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LONGITUDINAL MAGNETORESISTANCE OF P-TYPE SILICON UNDER UNIAXIAL ELASTIC DEFORMATION

Abstract. An increase in the mobility of holes and electrons at uniaxial stress (compression or tension) was found, that is important in the technology of manufacturing transistors. We present the results of the pyezo resistance phenomenon, which increases the mobility of holes and electrons when uniaxial pressure is applied to the main crystallographic axes. It means the transformation by uniaxial pressure of the isoenergetical surface.

Key words: magneto resistance, pyezo resistance, silicon, uniaxial elastic deformation.

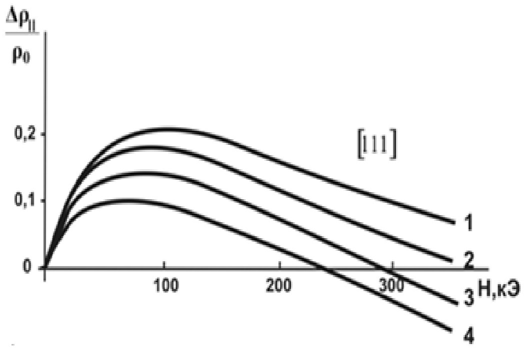
The special character of the change in the spectrum of the silicon valence band under uniaxial elastic deformation opens up new possibilities for studying the processes of current carrier scattering. In this regard, it would be interesting to study the effect of uniaxial elastic deformation on the valence band, since the latter, in addition to degeneration, changes the structure of the valence band and, with sufficient deformation, the gap between the valence subzones of heavy and light holes becomes so large that all charge carriers will be in the lower energy subzone of heavy holes. At the same time, if the measurements are carried out in weak electric fields, it is possible to study the magneto resistance only in one subzone of heavy holes (in the zone $j = \pm\frac{1}{2}$)).

The results of such experimental researches are shown in the figure.1 (at T=77.4 K) for p-type silicon crystals [1-3]. P-type silicon crystals with resistivity $\rho_{300K} = 70 Ом \cdot см$ were studied which were cut by the main crystallographic directions [111] at 77.4 K.

The transition of light holes into the subzone of heavy holes was completely excluded in our researches, because uniaxial pressure splits the subzone so that it becomes impossible to transition without external influence (for example, a strong electric field or powerful light). Since acoustic phonons are the main scattering mechanism for the samples studied by us at 77.4 K, it is natural to assume that negative magneto resistance is due to them, because uniaxial elastic deformation does not affect the scattering mechanism.

To determine the cause of negative magneto resistance, the studied samples were undergone to uniaxial elastic deformation [4]. As seen in figure 1, uniaxial elastic deformation does not remove the decline, but rather slightly increases it, and the magneto resistance gradually decreases with increasing uniaxial pressure and when the reaching the value X=6•103kg/cm2.it stops to depend on the pressure. Such action of p-type silicon magneto resistance was observed by us in our work [5].

In the saturation field of the pyezo resistance, the falling part of the magneto resistance crosses the zero line, forming a negative magneto resistance. In this regard, the saturated part of the magneto resistance in the case of $X \parallel J \parallel H \parallel [111]$ is reduced by two times in size.



$X \cdot 10^3, кГ / см^2$: 1-X=0; 2-1; 3-2; 4-3; 5-4, $\rho_{300K} = 70 Ом \cdot см, T = 77{,}4K$

Figure 1- Dependence of magneto resistance on magnetic field strength at uniaxial deformation along crystallographic axes

This is due to the fact that when a uniaxial elastic compression deformation is applied to the crystal, along with the migration of light holes into the zone of heavy holes, the zone spectrum is rearranged, leading to the fact that with increasing pressure, heavy holes become lighter, their mobility increases, therefore, the magnitude of magneto resistance decreases.

The value of uniaxial elastic deformation achieved by us was sufficient to transform the isoenergetic surfaces of the valence subzones into ellipsoids of rotation (figure 2).

