Cyclotron absorption in GaSb–InAs–GaSb quantum wells

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A splitting of the cyclotron-absorption line has been observed in a GaSb–InAs–GaSb quantum-well system. The behavior of the splitting was studied as the laser photon energy and the strength and direction of the applied magnetic field were varied. The results are explained on the basis of a model involving a lifting of spin degeneracy.

The GaSb–InAs–GaSb system has attracted interest for a long time because of several interesting properties, e.g., the transition[1,2] from a semiconducting state to a semimetallic state when the thickness of the InAs layer becomes greater than 100 Å. Research on the cyclotron absorption of an InAs layer 200 Å thick in GaAs has revealed[2] electrons and holes with effective masses $m = 0.037m_0$ and $m = 0.35m_0$. The hole density depends very strongly on the strength of the applied magnetic field, vanishing when this field reaches a value of about 7.6 T.

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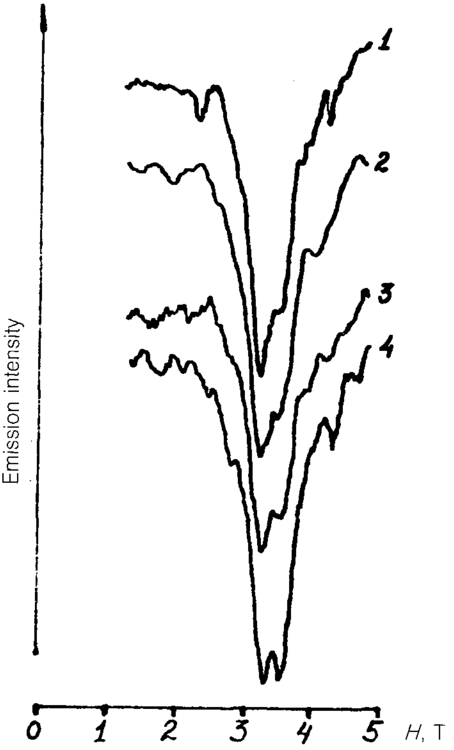

FIG. 1. Cyclotron absorption in 2D GaSb–InAs–GaSb systems [for a sample with a mobility $\mu = 110\,000$ cm/(V·s)]. Photon energy of the probing light, meV: *1*—8.76; *2*—8.84; *3*—8.91; *4*—9.0.

In this letter we are reporting an observation of a splitting of the cyclotron-absorption line in the GaSb–InAs–GaSb system. The light source was a germanium cyclotron laser with a continuously tunable frequency, so the absorption could be detected at arbitrary photon energies over the laser tuning interval. The light was detected by a gallium-doped germanium photodetector. Since the sensitivity of the photodetector depends very strongly on the frequency in the frequency interval studied, the energy of the laser photon was held constant in the experiments, and the magnetic field at the sample was varied.

The structures were grown by molecular beam epitaxy on semi-insulating GaAs substrates. The thickness of the GaSb buffer layer, of the InAs quantum well, and of the GaSb upper layer were 1 μm, 200 Å, and 200 Å, respectively. The electron mobility in the two samples studied, with densities $\sim 9 \times 10^{11}$ cm^{-2}, were 5×10^4 cm^2/(V·s) and 1.1×10^5 cm^2/(V·s) at 4.2 K. The mobility was increased by introducing a narrow (20-Å) InAs quantum well in front of the 200-Å quantum well with 2D carriers.[3]

Figure 1 shows the absorption as a function of the magnetic field according to measurements in the Faraday geometry, for various energies of the laser photon. We see that the cyclotron-absorption line splits in two; the two components are separated by a distance of 2–2.8 kG. The intensity ratio of these lines is very sensitive to the energy of the laser photon, which was varied from 8 to 9.5 meV.

Experiments carried out on different samples revealed a similar behavior of the lines. To determine the nature of the absorption, we rotated the sample in a magnetic field (the normal to the surface of the sample made an angle of 45° with the field direction). Observations in this geometry showed that the positions of both peaks are determined by the magnetic field component perpendicular to the plane of the InAs layer. This fact is evidence that the absorption is indeed associated with the 2D system of charge carriers.

