Influence of intervalley redistribution of electrons on the oscillistor frequency in silicon and germanium

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Uniaxial deformation and an electric field increased strongly the oscillistor frequency in Si and Ge. The effect was due to an intervalley redistribution of electrons in these semiconductors.

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An experimental and theoretical investigation was made of the influence of the intervalley redistribution of electrons resulting from uniaxial deformation of a crystal or the application of a heating electric field on the oscillistor (helical instability) frequency[1)] in silicon and germanium. The electron mobility anisotropy appears very clearly under intervalley redistribution conditions and this gives rise to an ambipolar drift of the helical perturbations in a longitudinal electric field even when the total electron and hole densities are exactly equal. This is why the oscillistor excitation threshold increases fairly strongly as a result of a relatively slight intervalley redistribution.[5,6] Since this ambipolar drift of quasineutral helical perturbations of the electron density in an electric field is equivalent to an azimuthal rotation of the plasma,[7] we may expect an intervalley redistribution to increase the oscillistor frequency because the correction to the frequency $f' = kb_aE/2$ (k is the wave vector and b_a is the ambipolar mobility) increases with the degree of redistribution. This will be considered below in the specific case of the oscillistor effect in Si and Ge.

We recall that, near the bottom of the conduction band, the constant-energy surfaces of silicon are described by six ellipsoids of revolution which are oriented in pairs along the ⟨100⟩ axes, whereas, in the case of germanium, these surfaces are four ellipsoids elongated along the ⟨111⟩ axes. The intervalley redistribution effect is strongest when a deformation (or a strong electric field) is directed along one of these axes. Compression of a crystal transfers electrons to valleys elongated along the deformation direction but a tensile stress removes electrons from such valleys. The field heating of electrons transfers them to the valleys elongated along the field. If the redistribution is due to a heating electric field, the dependence $f'(E)$ is nonlinear. In the case of Ge and Si, a significant electron distribution between the valleys occurs for $p > 100$ kg/cm² and $E > 100$ V/cm[8,9] if the lattice temperature is $T = 77$°K.

Figure 1 shows the experimental dependences of the oscillator frequency on the pressure (Si; H, E ∥ ⟨100⟩) and electric field (Ge; H, E ∥ ⟨111⟩). The experiments were carried out at liquid nitrogen temperature to ensure a significant intervalley redistribution of electrons. An electron-hole plasma was injected into p-type crystals; the basic arrangement was similar to that described earlier.[5] It is clear from Fig. 1 that the dependences of the oscillistor frequency on the pressure and field were in good agreement with the qualitative considerations put forward above. For H, E ∥ ⟨111⟩ (and also for fields parallel to ⟨100⟩ in the case of Ge), no intervalley redistribution took place and, therefore, the oscillistor frequency should not change, in agreement with our experimental results.

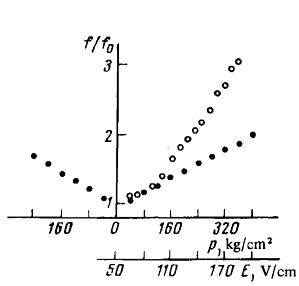

FIG. 1

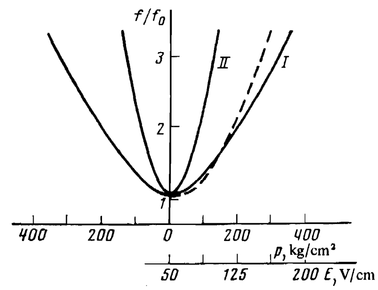

FIG. 2

FIG. 1. The black dots (●) represent the experimental pressure dependence of the oscillistor frequency in p-type Si ($E = 75$ V/cm); the right-hand side corresponds to compression and the left-hand side to tension. The open circles (○) represent the dependence of the oscillistor frequency in p-type Ge on the electric field ($H = 2$ kOe). The oscillistor frequency is $f = f' + f_0$, where $f_0 \approx 0.5$ MHz is the frequency in the absence of intervalley redistribution.

FIG. 2. Calculated dependences of the oscillistor frequency on the pressure (continuous curves) and electric field (dashed curve) applied to Si. The electric field is assumed to be $E = 10$ V/cm for curve I and 75 V/cm for curve II. The magnetic field is taken to be $H = 2$ kOe.

The corresponding calculated dependences of the oscillistor frequency on the pressure or electric field applied to Si are given in Fig. 2 (practically identical dependences are obtained for Ge). The calculations were carried out in the two-valley model[5] for the case of a surface helical wave.[10] It was assumed that the electron gas consisted of two ensembles in which the electrons had different mobilities (b) along and at right-angles to the electric field. This model described well the real situations in Si and Ge. The hole mobility was assumed to be isotropic. The correction to the oscillistor frequency, due to the ambipolar drift under intervalley redistribution conditions, was calculated in the $(bH/c)^2 \ll 1$ approximation for a quasineutral plasma ($n = p$). The calculated curves were plotted using the experimental dependences of the ratio of the electron densities in the valleys on the pressure and electric field.[8,9] It is clear from Figs. 1 and 2 that the calculations were in agreement with the experimental results. These results indicate that it should be possible to investigate the nature of the intervalley redistribution in semiconductors by determining the change in the oscillistor frequency.

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1)The phenomenon of helical instability in the electron–hole plasma of semiconductors, which appears in sufficiently strong parallel magnetic and electric fields, was discovered by Ivanov and Ryvkin [1] in Ge and was explained by Flicksman [2] on the basis of the Kadomtsev-Nedospasov helical instability theory [3] developed for a gas plasma. Subsequently, this phenomenon was called the oscillistor effect. [4]

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