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ON THE DETERMINATION OF SOME ELECTRICAL CONDUCTION PARAMETERS OF GaAs-n BY MAGNETORESISTANCE MEASUREMENTS

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The geometrical magnetoresistance is presented as a means of determining conduction parameters for high mobility semiconductors. The measurements have been made on the bulk-grown GaAs-n "sandwich" structures and on Gunn diodes without magnetic cap.The magnetoresistance mobility has been determined by measuring the variation of active layer resistance in a low magnetic field perpendicular to the electric field direction. For this purpose the metal-semiconductor contact resistance, determined from the structure resistance vs.magnetic field intensity and the angle between the magnetic field and the electric field, has been used. In order to determine the scattering coefficient, the Hall mobility has been determined by using the van der Paw method .The resistivity has been obtained from the active layer resistance and the sample geometry. The concentration of charge carriers has been determined from resistivity and the Hall mobility. The charge carrier mobility has been found in the small area covered by the contact.

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1. Theoretical considerations

In the case of an isotopic solid, in the absence of the temperature gradients, and at small enough magnetic fields ($\mu_H H << 1$), the following relation is valid for transversal magnetoresistance [1-7]

$$\frac{\Delta\rho}{\rho_0} = H^2\mu_H^2\left(\frac{\langle\tau^3\rangle\langle\tau\rangle}{\langle\tau^2\rangle^2} - 1\right) \tag{1.1}$$

Here ρ_0 is the zero magnetic field intensity, $\Delta\rho$ the variation of the resistivity in magnetic field, H the magnetic field intensity, perpendicular to the direction of the electric field, μ_H the Hall mobility, and τ the relaxation time; < > is the statistical average over energy [1,9].

The geometrical magnetoresistance, i.e. the magnetoresistance that is a consequence of the geometry of the sample, is particularly intersting in the case of the "sandwich" structure (Fig.1), which contains a semiconductor layer of thickness d small enough compared to against the dimensions of the surface S_c to which metallic contacts are attached.

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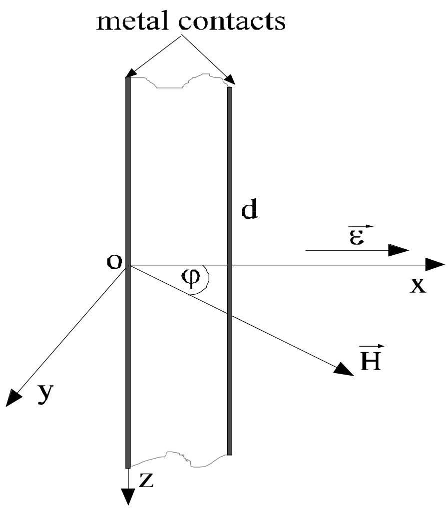


Fig. 1. The “sandwich” structure

In the case of the “sandwich” structure for intermediate values of the magnetic field, the measured resistance R_m is [9]

$$R_m(\varphi, H) = \frac{a(H)}{1 + b(H)\cdot\cos^2\varphi} + R_c \tag{1.2}$$

where φ is the angle between the direction of the magnetic field and the direction of the electric field, a(H) and b(H) are constants equal to either $R_\rho^0\frac{\sigma_0}{\sigma_\perp}$ and $\frac{\sigma_{||}}{\sigma_\perp} - 1$, respectively in the case of quasi-isotropic material, or $R_\rho^0\left(1+\mu_H^2H^2\right)$ and $\mu_H^2H^2$ in the case of the completely isotropic material, R_c is the metal-semiconductor contact resistance together with other serial resistances (such as connection conductors), considered independent of the magnetic field intensity and angle φ. Here R_ρ^0 and σ_0 represent the resistance of the active semiconductor layer and the conductivity in zero magnetic field, respectively, and $\sigma_\perp$ and $\sigma_{||}$ the conductivity in transverse and longitudinal magnetic fields, respectively.