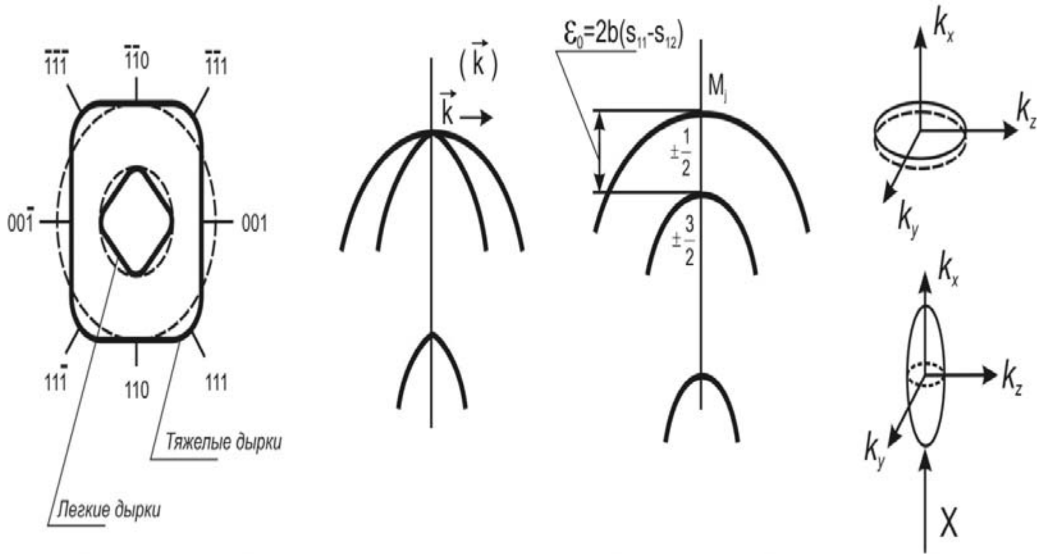


Figure 2 - Zone structure of silicon

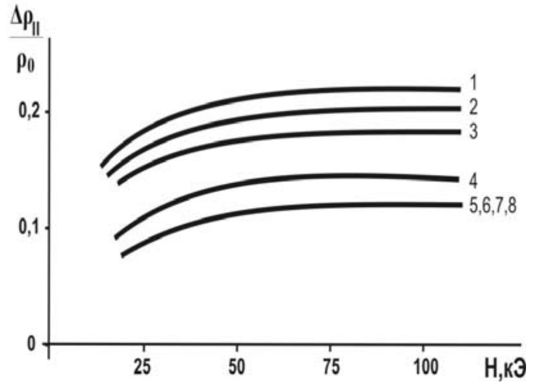
Thus, in fact, we are dealing only with a subzone of heavy holes (in the zone $j = \pm \frac{1}{2}$ is formed flattened, and in the zone $j = \pm \frac{3}{2}$ ellipsoids are formed elongated along the axis of deformation).

Therefore, it is natural to assume that the negative magneto resistance can be caused both by a change in the magnetic field of scattering on acoustic phonons, and not by the parabolicity of the zone.

Negative magneto resistance is observed in all studied silicon crystals with current carrier concentrations less than $10^{15} см^{-3}$ and $T \le$200K.

When a uniaxial elastic compression strain is applied to the crystal, along with the migration of light holes into the zone of heavy holes, the zone spectrum is rearranged, leading to the fact that with increasing pressure, heavy holes become lighter, their mobility increases, and the value of pyezo resistance decreases accordingly, therefore, the value of magneto resistance decreases.

This can be seen in figure 3, constructed by measuring the magnetoresistance of silicon p-type $\rho_{300K} = 10 Ом \cdot см$ C, T=77.4 K at different values of uniaxial pressure.



$X \cdot 10^3, кГ/см^2$: 1-0; 2-1; 3-2; 3-3; 4-3; 5-4; 6-5; 7-6,8-7. $\rho_{300K} = 10 Ом \cdot см$, $T = 77{,}4K$

Figure 3-Dependence $\Delta\rho_{II}/\rho_0 = f(H)$ at different values of pressure

In the book [5] of the famous scientist I. M. Tsidilkovsky it is said that if the effective mass of conductivity of charge carriers takes a negative value, then the resistance of the sample will be negative. By placing such a sample in the resonant circuit or cavity of the resonator, continuous stable oscillations in the circuit or resonator can be maintained. Thus, a semiconductor with a negative effective conduction mass of charge carriers can be used as a oscillator.

