Magnetically induced polarization-dependent ballistic photo-emf in a semiconductor-metal structure

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A magnetic field directed parallel to the surface has been observed to induce a polarization dependence of the photo-emf in Al-n-GaAs structures at 1.6–4.2 K. The effect stems from an optical alignment of pulses of ballistic photoelectrons and an inelastic interaction with the semiconductor-metal interface.

Efanov and Éntin[1] have predicted the existence of a magnetically induced polarization-dependent component of the ballistic photo-emf in a semiconductor-metal structure as the result of an optical alignment of pulses of photoelectrons in the semiconductor[2,3] and the inelastic nature of the interaction at the interface with the metal.[4] The reason for the appearance of this component is that the number and direction of motion of the "aligned" ballistic photoelectrons incident on the semiconductor-metal interface depend on the relative orientation of the vector magnetic field and the vect polarization of the light, which are parallel to the surface.

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In the present letter we report an observation of the effect predicted in Ref. 1. The photo-emf and its polarization-dependent component were measured by a polarization-modulation method[5] as light was incident normally on a structure consisting of semitransparent aluminum and n-type GaAs (Ref. 4). We used epitaxial films with a (100) orientation, for which there is no polarization-dependent photo-emf associated with the corrugation of the valence band.[6] In an effort to eliminate the polarization-dependent linear photovoltaic effect which results from the circumstance that GaAs lacks a center of symmetry,[7] we switched the light polarization between the [010] and [001] directions, for each of which the photovoltaic effect vanishes. The magnetic field **B** was oriented along the [001] axis in the plane of the sample.

The spectrum of the oscillating photo-emf measured at $T = 4.2$ K, with intensity-modulated light is similar to that which we reported previously (curve 1 in Fig. 2 in Ref. 4). The shape of the spectrum is evidence that the primary mechanisms for the appearance of the oscillations in this experiment are increases in the flux of hot electrons to the surface with an increase in the initial energy of these electrons and the stepwise thermalization of the photoelectrons, accompanied by the emission of optical phonons. When the polarization of the light is modulated, the magnetic field gives rise to a photo-emf at the modulation frequency (curves 1–3 in Fig. 1). According to Ref.

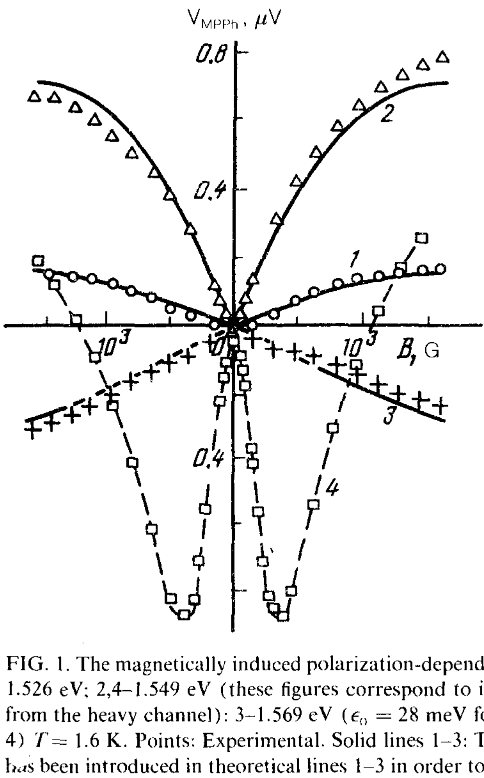

FIG. 1. The magnetically induced polarization-dependent photo-emf versus B at various photon energies: 1–1.526 eV; 2,4–1.549 eV (these figures correspond to initial energies $\epsilon_0 = 6$ and $\epsilon_0 = 27$ meV for electrons from the heavy channel): 3–1.569 eV ($\epsilon_0 = 28$ meV for electrons from the light channel). 1–3) $T = 4.2$ K; 4) $T = 1.6$ K. Points: Experimental. Solid lines 1–3: Theoretical. A semiempirical factor $[1 + (B/B_0)^2]^{-1}$ has been introduced in theoretical lines 1–3 in order to describe the deviation of the measured results from a linear behavior at $|B| \gtrsim 500$ G. Dashed line 4 is simply drawn through the experimental points.