Returning to the relation (1.1), we can mention the fact that $\mu_H^2H^2 = \left(\frac{\Delta\rho}{\rho_0}\right)_c$ is the τ=const Corbino magnetoresistance [1]; thous the relation (1.1) becames,

$$\left(\frac{\Delta\rho}{\rho_0}\right)_m = \left(\frac{\Delta\rho}{\rho_0}\right) + \left(\frac{\Delta\rho}{\rho_0}\right)_c = H^2\mu_H^2\frac{<\tau^3><\tau>}{<\tau^2>^2} \tag{1.3}$$

or in the case of the “sandwich” structure,

$$\frac{\Delta R}{R_p^0} = \xi\mu_H^2H^2 \tag{1.4}$$

Here,

$$\xi = \frac{<\tau^3><\tau>}{<\tau^2>^2} \tag{1.5}$$

is the scattering coefficient [2,10], and ΔR the variation of the structure resistance in the presence of the magnetic field perpendicular on the electric field.

In the case of the small area contacts (Fig. 2), resolving the potential problem, we can obtain for the "spreading" magnetoresistance [11], in the case of a GaAs-n sample,

$$\frac{\Delta R}{R_p^0} = \frac{1}{2}\mu_H^2 H^2 \cdot \left[1 - \left(A - \frac{1}{2}\right)\cdot \sin^2\theta\right] \tag{1.6}$$

in wich R_p^0 is the contact area zero magnetic resistance, θ the angle between the direction of the magnetic field intensity $\vec{H}$ and the normal direction of the surface Σ_2, μ_H the Hall mobility in the small contact surface Σ_2 covered by the contact, ΔR the variation of the resistance of the structure in magnetic field, and A a constant.

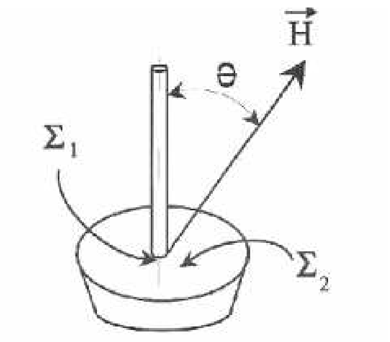


Fig. 1.2. Small area contact.

From relation (1.6) we can obtain,

$$A - \frac{1}{2} = \frac{\left.\frac{\Delta R}{R_p^0}\right|_0 - \left.\frac{\Delta R}{R_p^0}\right|_{90}}{\left.\frac{\Delta R}{R_p^0}\right|_0} \tag{1.7}$$

hear $\left.\frac{\Delta R}{R_p^0}\right|_0$ and $\left.\frac{\Delta R}{R_p^0}\right|_{90}$ being the values of the ratio $\frac{\Delta R}{R_p^0}$ in the case $\theta = 0^\circ$ and $\theta = 90^\circ$ respectively.

2. Measurement of the geometrical magnetoresistance

From a practical point of view the interest in the studies of the geometrical magnetoresistance arises firstly from the possibility which it offers to determine the charge carrier mobility for extrinsic materials. In the case of the structure from Fig. 1, we can define the magnetoresistance mobility μ_m [12] by the relation,

$$\frac{\Delta R}{R_p^0} = (\mu_m H)^2 \tag{2.1}$$

where R_p^0 is the resistance of the active layer in zero magnetic field, and ΔR the variation of the active layer resistance as a consequence of the application of the H magnetic field, perpendicular at the contact surface.

Comparing (2.1) and (1.4) we can obtain for the scattering coefficient,

$$\xi^{\frac{1}{2}} = \frac{\mu_m}{\mu_H} \tag{2.2}$$

On this basis μ_H can be calculated if μ_m and ξ are measured.

The mobility μ_m is obtained at a given temperature from the slope of the straight line $\frac{\Delta R}{R_p^0} = f(H^2)$ for values of magnetic field wich are low enough to meet the requirement $\mu_m H << 1$ (in the case of GaAs-n samples, room temperature Hall mobility is $\mu_H \approx 6000 cm^2 V^{-1} s^{-1}$ and $\xi \approx 1$, such that for magnetic field intensity H=6 kG we obtain $(\mu_H H)^2 \approx 0.36$).