To explain the splitting of the cyclotron-absorption line, we invoke the Rashba model.[4] According to that model, the spin degeneracy is lifted in the symmetric well in the GaSb–InAs–GaSb system because of the internal electric field, which is directed perpendicular to the plane of the well. The electron spectrum thus has two branches, which correspond to different spin directions. The energy gap between these branches increases with increasing magnitude of the wave vector directed along the layer. The dispersion relation in this case is

$$E^{\pm}(k) = \frac{\hbar^2 k^2}{2m^*} \pm \alpha k,$$

where k is the magnitude of the wave vector component parallel to the plane of the layer, and the coefficient α is determined by the properties of the particular system.[5] This fact leads in turn to the existence of two series of Landau levels:

$$\epsilon_n^{\pm} = \hbar\omega^*(n \pm \sqrt{\delta^2 + \gamma^2 n}; \qquad n \geq 0$$

with different cyclotron-transition energies. Here $\epsilon_n^{\pm}$ is the energy of Landau level n (the $\pm$ correspond to the different spin directions); $\omega^* = eH/m^*c$; $\delta = \frac{1}{2}(1 - gm^*/2m_0)$; $\gamma = 2/\hbar\ (m^*\alpha^2/2\hbar\omega^*)^{1/2}$; m_0 is the mass of the free electron; and g is the g-factor. As a result, two lines, associated with transitions in these two series, are seen in the cyclotron absorption.

Knowing the difference between the energies of the two cyclotron-absorption lines, we can determine the spin-splitting parameter: $\alpha \approx 3 \times 10^{-9}$ eV·cm. This value is in reasonable agreement with the data of Ref. 6.

The dependence of the line intensities on the photon energy of the probing light can be explained in terms of a change in the position of the corresponding Landau levels with respect to the Fermi level, accompanied by a change in the ratio of level populations. Here one should take into account the circumstance that the spacing of the Landau levels in the GaSb–InAs–GaSb system is extremely nonuniform.

A splitting of the cyclotron-absorption line in GaSb–InAs–GaSb heterostructures was first observed by Guidner *et al.*[7] However, those investigators invoked a totally different mechanism to explain this splitting. Their mechanism involved a filling of two quantum-size subbands. Calculations show, on the other hand, that only one subband is filled in a quantum well 200 Å wide (in agreement with, for example, Ref. 8). The mechanism proposed in Ref. 7 thus cannot be used to explain the results presented here.

That there are two series of Landau levels is supported by the characteristic beats in the Shubnikov–de Haas oscillations in relatively weak magnetic fields (Fig. 2).

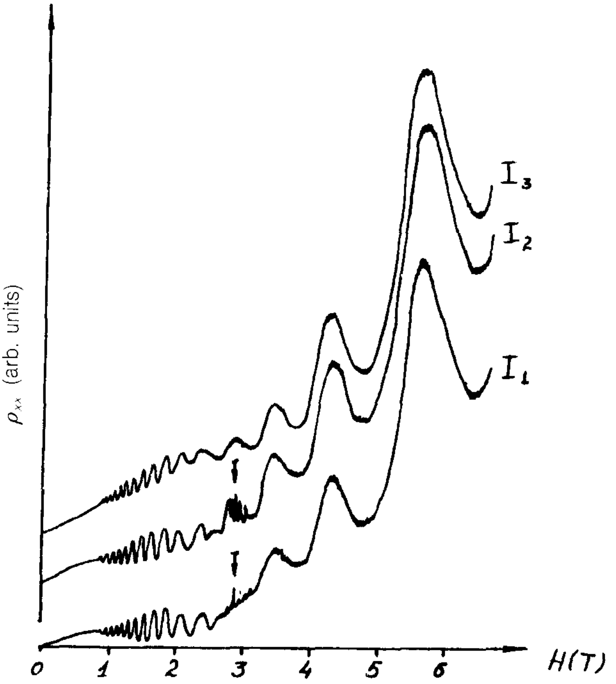

FIG. 2. Shubnikov–de Haas oscillations. Current through the sample (μA): I_1—0.1; I_2—0.15; I_3—0.25. The arrows show the point of an instability.

These oscillations are seen as oscillations of the voltage across the contacts on the sample, which was in the form of a Corbino disk, during the flow of a direct current through the sample. Unfortunately, it is not possible to find the difference between the electron densities in the subbands with the different spin orientations or thus the value of α, since there is only one node in the observed beats.

During observations of the Shubnikov–de Haas oscillations we observed an instability, which was seen as jumps in the voltage near the oscillation node. A characteristic feature of this instability is the existence of an optimum value of the current, at which the instability is most apparent. As the current is raised from 0.1 to 0.25 μA, the voltage across the sample increases sharply during the first period of the beats, and the relative amplitude of the beats decreases. The beats eventually disappear at currents above 1 μA. This result is evidence of a heating of the electrons, which may be accompanied by a change in the ratio of the corresponding relaxation times in the spin-split subbands. The instability may be linked with this heating and may occur because the voltage jumps between two stable states at the beat node. A more detailed analysis of this instability will require some further experiments.

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