To do this, some conditions must be fulfilled. In order the effective mass of conductivity to be negative, representing for a complex law of dispersion some averaged value of the component of the inverse mass tensor., it is necessary to concentrate most of the charge carriers in the field of k-space where the effective mass in this direction is negative. According to what was said earlier, in germanium and silicon, for example, the wave vectors of most of the heavy holes must fall into one of the cones of negative effective masses. In this case, in the direction perpendicular of the axis of the cone, the resistance should be negative. As the wave vector and the speed of holes are related to each other, for the occurrence of a negative resistance it is necessary that the directions of the holes\ speed were to a limited extent or, in other words that a bunch of holes was created in the crystal. This is prevented by collisions of holes with irregularities of the crystal lattice. After each collision, the direction of the speed hole is changed. A very important type of interaction between charge carriers in germanium and silicon, namely scattering on acoustic phonons, which is almost elastic and isotropic, should lead to the fact that most of the charge carriers will leave a relatively narrow cone of negative effective masses, and, therefore, the generator in such conditions is impossible to realize.

As it is impossible to completely avoid collisions of charge carriers in the crystal, it is necessary to try to find out which scattering mechanism least prevents the formation of a beam of charge carriers. Two types of collisions could provide this:

1. Collisions, in which the direction of speed is generally changed very little. Such scattering mechanisms in crystals practically do not exist.
2. Collisions, in which the charge carrier almost completely loses energy and impulse, the electric field speeds up it after the collision in the right direction.

Inelastic scattering on optical phonons is just the kind of interaction of charge carriers with the crystal lattice, which is less than others prevents the formation of a carrier beam with negative effective masses. Indeed, after each act of inelastic scattering on optical phonons, the charge carrier loses almost all energy and impulse and then can be speeded up by the electric field in the desired direction (in the field of negative effective masses) until the next collision. Therefore, the predominant scattering on optical phonons should not prevent the creation of an amplifier (generator).

Semiconductors having charge carriers with negative effective masses and which have a high probability of scattering of these carriers on optical phonons are able to serve to amplify or generate (microwave-ultrahigh frequency) oscillations

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БІР ОСЬТІ СЕРПІМДІ ДЕФОРМАЦИЯ КЕЗІНДЕГІ Р-ТИПТІ КРЕМНИЙДІҢ БОЙЛЫҚ МАГНЕТТІК КЕДЕРГІСІ

Аннотация. Бір осьтік кернеу (сығылу немесе созылу) кезінде кемтіктер мен электрондардың қозғалғыштығының артуы анықталды, бұл транзисторларды дайындау технологиясында маңызды болып саналады. Бас кристаллографиялық осьтерге біросьті қысымды түсіргенде, кемтіктер мен электрондардың қозғалысы артатынын, пъезокедергі құбылыстарының нәтижелесінде болатынын ұсынамыз. Бұл изоэнергетикалық беттің бір осьтік қысымының өзгеруімен түсіндіріледі.

Түйін сөздер: магниттік кедергі, пъезокедергі, кремний, бір осьті серпімді деформация.

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ПРОДОЛЬНОЕ МАГНЕТОСОПРОТИВЛЕНИЕ КРЕМНИЯ Р-ТИПА ПРИ ОДНООСНОЙ УПРУГОЙ ДЕФОРМАЦИИ

Аннотация. Установлено увеличение подвижности дырок и электронов при одноосном напряжении (сжатии или растяжении), что немаловажно в технологии изготовления транзисторов. Представляем результаты явления пъезосопротивления, которое увеличивает подвижности дырок и электронов при приложении одноосного давления X к главным кристаллографическим осям. Этим объясняется преобразование одноосным давлением изоэнергетической поверхности.

Ключевые слова: магнетосопротивление, пъезосопротивление, кремний, одноосная упругая деформация.

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