The samples we used are based on bulk-grown GaAs-n (accordingly numbered PC i-j, i and j being the order of the small area contact samples), and on epitaxial GaAs-n leyer grown in the shape of Gunn diodes (numbered EI, EII, etc).

The calculation of the magnetoresistance mobility requires the evaluation of the active layer resistance R_p^0 of the structure represented in Fig. 1; this must be separated from the metal-semiconductor contact resistance R_c, which often influences decisively the measurements of the resistance in magnetic field.

The relation (1.2) offers a basis for determining R_p^0. Thus, if $R_m(\varphi, H)$ is measured for a number of values of the angle φ at a constant value of magnetic field

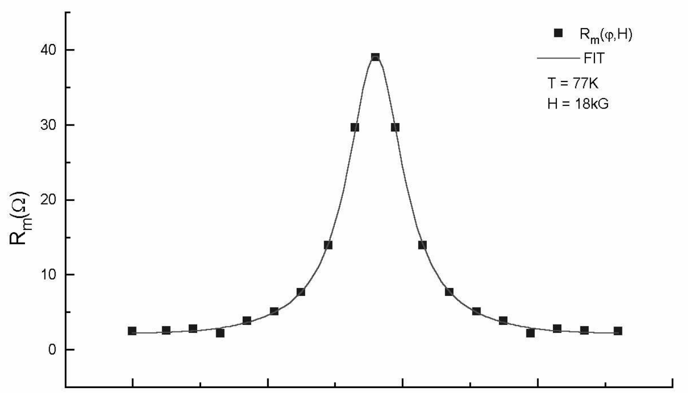


Fig. 3.

Fitting relation $R_m(\varphi, H) = \frac{a(H)}{1 + b(H)\cos^2\varphi} + R_c$ with exerimentals dates in the case of sample E II

($a = 38.88576\Omega; b = 20.19378; R_c = 0.39372\Omega$)

intensity, fitting the experimental values of R_m with theoretical relation (1.2), the values of constants a(H), b(H) and R_c result; the resistance of the active layer resistance is obtained from the relation,

$$R_p^0 = R_m^0 - R_c \tag{2.3}$$

where R_m^0 is the measured resistance of the structure obtained at zero magnetic field.

Measuring the geometrical dimensions of the structure, with the help of R_p^0 we can obtain the resistivity ρ of active layer of the structure.

Using the resistivity ρ and the Hall mobility μ_H, the carrier concentration n can be obtained i.e., [6,7]

$$n = \frac{1}{\rho\mu_H e} \tag{2.4}$$

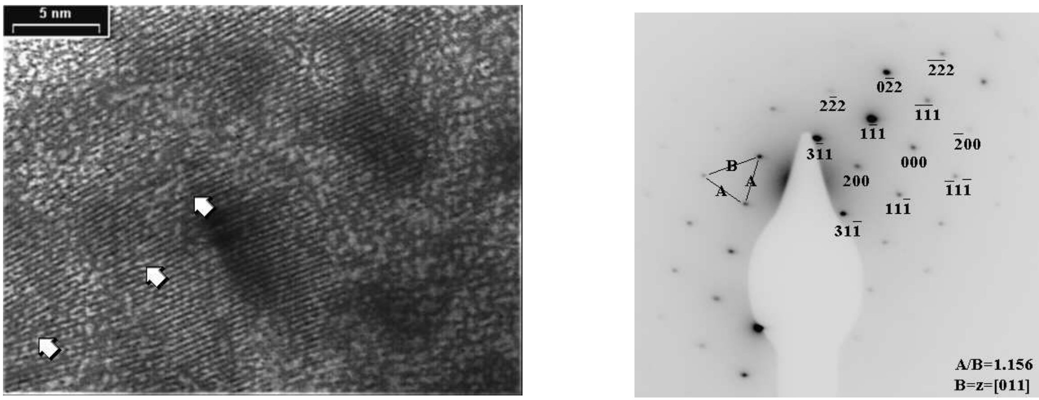
e being the elementary charge.

On the other hand, on the basis of the constants a, b and R_c, the ratios $\sigma_0/\sigma_{||}$ and $\sigma_{||}/\sigma_{\perp}$ can be obtained, which in turn, provide information on the crystal anisotropy [13,14].

