

Measurement of Charge Density and Mobility in Semiconductors in the Strong Magnetic Field

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Abstract. *In the semiconductors when the strong constant magnetic field H is applied the non-dissipative Hall currents appear and helicon magnetoplasma waves may be excited. The semiconductor sample becomes partially transparent under these conditions. In the case of resonance the transparency coefficient has maximum or minimum depending of resonance number. For fixed values of H and excitation frequency ω the charge density and mobility may be found. Measurements were conducted in the range of radio frequencies 10-2000 MHz, and magnetic fields 0-32 Tesla for n -InSb and n -Ge.*

Keywords: n -InSb, n -Ge, magnetic fields.

1. Introduction

Propagation of electromagnetic waves through solid state plasmas in a magnetic field is the subject of intense experimental and theoretical investigations. Under the condition $\omega_H \gg \omega \gg \tau^{-1}$, here ω_H is the cyclotron frequency of the charge carriers, ω the wave frequency and τ is the electron relaxation time, Alfvén waves can be excited in compensated semiconductors. When the solid state plasma is not compensated, i.e. when the number of electrons and holes are unequal, there may exist a large Hall current in high magnetic fields and the nature of the wave is dominated by the non-dissipative Hall conductivity. This is known as the helicon waves [1]. Helicons have an exact analogy with the whistlers which are frequently propagated in the rarefied plasma of the Earth's atmosphere. The helicon beams are being used for RF antenna modeling, investigation of self-focusing and diffraction of electromagnetic radiation, etc. [2]. The purpose of the present communication is to deliver the experimental and theoretical results concerning the excitation of helicons in the solid state plasma of semiconductors and their application for contact less measurement of charge carrier's density and mobility.

2. Subject and methods.

The block diagram of the experimental device is shown in Fig.1.

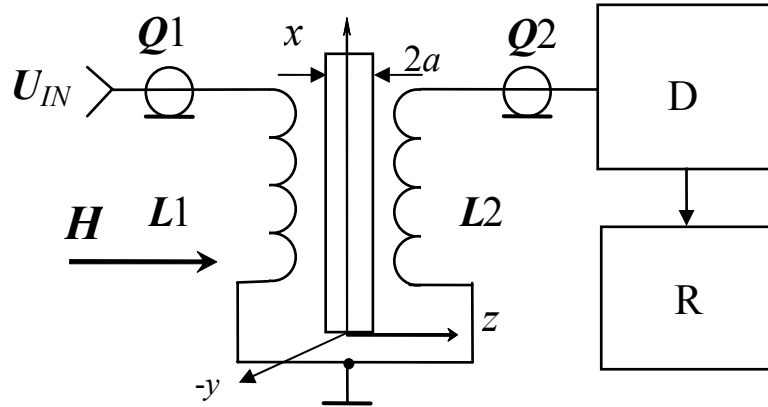


Fig.1 The experimental device.

Here in a centre is semiconductor sample in the form of plate; $L1$ is excitation coil; $L2$ is pickup coil; $Q1$ and $Q2$ are coaxial cable lines, D is detector and R -register. The direction of coordinate axes x , y , z are also shown. The constant magnetic field H is directed along the axis z and is perpendicular to the sample plane x - y . The sample thickness is $2a$ and the dimensions of the plate in x - y plane are much larger. The excitation coil $L1$ is connected to the RF generator of radio frequency ω .

In zero magnetic field ($H=0$) the currents induced in the semiconductor are directed in such a way so as to counteract the penetration of the RF energy. As a result the oscillating RF field will be other than zero only to a certain depth δ (skin-depth).

$$\delta = \frac{c}{(2\pi\tau\omega)^{-1/2}}, \quad (1)$$

were δ is the conductivity of the sample, c – velocity of light (Gauss units).

