Far-infrared transient- resonant Faraday rotation induced by non-equilibrium electrons in compensated p-InSb under pulsed photo-excitation

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Abstract

We have made our first attempt to investigate the resonant-transient Faraday effect induced by conduction and bound electrons in compensated p-InSb under pulsed-photoexcitation at 4.2 K with use of the far-infrared laser. The Faraday rotation angle is extremely sensitive to the refractive index for the left-hand and the right-hand circularly polarized wave. Meanwhile ionized donors in compensated semiconductors are neutralized by photoexcitation and the resonant phenomena by these neutralized impurities bring a big change of refractive index in semiconductors. As donor electrons excited by the photo-pulse relax with a finite lifetime, the refractive index dominated by these donor electrons has time-dependent nature, and thus we are able to observe the transient-Faraday effect through the time-resolved experiments.

Key words: Faraday effect; far-infrared; p-InSb; cyclotron resonance

In semiconductors, magneto-optical absorption measurement is one of basic method to investigate various resonant transitions of charged carriers as cyclotron resonance (CR) and Zeeman impurity absorption, so-called impurity cyclotron resonance (ICR). But these transitions can be also investigated through the change of refraction index resulting from the induced-dipole moment by these resonant absorptions. Faraday rotation is a well-known magneto-optical effect related with birefringence effect caused by left-hand and right-hand circularly polarized lights. This effect is that the rotation of polarization direction of linearly polarized light is induced, because of difference in the phase velocity between left-hand and right-hand circularly polarized lights in the magnetic field. In the case of resonant Faraday effect, resonant absorption makes the polarization state of the incident light change from linearly polarized to elliptically polarized one.

So far studies of Faraday effect in semiconductors focus on infrared free carriers Faraday effect and interband Faraday effect. The spectra shown in these reports are mainly located between infrared and visible region. In this study we report on the far-infrared (FIR) transient-Faraday effect associated with intraband transition as CR and ICR for non-equilibrium carriers with finite lifetimes in compensated p-InSb. Faraday effect due to these carriers has time dependent nature and we obtain the time-dependent dielectric function caused by non-equilibrium carriers through the time-resolved measurements. Fujii et al. have carried out the time-resolved magneto-optical absorption measurements for photoexcited electrons in p-InSb.[1,2] The relaxation process of photoexcited electrons in p-InSb is divided into two parts, i.e., the fast process is related to the spin relaxation of conduction electrons and the second slow decay process

has relations with conduction and donor electrons, of which density are dominated by the donor-acceptor recombination. Our experimental results are connected with the second process of ICR and CR.

We have carried out the experiment at 4.2 K for a p-type InSb, of which donor and accepter concentrations are $1.0 \times 10^{14} cm^{-3}$ and $1.1 \times 10^{14} cm^{-3}$, respectively.

We have employed a pulsed-discharge type H_2O FIR laser as a probe light and the wavelengths are 119μm and 220μm. The FIR light incident on a sample was shaped by a linear polarizer inserted just before the sample in complete linearly-polarized light. The FIR light through both the sample and an analyzer is detected by a photoconductive-type Ge/Sb or InP detector. We have measured three spectra for different angle θ between the axes of the polarizer and the analyzer and estimated elliptic polarization state of the transmitted light emerging as an elliptic light under resonance in the material. Electric field amplitude $\mathbf{E}$ of the ellipticity polarized light is written as $\mathbf{E} = E_x \mathbf{e}_x + E_y e^{i\gamma} \mathbf{e}_y$, where E_x and E_y is x and y components of $\mathbf{E}$, and γ show phase difference between E_x and E_y. So three independent variables, E_x, E_y and γ, can be determined from the three spectra including different information for elliptic polarization state. Needless to add, Faraday rotation angle is calculated from these spectra. Three spectra for $\theta = -\frac{\pi}{4}$, 0 and $\frac{\pi}{4}$ were obtained, and the situation for $\theta = 0$ corresponds to the case of the analyzer parallel to the polarizer.