3. The preparation of the sample

The bulck-grown GaAs-n samples were obtained from slices of $250\mu m$ thick n-type material cut out beforehand in the direction <111>. The HRTEM fase contrast image on the [111] planes is presented in Fig. 3a; the interplanare distance in this case is d_{111}=0.3259 nm. În Fig. 3b is presented the indexation of the difraction image on the [011] axis.

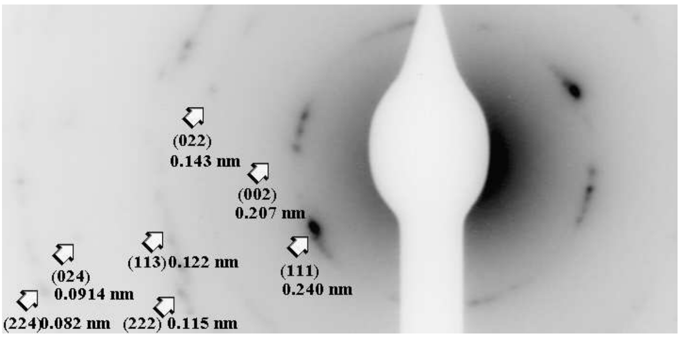
Plates with an area of ≈ 1 cm^2 were detached from these slices. They were degreased by washing in an ultrasonic bath, succesively in trichlorethylene and acetone of electronic purity; the slices were after that cleaned for 30 seconds in a solution of sulphur acid oxigenated and bidistilled water in the ratio 3:1:1. After this chemical treatment, an alloy of Au-12 % Ge -3 % Ni was deposited by evaporation in a vacuum of $\approx 10^{-5}$ torr on one of the surface of the plates and on a large number of small area contacts, on the oposite surface of the plates.



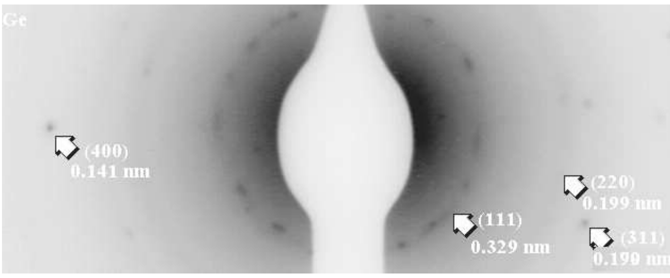
a b

Fig. 3. a) HRTEM image with <111> plane franjes for GaAs-n. Arrow indicate crystal structure defect probably from doping process; b) Indexation of difraction image along [011] zone axis reveal FCC structure (d_{111} = 0.32558 nm, d_{200} = 0.28378 nm, d_{220} = 0.20588 nm, d_{311}=0.1660 nm).

The depositing proces was followed by a process of synterisation for 2 minutes at 450^{o}C. The electron difraction images of the metal-semiconductor contacts sre presented in Fig. 4. On the surfaces thin golden wires having a diameter of $\approx 30\mu m$ were attached by thermocompression in order to obtain the current contacts [15-17,18]; such a sample is presented in Fig. 5.



a



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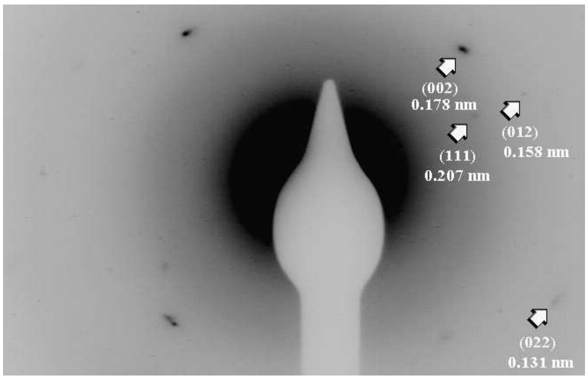

c

Fig. 4. Electron difraction images of metal-semiconductor contacts in the case of bulck-grown GaAs-n samples a) the difraction gold rings; b) the difraction Ge rings; c) the difraction Ni rings.

