THE ACCURACY OF PULSED MAGNETOPLASMA INTERFEROMETER MEASURING ELECTRICAL PROPERTIES OF SEMICONDUCTORS

Laimis Laurinavichus, Jurij Novickij, Viktoras Filipavichus
Department of Electrical Engineering, Vilnius Gediminas Technical University
Sauletekio av.11, LT-2040 Vilnius Lithuania
Phone: + 370 2 763855; E-mail: laurinavicius@el.vtu.lt

The magnetoplasma interferometer with pulsed magnetic field source and its measurement accuracy are described. The total accuracy of concentration and mobility measurements free charge carriers depends on oscillations amplitudes and magnetic induction relative errors in general. Also it was determined that magnetoplasma beam spread is influenced on mobility accuracy and correction coefficients should be introduced to mobility formula.

Introduction

Main electrical properties of semiconductors are determined by values of concentration and mobility of free charge carriers in semiconductors. High frequency methods are successfully used for investigations of semiconductors and semimetals due to their universality[1]. One of well known methods is Rayleigh interferometry when transmitted via investigated specimen signal is compared with reference signal. The reference signal has a constant phase and an amplitude. The amplitude and wave length of transmitted wave depend on electrical properties of a semiconductor. Therefore observing dimensional resonance of magnetoplasma waves in a semiconductor specimen it is possible to determine the concentration and mobility of free charge carriers of semiconductors. But measurement ranges are strongly limited by the value of magnetic induction. Therefore ranges of measurements can be expanded by the application of pulsed magnets which can generate a strong magnetic field.

The structure of magnetoplasma interferometer

Experimentally resonance curves of magnetoplasma waves can be observed with high frequency Rayleigh interferometer which simplified block diagram is shown in Fig. 1

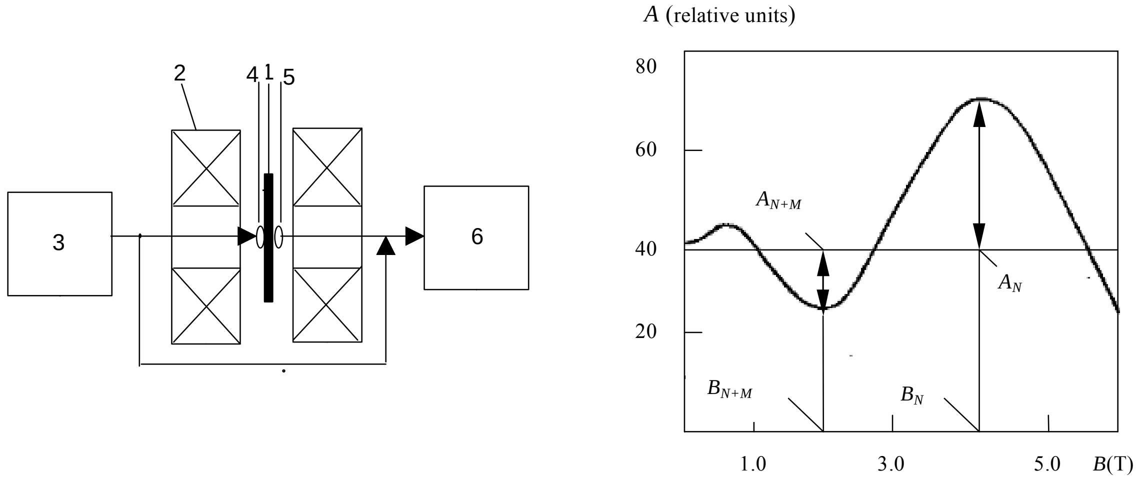

Fig. 1. Block diagram and external signal of magnetoplasma interferometer

A semiconductor plate 1 is put in pulsed magnetic field generated by two axial solenoids 2. High frequency generator 3 is connected with exciting coil 4. The magnetoplasma wave is excited in local area of a semiconductor plate put in a pulsed magnetic field. Propagating across semiconductor plate magnetoplasma wave is indicated by receiving coil 5. A receiving signal interferes with a reference signal. Obtained Rayleigh interferogram is registered by memorized oscilloscope 6. Described magnetoplasma interferometer has also a pulsed current source, high frequency detector, magnetic field sensor and a scanning mechanism which are not shown.

