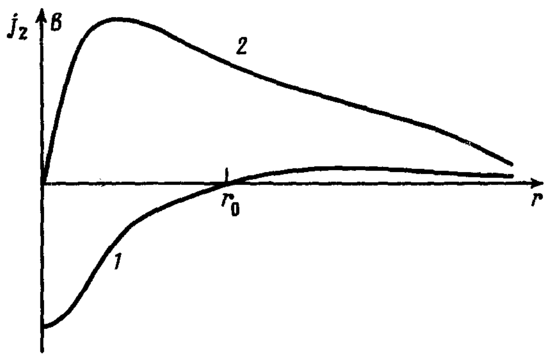

FIG. 2. The j_z profile (curve 1) and the magnetic-field profile (curve 2) in the plane of the p-n junction.

$$r_0 \approx L \ln\left[\frac{4(d/L)^2}{1+\sigma}\,\frac{q\mu_p N}{LG}\,e^{d/L}\right],$$

where μ_p is the hole mobility, N is the impurity concentration in a p-type semiconductor, and G is the conductivity of a p-n junction per unit area.

A toroidal electric current produces an azimuthal magnetic field which remains within bounds of the semiconductor. The distribution of the magnetic field in the plane of the p-n junction is shown in Fig. 2. The maximum field

$$B \approx \frac{q \cdot P}{ch\nu(\sigma+1)L}\,e^{-d/L}$$

is reached when $r \approx L$. At $P \approx 10^{-4}$ W we have $L = 10^{-3}$ cm, $\sigma \approx 1$, and $B \approx 10^{-2}$ Oe.

Generation of a magnetic field by light is essentially a photomagnetic effect which is the inverse of the Kikoin-Noskov effect. In the case we are considering, the magnetic field is concentrated in the semiconductor. This effect could lead to some interesting results if the properties of the semiconductor change in the attainable range of the magnetic fields, e.g., in a magnetic semiconductor. The current configuration considered here produces a light-controlled toroidal moment which can be determined from the electric field[1] generated in the surrounding medium by an unsteady light which excites an alternating current. If the inhomogeneity of the semiconductor is not parallel to the surface exposed to light, the current profile changes in such a way that it gives rise to a magnetic moment in addition to a toroidal moment, causing the magnetic field to spread beyond the limits of the sample.

2. Let us consider a homogeneous bipolar semiconductor in an external uniform magnetic field B_0 perpendicular to the surface of the sample $z = 0$. Let us assume that this semiconductor is illuminated by a beam of light with photon energy near the intrinsic absorption.

The local illumination produces diffusion flux of photoelectric charge carriers directed along the z axis and radially. Because of the Kikoin-Noskov effect, the radial diffusion flux of photoelectric carriers give rise to the appearance of closed nondissipative currents with a cylindrical symmetry relative to the z axis. In other words, diffusion currents give rise to a Carbino's disk geometry.

The length scale of the variation of all the generated fields is on the order of the diffusion length of the charge carriers. Calculation gives the following estimate of the magnetic field generated by the ring currents

$$B_z \approx q\,\frac{\mu_n + \mu_p}{c}\,B_0\,\frac{P/h\nu}{Lc}\;.$$

Here μ_n and μ_p are the electron and hole mobilities. If the parameters are the same as those in Sec. 1 and $\mu_{n,p}\, B_0/c \approx 1$, we find $B_z \approx 10^{-2}$ Oe. The profiles of the zth and rth components of the magnetic field in the $z = 0$ plane for $\sigma = \gamma_{n,p} = a/L = 1$ are plotted in arbitrary units in Fig. 3.

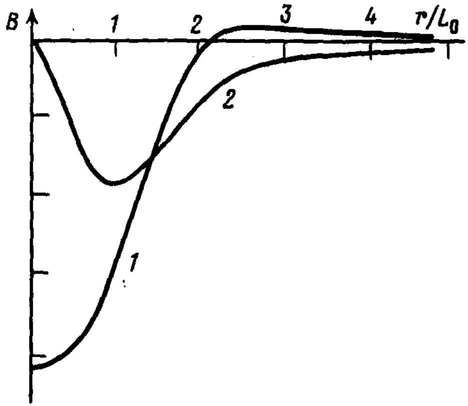

FIG. 3. Spatial distribution of the magnetic field of the ring currents in the $z = 0$ plane. 1—B_z; 2—B_r.

A local illumination of a homogeneous semiconductor in an external magnetic field perpendicular to the direction of the light beam produces an ordinary Kikoin-Noskov effect in a region of length scale $\approx L$.

The effects we have described could be used for diagnostic studies of semiconductors based on the photothermic effect or on the magnetic fields of closed currents.

[1]M. A. Miller, Usp. Fiz. Nauk **142**, 147 (1984) [Sov. Phys. Uspekhi **27**, 69 (1984)].

Translated by S. J. Amoretty