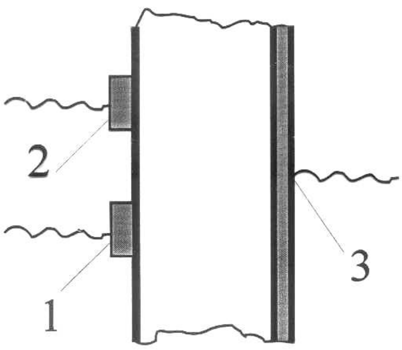

Fig. 5. 1, 2 small area contacts; 3-surface contact.

The epitaxial GaAs-n samples were made from Gunn diodes without the magnetic cap [11, 18]. In this case, by contact resistance R_c it is understood the sum of the resistance of the golden wires attached to the structure, the resistance of the high conductivity layer and other series resistances due to connection.

4. Experimental results

Calculating, at different temperatures, the values of the metal-semiconductor contact resistance R_c, active layer resistance R_p^0, conductivity σ, magnetoresistance mobility μ_m and Hall mobility μ_H (considering $\xi = 1$ [7,9]), we obtain in the case of E II sample the results presented in Fig. 6. Similar results were obtained for all other samples.

The measurements show an increase of the metal-semiconductor contact resistance R_c with the decrease of temperature. In all cases, i.e. bulck-grown GaAs-n samples and epitaxial GaAs-n samples, the decrease of temperature leads to the increase of R_c. This increase may be explained by a "freesing" process of the charge carriers with the decrease of the temperature. On the other hand if the sample are the subject to repeated changes in temperature from room temperature to liquid nitrogen temperature the quality of the metal-semiconductor contact is damaged.

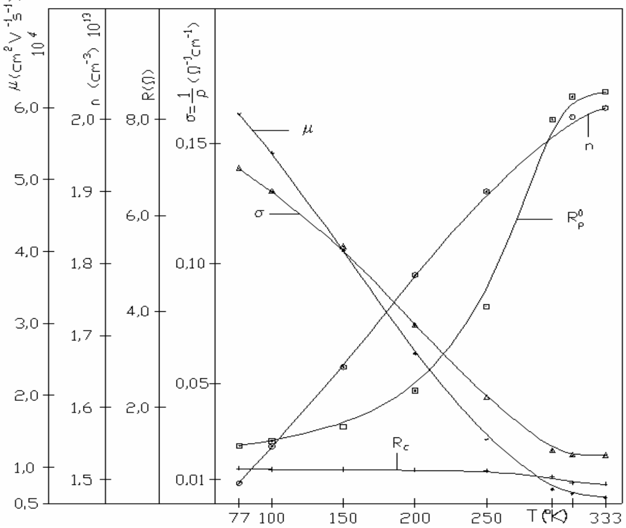

Fig. 6. The dependences $R_c=R_c$ (T), $R_p^0 = R_p^0(T)$, $\sigma=\sigma(T)$, $\mu=\mu(T)$ and n=n(T) in the case of epitaxial grown GaAs-n sample EII.

From the experimental data presented in Fig. 6 we have found that the temperature dependence of the Hall mobility, on the straight line interval, of the curve $\mu = \mu(T)$, has the power law dependence $\mu_H \approx T^{-1.54}$. Taking into account that temperature dependence of Hall mobility corresponding to the scattering on accoustic phonons has the shape $\mu_H \approx T^{-1.5}$ [20], we can conclude that for temperatures larger than the liquid nitrogen temperature, the main scattering mechanism is on acoustic and optical phonons.

The carrier concentration increase with the increase in temperature (Fig. 6); such a behavior is valid in the case of all samples examinated. The explanation of the increase of the carrier concentration is based on the fact that the epitaxial GaAs-n active layer in discution is a compensated extrinsec material [20]; for the sample EII the compensation ratio is $\frac{N_A}{N_D} = 0.969$, N_A and N_D being the acceptor and donor concentrations respectively. We have determined the compensation ratio from empirical Wolfe's curves [21,7] using the carrier concentration and carrier mobility at 77 K and the room temperature carrier concentrations.