Non-equilibrium carriers are created by photo-pulse excitation with a xenon flash lamp. The lamp with the pulse width of $\sim 1\mu$m is operated at repetition rate of 15Hz. Let us denote the intensity of transmitted FIR beam without photoexcitation by I_0 and that with photoexcitation by I. The increment in transmitted FIR beam by Faraday effect upon photoexcitation can be obtained as I/I_0 by mean of two-channel boxcar. Thus one can obtain the genuine contribution of photoexcited non-equilibrium carriers to Faraday effect.

One notices that the decay profile of spectra under the parallel polarizer configuration ($\theta = 0$) as shown in Fig.1(b) is similar to the absorption spectra. In the case of the parallel polarizer configuration, however, absorption signals are much larger than Faraday rotation signals. Strong broad peak at lower field and weak sharp peak at higher field correspond to ICR and CR, respectively. On the other hand, Faraday rotation signal for $\theta = -\frac{\pi}{4}$ is stronger than that for $\theta = 0$ as shown in Fig.1(a). The peak shift of ICR signal to lower field at 40μs is of course due to resonant-Faraday effect and this spectrum is considerably different from other ones.

In Fig.1(c) we show Faraday rotation angle calculated from spectra obtained under three different configurations. It is found that the rotation angle for ICR is anti-symmetrical. The maximum rotation angle for ICR is shown in Fig.1(c) as a function of delay-time

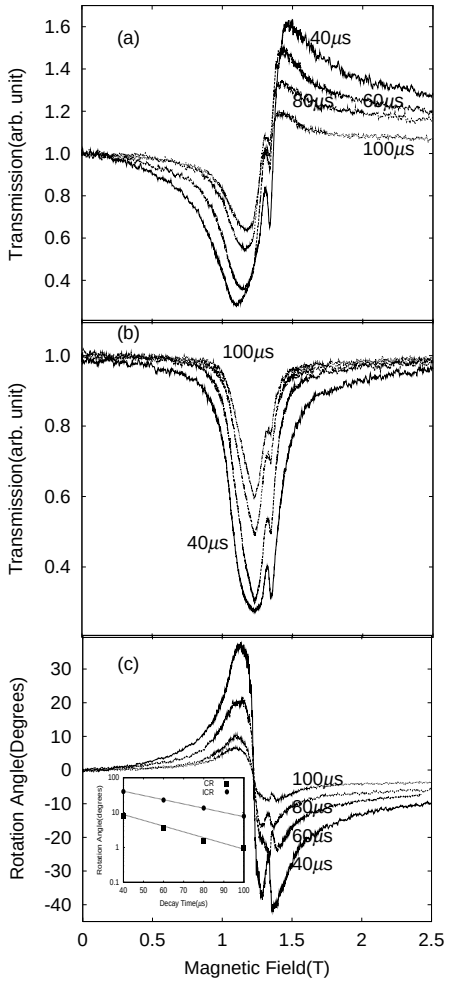

Fig. 1. Transmitted FIR spectra of 119μm at 4.2K for various delay-time after photoexcitation pulse. Signals are obtained for (a)$\theta = -\frac{\pi}{4}$ and (b) $\theta = 0$. Fig. 1(c) shows the time-dependent Faraday rotation angle estimated from Figs. 1(a), 1(b) and the data for $\theta = \frac{\pi}{4}$.

after photoexcitation. It reaches to 30 degrees at 40μs. At 1.35T, a few sharp structures caused by CR are recognized. Time variation of the rotation angle shown in the inset of Fig.1(c) should be connected with both CR and ICR for non-equilibrium carriers, and the decay constant for rotation angle is obtained as 35μs.

We have for the first time observed FIR resonant-transient Faraday effect caused by electrons in conduction band and bound states in compensated p-InSb under pulsed-photoexcitation at 4.2 K.

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References

[1] T.Ohyama, K.Fujii, E.Otsuka, Jpn. J. Appl. Phys. **21** (1982) 865.

[2] K.Fujii, T.Ohyama, E.Otsuka, Jpn. J. Appl. Phys. **26** (1987) 868.