Accuracy evaluation of magnetoplasma interferometer

Having two extreme points of the interferogram, values of concentration and mobility of free charge carriers of semiconductors are determined according to formulas [2].

$$n=\frac{\varepsilon_0\pi c^2}{2efd^2}\frac{M^2}{\left(B_N^{-1/2}-B_{N+M}^{-1/2}\right)^2},\qquad \mu=\frac{\pi}{2}M\frac{B_N^{-1}+\left(B_N B_{N+M}\right)^{-1/2}+B_M^{-1}}{\ln\left[\frac{A_N}{A_{N+M}}\left(\frac{B_{N+M}}{B_N}\right)^{1/2}\right]}. \qquad (1)$$

where n is concentration, μ is mobility of free charge carriers. Indexes N, $N+M$ mean the order of extreme points, A_N , A_{N+M} are amplitudes of oscillations, B_N , B_{N+M} are values of magnetic induction in extreme points respectively. The relative error of concentration determined by formula (1) can be expressed as $\left(\frac{\Delta n}{n}\right)=\sqrt{\left(A_f\left(\frac{\Delta f}{f}\right)\right)^2+\left(A_d\left(\frac{\Delta d}{d}\right)\right)^2+\left(A_{B_N}\left(\frac{\Delta B_N}{B_N}\right)\right)^2+\left(A_{B_{N+M}}\left(\frac{\Delta B_{N+M}}{B_{N+M}}\right)\right)^2}$,where $\frac{\Delta f}{f}$, $\frac{\Delta d}{d}$, $\frac{\Delta B_N}{B_N}$, $\frac{\Delta B_{N+M}}{B_{N+M}}$ are relative errors of frequency, sample thickness, magnetic induction respectively. A_f,,A_d, A_{B_N} , $A_{B_{N+M}}$ are influence coefficients proportional to partial derivatives of output signal. The values of these coefficients are determined as

$$A_f=-1,\quad A_d=-2,\ A_{B_N}=\frac{1}{1-\sqrt{B_N/B_{N+M}}},\quad A_{B_{N+M}}=\frac{\sqrt{B_N/B_{N+M}}}{\sqrt{B_N/B_{N+M}}-1}. \qquad (2)$$

A relative error of frequency determination of modern generators is less then ± 1 %. The thickness of the specimen can be measured with the micrometer had a relative error less then ± 1 %. Pulsed magnetic field induction and interferometer output signal are controlled by memorized oscilloscopes traditionally. So magnetic field and amplitudes of oscillations can be determined with relative error ± (5 to 10) %.

Taking $\frac{\Delta f}{f}=\pm 1\%$, $\frac{\Delta d}{d}=\pm 1\ \%$, $\frac{\Delta B_N}{B_N}=\frac{\Delta B_{N+M}}{B_{N+M}}=\pm 5\%$ it was cleared that the relative error of concentration is determined by ratio B_N/B_{N+M} in general and one does not exceed ± 10 % for $B_N/B_{N+M}>4$.

The relative error of mobility can be expressed as

$$\left(\frac{\Delta\mu}{\mu}\right)=\sqrt{\left(K_{A_N}\left(\frac{\Delta A_N}{A_N}\right)\right)^2+\left(K_{A_{N+M}}\left(\frac{\Delta A_{N+M}}{A_{N+M}}\right)\right)^2+\left(K_{B_N}\left(\frac{\Delta B_N}{B_N}\right)\right)^2+\left(K_{B_{N+M}}\left(\frac{\Delta B_{N+M}}{B_{N+M}}\right)\right)^2} \qquad (3)$$

Influence coefficients K determine by following equations :

$$K_{A_N}=-\frac{1}{\ln A_N/A_{N+M}-\ln\sqrt{B_N/B_{N+M}}},\ K_{A_{n+m}}=\frac{1}{\ln A_N/A_{N+M}-\ln\sqrt{B_N/B_{N+M}}},\ K_{B_N}=-\frac{1+\frac{1}{2}\sqrt{B_N/B_{N+M}}}{1+\sqrt{B_N/B_{N+M}}+B_N/B_{N+M}}+\frac{1}{2\left[\ln A_N/A_{N+M}-\ln\sqrt{B_N/B_{N+M}}\right]},$$

$$K_{B_{N+M}}=-\frac{B_N/B_{N+M}+\frac{1}{2}\sqrt{B_N/B_{N+M}}}{1+\sqrt{B_N/B_{N+M}}+B_N/B_{N+M}}-\frac{1}{2\left[\ln A_N/A_{N+M}-\ln\sqrt{B_N/B_{N+M}}\right]}. \qquad (4)$$