The decrease of conductivity σ, correlated with the increase of the resistance of the active layer with the increase of temperature are determined by the strong decrease of the carrier mobility even though the carrier concentration increases with T. Such a behavior of the conductivity is observed for all the samples studied.

The relation (1.6) can be utilised in order to determine the local Hall mobility on the basis of the small area contact geometry from Fig. 5. Thus, we obtain the resistance R_p^0 between contacts 1 and 2, and also the variation ΔR in the perpendicvular magnetic field on the contact surface. The resistance R_p^0 is,

$$R_p^0 = R_{m0} - R_c \tag{4.1}$$

Here R_{m0} is the zero magnetic field measured resistance and $R_c=R_{c1}+R_{c2}$ the contact metal-semiconductor resistance of smal area contacts 1 and 2. The resistances R_{c1} and R_{c2} can be measured by the rotation method in magnetic field, using relation (1.2) with electric field between contacts 1 and 3 and 2 and 3 respectively.

In Fig. 7 is presented the exsperimental results in the case of sample PC 11-21; PC 15-1 and PC 11-1.

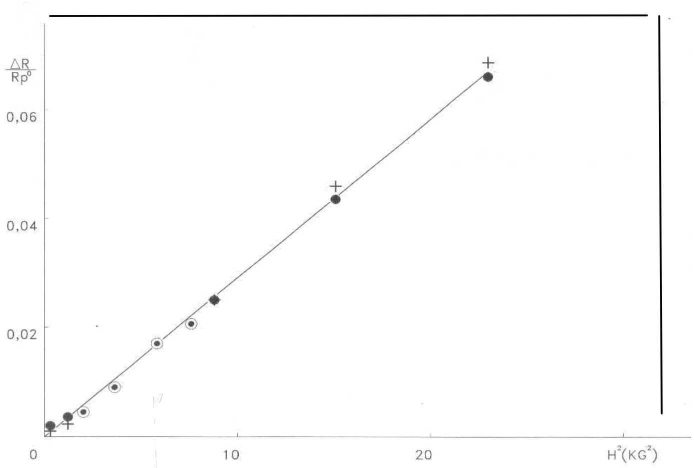

Fig. 7. The dependence $\frac{\Delta R}{R_p^0}$ vs. H^2 at the room temperature (• PC11-21; + PC15-1; ⊙ PC11-1).

At the room temperature we have been obtain μ_H=6060 $cm^2V^{-1}s^{-1}$ in good agreement with the value obtaind by van der Paw method [22,7].

On the basis of the measurements in magnetic field paralel with the contact surface it was determined the constant A=0.62 in very good agreement with the value given by different autors.

5. Conclusions

Based on the theoretical considerations and on the obtained experimental results, one can formulate the following conclusions with a general character:

a. In order to make easier the interpretation of the results found in an experimental way, we used the resistance of the sample in a magnetic field under the form,

$$R_m(\varphi, H) = \frac{a(H)}{1 + b(H) \cdot \cos^2 \varphi} + R_c$$

a(H) and b(H) signifyng $R_p^0 \dfrac{\sigma_0}{\sigma_\perp}$ and $\dfrac{\sigma_{||}}{\sigma_\perp} - 1$ for the samples with quasiisotropic active layer or $R_p^0\left(1 + \mu_H^2 H^2\right)$ and $\mu_H^2 H^2$ for the sample with the isotropic active layer.

b. To determine the electrical parameters of the gallium arsenide we conjoined the method for the determination of the magnetoresistance mobility on the basis of the magnetoresistance measurements at a low magnetic field, with the method for the determination of the metal-semiconductor contact resistance by measuring the resistance in a magnetic fields vs. the angle between the direction of the magnetic field and the direction of the electric field.

c. In the case of small area contacts the potential problem has been resolved. On this base, the local Hall mobility was determinated. On the other hand, it was determinated the constant A from relation,

$$A - \frac{1}{2} = \frac{\left.\dfrac{\Delta R}{R_p^0}\right|_0 - \left.\dfrac{\Delta R}{R_p^0}\right|_{90}}{\left.\dfrac{\Delta R}{R_p^0}\right|_0}$$

in good agreement with the value given by different autors.

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