the particle.

The optical-gasdynamic acceleration of particles can be used to obtain artificial micrometeorites and to investigate their action on materials, to develop methods of protection against micrometeorites or man-made particles projected in space by acting on them with laser beams, and also to divert dust particles and droplets from a powerful laser beam and prevent the scattering or blocking of the beam by clouds. The accelerated particles are of particular interest in connection with the proposal [2] of obtaining a thermonuclear burst by letting fast particles strike a target.

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MAGNETIC-IMPURITY RESONANCE IN SEMICONDUCTORS

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We consider in this note semiconductors with several energy valleys in p-space. The purpose of the note is to point out a unique resonant dependence which can be exhibited in such semiconductors by the probability of electron scattering by impurities, accompanied by a transition between individual valleys, as a function of the magnetic field. The presence of such resonances can lead to oscillations of the static electric conductivity (and also of a number of other kinetic coefficients) as the magnetic field is varied.

Conduction electrons belonging to a certain valley α have in a magnetic field a spectrum consisting of a system of Landau levels, whose position is given in the simplest case (to which we confine ourselves here) by the formula

$$\epsilon_\alpha(n_\alpha,\sigma_\alpha) = \hbar\Omega_\alpha(n_\alpha + \frac{1}{2}) + \mu_\alpha H\sigma_\alpha + \Delta\epsilon_\alpha. \tag{1}$$

Here $n_\alpha = 0, 1, 2, \ldots$, $\Omega_\alpha = eH/m_{\perp\alpha}$, c is the cyclotron frequency, e the charge of the electron, $m_{\alpha\perp}$ the corresponding "transverse" effective mass, H the magnetic field, μ_α the effective magneton determining the splitting of the electron spin levels, $\sigma_\alpha = \pm 1$, and $\Delta\epsilon_\alpha$ characterizes the position of the bottom of the α-th valley relative to a certain origin which is common to all the valleys.

The density of the electron states has in a magnetic field a singularity (sharp maximum) at energy values coinciding with the positions of the corresponding Landau levels. In calculating the probability of the intervalley transition for electrons with a given energy, it is necessary to average over the initial states and sum over the final ones. As a result, the expression for the transition probability contains the product of the densities of the initial and final states. This product has a maximum when the position of two Landau levels belonging to different valleys coincides. This is the condition for the magnetic-impurity resonance, which is written, for transitions between two valleys α and β, in the form

$$\hbar\Omega_\alpha (n_\alpha + \frac{1}{2}) + \mu_\alpha H \sigma_\alpha + \Delta\epsilon_{\alpha\beta} = \hbar\Omega_\beta (n_\beta + \frac{1}{2}) + \mu_\beta H \sigma_\beta, \tag{2}$$

where $\Delta\epsilon_{\alpha\beta} = \Delta\epsilon_\alpha - \Delta\epsilon_\beta$.

If $\Delta\epsilon_{\alpha\beta} = 0$, as is the case for example for transitions between valleys with centers on the [111] axes in n-Ge, then the magnetic field drops out from condition (2), and resonance can be attained only by changing the orientation of the magnetic field relative to the crystallographic axes. A more interesting case, however, is when $\Delta\epsilon_{\alpha\beta} \neq 0$, and when the resonances can be produced by varying the magnitude of the magnetic field (at a fixed direction). This includes, for example, the case of "central" and "side" valleys in n-GaAs (where $\Delta\epsilon_{\alpha\beta} = 0.36$ eV), and in a number of other semiconductor compounds. Also included is the case of pre-deformed germanium and silicon, where the static deformation causes the bottoms of some valleys to rise and those of others to drop, as a result of which the difference $\Delta\epsilon_{\alpha\beta}$ may become appreciable.

In the general case the picture of the oscillations is complicated and has no periodicity in either H or 1/H. Exceptions are possible, however. These include, for example, the case of pre-deformed semiconductors of the n-Ge or n-Si type. If the magnetic field in them is directed in such a way that $\Omega_\alpha = \Omega_\beta$, and the transitions without spin flip are significant, then the transition probability is a periodic function of 1/H with period

$$\Delta(1/H) = e\hbar/(m_\perp c/\Delta\epsilon_{\alpha\beta}). \tag{3}$$

To observe the magnetic-impurity resonance it is necessary that Landau levels exist in the two valleys between which the transitions take place. The corresponding condition is

$$\Omega\tau \gg 1, \tag{4}$$

where τ is the conduction-electron relaxation time.

Oscillations of this type can occur for both Fermi and Boltzmann statistics. In this respect, magnetic-impurity resonance oscillations differ substantially from the Shubnikov - de Haas effect and recall the magnetophonon resonance considered earlier by Firsov and the author [1-3] and by Efros [4] (see also [5]) and the spin-magnetophonon resonance, investigated by Pavlov and Firsov [6].

In the case of Boltzmann statistics with $|\Delta\epsilon_{\alpha\beta}| \gg kT$, the probability of intervalley transitions is proportional to $\exp(-|\Delta\epsilon_{\alpha\beta}|/kT)$, i.e., it is quite small. The reason for it is that the number of electrons with corresponding energy is small. In such a case, the magnetic-impurity resonance is best observed in experiments with "hot" electrons, since the "heating" of the electrons with the aid of a constant electric field or by some other means can greatly increase the number of intervalley transitions (cf. [7]).

An oscillatory dependence of the probability of intervalley transitions should be revealed experimentally in the oscillations of the transverse magnetoresistance. The latter is proportional to the scattering probability and therefore should go through a maximum if the resonance condition is satisfied (cf. [1,5]). It must be borne in mind, however, that intervalley transitions are usually much less frequent than intravalley transitions, and therefore the oscillating contribution from them will not always be noticeable against the corresponding background.

The probability of intervalley transitions can be measured also directly by investigating different acoustic effects in semiconductors [8,9]. Gantsevich and the author [10] have already discussed the possibility of using these effects to study magnetophonon resonant oscillations of the probability of intervalley transitions. The same paper contains also an expression for the probability of intervalley impurity scattering in the case when $\Delta\epsilon_{\alpha\beta} = 0$. The quantitative analysis in [10] can be extended with almost no modification to include the case $\Delta\epsilon_{\alpha\beta} \neq 0$.

A study of the magnetic-impurity resonance can yield interesting information on the electron spectrum of semiconductors, on the value of $\Delta\epsilon_{\alpha\beta}$ for different energy minima, and on the probabilities of intervalley transitions.

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STIMULATED EMISSION OF AN ENSEMBLE OF SCATTERING PARTICLES WITH NEGATIVE ABSORPTION

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1. The presently known quantum generators constitute an optically homogeneous medium with negative absorption and a configuration of elements that return the radiation to the medium in order to effect feedback. If the radiation is returned with the aid of a system of mirrors, such as a Fabry-Perot resonator [1], then the feedback is resonant, and if backward scattering is used, then the feedback is nonresonant [2]. We considered in [3] a case