Choosing $\frac{\Delta B_N}{B_N}=\frac{\Delta B_{N+M}}{B_{N+M}}=\pm 5\ \%$ and $\frac{\Delta A_N}{A_N}=\frac{\Delta A_{N+M}}{A_{N+M}}=\pm 10\ \%$ it was found that the relative error of mobility is depended on ratios B_N/B_{N+M} and A_{N+M}/A_N . A relative error of mobility does not exceed ± 20 % if $A_N/A_{N+M}>\left(B_N/B_{N+M}+2\right)$, what can be carried out in most experiments. Magnetoplasma wave can be excited in a semiconductor locally as a beam [3]. The distribution of axially symmetric magnetoplasma beam excited by a coil in the semiconductor plate is shown in Fig. 2.

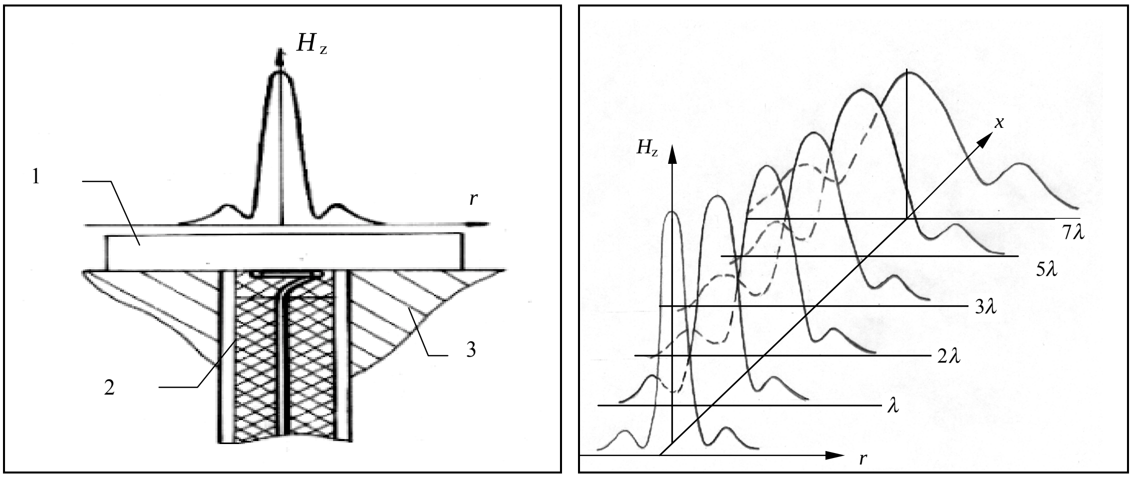

Fig. 2 The distribution of axially symmetric magnetoplasma beam in the semiconductor sample 1 with thickness $x = 7\lambda$ excited by coaxial probe 2.

The amplitude of magnetoplasma wave beam propagated through the specimen is reduced due to the spread of the magnetoplasma beam in local case of magnetoplasma wave excitation. Therefore it is necessary to introduce the correction coefficients in formula (1) to reduce the error of measurements of mobility of free charge carriers. The formula for determination of mobility of free charge carriers looks as following:

$$\mu = \frac{\pi}{2} M \frac{B_N^{-1} + \left(B_N B_{N+M}\right)^{-1/2} + B_M^{-1}}{\ln\left[\frac{A_N K_N}{A_{N+M} K_{N+M}} \left(\frac{B_{N+M}}{B_N}\right)^{1/2}\right]}, \tag{5}$$

where K_N, K_{M+N} are correction coefficients for N and $N+M$ extreme points of the interference curve.