In the strong constant magnetic field H the no dissipative Hall currents appear and helicon magnetoplasmic waves may be excited. In this case the excited helicon is a circularly polarized plane wave of the form $\exp[i(kz - \omega t)]$. The semiconductor sample becomes partially transparent under these conditions. The propagation vector k is to be in the z direction and may be calculated from the dispersion relationship (it is assumed that $\omega_H\tau \gg 1$)

$$k = \sqrt{\frac{\omega_p^2 \omega}{\omega_H c^2} \left(1 + \frac{i}{2\omega_H \tau}\right)}, \quad (2)$$

were ω_p is the plasma frequency, ω_H is the cyclotron frequency, τ is the electron relaxation time, and c is the velocity of light.

For n -type semiconductor the plasma and cyclotron frequencies are given by

$$\omega_p^2 = \frac{4\pi N e^2}{m}, \quad \omega_H = \frac{eH}{mc}, \quad (3)$$

where N , e , m , are the density, charge, and effective mass of electrons (Gauss units).

The helicon resonance frequencies in the semiconductor sample may be found from the condition

$$(\operatorname{Re} k)2a = n\pi, \quad n = 1, 2, 3, \dots \quad (4)$$

or in accordance with (2, 3)

$$2a\sqrt{\frac{4\pi Ne\omega}{Hc}} = n\pi, \quad n = 1, 2, 3, \dots \quad (5)$$

In the high magnetic fields H the pick-up coil signal is proportional to the transparency factor R . In the slowly varying field H the transparency factor R has the form [3]

$$R = 1 + m \cdot \operatorname{tg} ka, \quad (6)$$

and has maximum or minimum in resonant cases (3). The period of modulation is proportional to $H^{1/2}$ and the modulation depth depend on the coupling of excitation and pickup coils.

In the range of low frequencies ($\omega \ll \omega_{\text{rez}}$) and low magnetic fields the pickup signal has maximum [3] when

$$\omega_H \tau = 1. \quad (7)$$

Rewriting (7) in the form

$$\omega_H \tau = \frac{e\tau}{mc} H = uH = 1, \quad (8)$$

we can calculate the charge mobility u for the measured value of H .

This method of mobility determination does not require any information on the Fermi surface provided electron orbits are closed.

3. Experimental results.

The semiconductor specimens $n\text{-InSb}$ and $n\text{-Ge}$ were used for the measurements in the room temperature. Some experimental curves of the pickup signal versus constant magnetic field B are show on the Fig. 2 for various exciting frequencies.

Material $n\text{-InSb}$, thickness $2a=0,5$ cm. For the exciting frequency 40 MHz (see Fig.2 A) the first resonance $n = 1$ occurs at $B = 1,6$ Tesla and second ($n = 2$) at $B = 0,4$ Tesla. In both cases we obtain from (5) $N = 1,5 \cdot 10^{16} \text{ cm}^{-3}$. In higher frequencies (120-200-1000 MHz) and fields (0-32 Tesla) much more resonances exist (Fig. 2 B, C, and D) for the same electron density N .

Material $n\text{-Ge}$, thickness $2a = 0,5$ cm. Fig 2 E illustrates the determination of electron mobility by the use of f-la (8) for the low excitation frequency 350 KHz(in comparison with much higher helicon resonant frequency 25 MHz). The pickup signal has the maximal value at $B = 5$ Tesla and from (8) we have $u = B^{-1} = 2000 \text{ cm}^2/\text{Vs}$.

The electron density $N = 0,4 \cdot 10^{16} \text{ cm}^{-3}$ for the same $n\text{-Ge}$ specimen was determined from Fig.2 F and f-la (5) with $B = 8$ Tesla, (or $H = 8 \cdot 10^4 \text{ Oe}$) and $\omega = 2 \cdot \pi \cdot 25 \text{ MHz}$. For $B \approx 2$ T we have the same density N for the second resonance ($n = 2$).