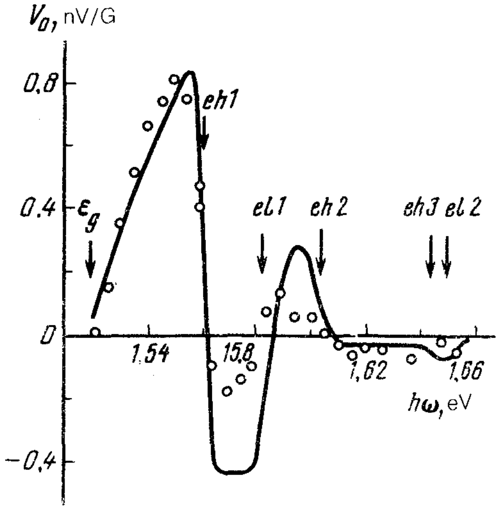

FIG. 2. Measured spectrum of the magnetically induced polarization-dependent photo-emf (points) and theoretical spectrum (solid line), which incorporates the contributions of the heavy and light channels as well as the conversion of the distribution function to a more nearly isotropic form upon the emission of LO phonons. The theoretical curve has been broadened phenomenologically with a parameter $\Gamma = 3$ meV. The arrows show the band gap $\epsilon_g = 1.519$ eV and the thresholds for the emission of LO phonons by electrons from the heavy channel (eh) and from the light channel (el).

1, the measured magnetically induced, polarization-dependent photo-emf which is measured is proportional to the magnitude of the magnetic field in weak fields[1)]: $V_{\text{MPPh}} = V_{\text{O}} |\mathbf{B}|$. The sign of this emf agrees with Ref. 1 and is evidence of an increase in the flux to the surface of ballistic photoelectrons, which are emitted primarily in the direction perpendicular to **B**. Confirmation that the observed effect is related to an optical alignment comes from the spectrum of the magnetically induced polarization-dependent photo-emf $V_O(\omega)$, which consists of damped alternating-sign oscillations[3] (Fig. 2). We see that the change in the sign of the emf occurs at the thresholds for the emission of LO phonons by electrons which are produced from bands of heavy and light holes upon a change in the photoproduction mechanism which makes the predominant contribution to this induced emf. The signs of this emf are different for transitions from the heavy- and light-hole bands because the directions of the predominant emission of photoelectrons are orthogonal for the two channels.[2] The damping of the oscillations in this emf stems from a partial conversion of the momentum distribution to a more nearly isotropic distribution upon the emission of LO phonons.[3]

At $T = 1.6$ K the photo-emf spectrum measured during modulation of the light intensity is dominated by the Dember ballistic emf, which results from a flux of photoelectrons away from the surface into the interior of the semiconductor (curve 1 in Fig. 1 in Ref. 4), by virtue of a decrease in the dark conductivity with decreasing temperature. It was established that the magnetically induced photo-emf arises in substantially weaker fields, $B \sim 100$ G, than at $T = 4.2$ K; furthermore, it has the opposite sign, as can be seen from curve 4 in Fig. 1. In this case the sign of the emf is evidence of an increase in the flux of photoelectrons into the interior of the semiconductor upon a rotation of the paths by the magnetic field; this result contradicts the theory of Ref. 1. This result shows that the interaction of electrons with the surface does not reduce to a free emission across a penetrable boundary, as was assumed in Ref. 1. Consequently, the magnitude and even the sign of the effect observed here depend on the microscopic mechanism for the inelastic interaction with the interface. In addition to the emission of photoelectrons into the metal, this mechanism might be a randomization of holes which have accumulated near the surface.[4] A final resolution of this question will require further experiments and a comparison with a quantitative theory.

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[1)]The photo-emf becomes a nonanalytic function of **B** in the theory of Ref. 1 in the approximation of surface absorption of light because of a large contribution from "grazing" paths.[1,8] When a finite absorption depth is taken into account we find $V \sim B^2$ in weak fields, but estimates show that the linear region, $V \sim |\mathbf{B}|$, may remain quite broad under our experimental conditions.

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