$$K_{N,N+M} = \left(r + d\,\mathrm{tg}\,\theta_{N,N+M}\right)^2 = \left(r + d\,\mathrm{tg}\left(\frac{1}{\pi r}\sqrt{\frac{\pi \cdot B_{N,N+M}}{2e\mu_0 f n}}\right)\right)^2, \tag{6}$$

where r is radius of exciting antenna, d is thickness of the specimen, n is concentration of free charge carriers determined by formula (1), f is frequency of magnetoplasma beam, e is electron charge, μ_0 is magnetic constant, $B_{N,N+M}$ is magnetic induction in N and $N+M$ extreme points. A relative error of mobility determination does not exceed ± 10 % for formula (5), what is two times better then under formula (1). The relative error because of magnetoplasma beam spread can be reduced constructively and values of concentration and mobility of free charge carriers in semiconductors mainly can be determined by the accuracy of measured magnetic induction and amplitudes of oscillations in extreme points in general. Total relative errors of measurements ± (10 to 20) % are acceptable for most applications.

Experimental results

The described magnetoplasma interferometer with pulsed magnetic field source up to 20 T was applied in investigations of narrow band semiconductors as InSb, CdHgTe. Measurements were done at room and liquid nitrogen temperatures. Obtained results of measurements of concentration and mobility of free charge carriers of semiconductors in different points of investigated specimens have a good coincidence with measurements by Hall method. At the worst case the total relative error of measurements does not exceed 10 % for concentration and 20 % for mobility. Some experimental data of measurements are offered in Fig.3

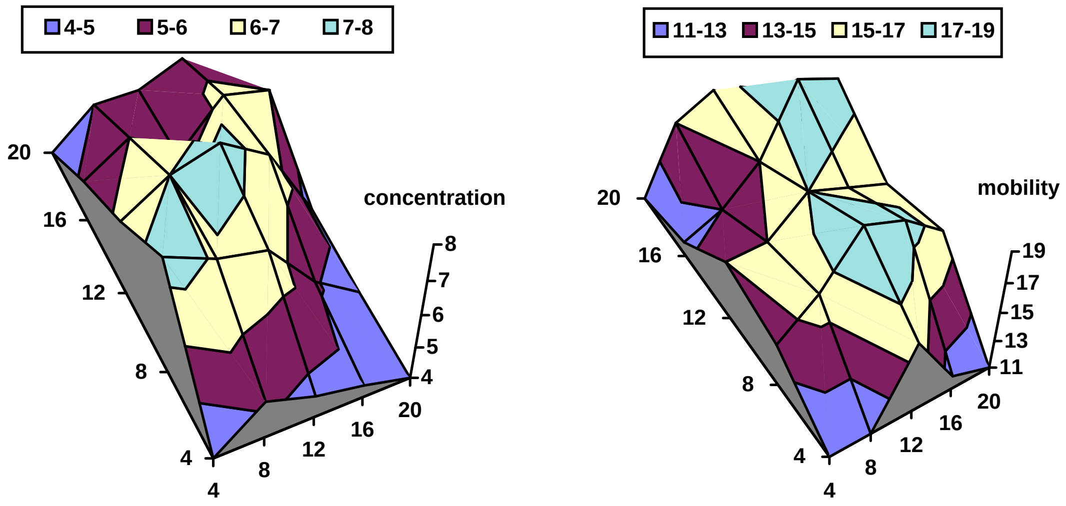

Fig.3 Distribution of concentration of free charge carriers (x10^{21} m^{-3}) and mobility of free charge carriers ($m^2V^{-1}s^{-1}$) in CdHgTe sample with dimensions 20x20mm.

Conclusions

The accuracy of measurements of concentration and mobility of free charge carriers of semiconductors depends on many factors. In first the mentioned accuracy is strongly depends on accuracy of oscillation's amplitudes and magnetic induction in extreme points. In second the accuracy depends on orders of extreme points of obtained interferogram. In third the accuracy of determination of mobility of free charge carriers of semiconductors depends on angular spread of magnetoplasma beam which can be taken into account by correction coefficients introducing to the formula of mobility of free charge carriers of semiconductors. But in any case magnetoplasma interferometers are very useful for most measurements of electrical properties of semiconductors. Described magnetoplasma interferometer with pulsed magnetic field source up to 20T provides non-contact measurements of concentration in (10^{20} to 10^{24}) m^{-3} range and mobility in (0,5 to 100) m^2 $V^{-1}s^{-1}$ range respectively. Relative error does not exceed ± 10 % for concentration and ± 20 % for mobility.

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