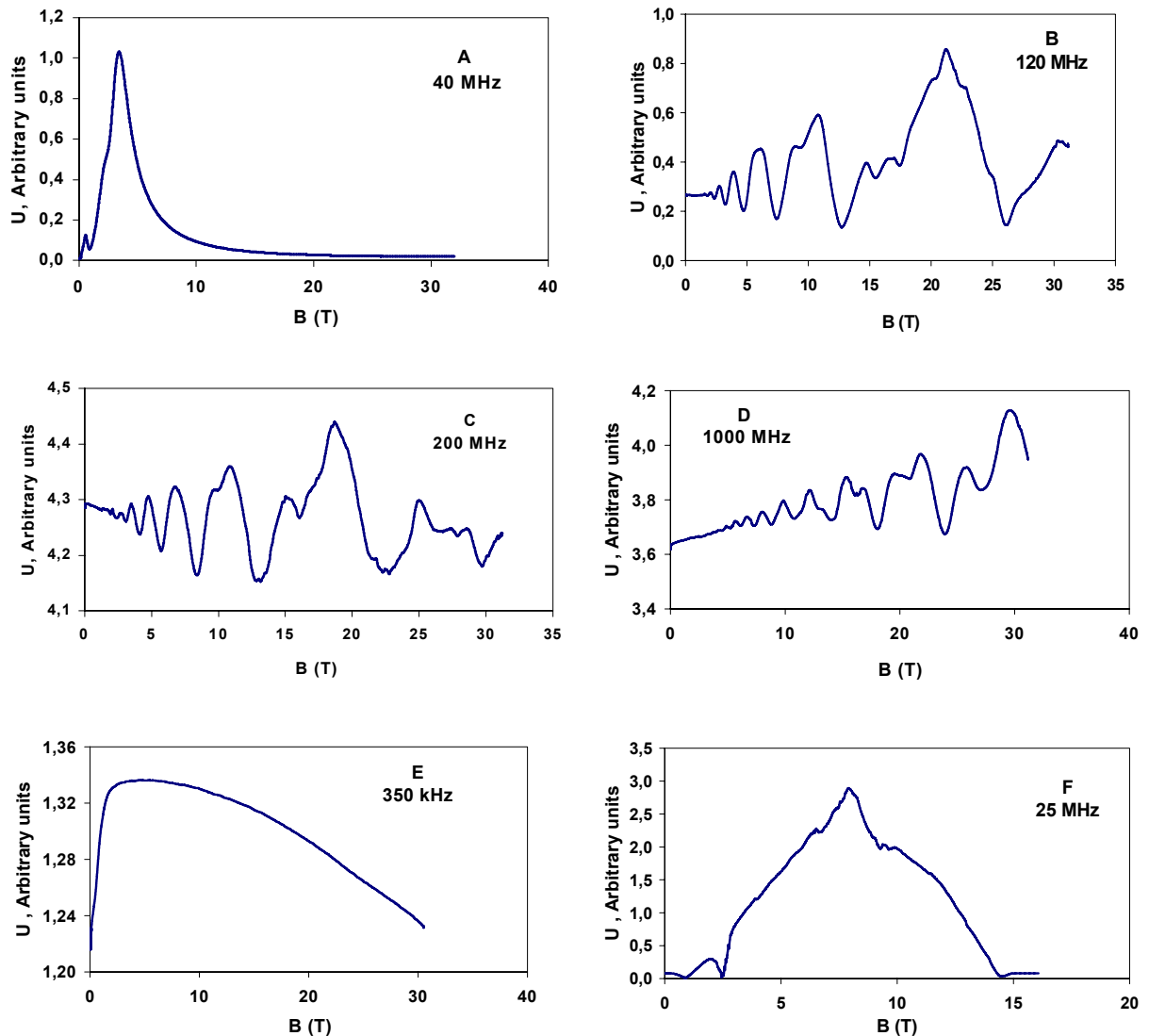


Fig.2. Pickup signal versus constant magnetic field induction B in Tesla for various exciting frequencies; n - $InSb$: A-40 MHz; B-120 MHz; C-200MHz; D-1000 MHz; n - Ge : E-350 KHz; F- 25 MHz.

4. Conclusions.

The measurements of charge density and mobility in semiconductors by the help of helicon waves may be provided in contactless mode. Practically all semiconductor materials thus may be investigated if the high magnetic field (~ 30 Tesla) is available. The measurement results are in compliance with data obtained by the use of different methods.

5. Acknowledgement.

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