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BAR-CONFIGURATION IN HALL MEASUREMENTS WITH GaAs

R. V. Ghita[*], C. Logofatu, C. Negrila, M. F. Lazarescu, A. S. Manea, V. Ciupina[a]

National Institute of Materials Physics, P.O. Box MG 7, Magurele, Bucharest, Romania,
[a]Department of Physics, Ovidius University of Constanta, RO-8700, Constanta, Romania

The electrical and transport properties of GaAs crystals such as resistivity (ρ), mobility (μ) and carrier concentration (n) depend on the purity and defects of a particular crystal. These parameters are normally obtained by performing a simple Hall effect analysis in a bar configuration. The technical procedure is connected with the design of appropriate contacts for Hall bar configuration. In order to ensure good ohmic contacts on GaAs, thin metal layers of Au-Ge-Ni have been deposited in high vacuum followed by heat treatment in low vacuum. Hall effect measurement is important for checking the quality of the GaAs wafers. We analyzed various GaAs wafers with (100) and (110), orientation obtained by LEC and HB methods. The resistivity of the wafers varied from low resistivity, n-type doped crystals ($n = 10^{18}$ cm^{-3}), to high resistivity crystals ($n = 10^{14}$ cm^{-3}). This paper presents the data of Hall characterization of wafers cut from GaAs crystals grown by different methods (LEC, HB).

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1. Introduction

The electrical and transport properties of GaAs crystals such as resistivity (ρ), mobility (μ) and carrier concentration (n) are dependent on the purity and defects of the crystal. In our experiment, these parameters are obtained by performing Hall measurements with GaAs in a bar configuration.

The GaAs samples were n-type doped with two kinds of donor atoms namely silicon and tellurium. The wafers were obtained by liquid encapsulated Czochralski (LEC) and Horizontal Bridgman (HB) methods and show (100) or (110) orientation. The Hall effect analysis was performed over 15 samples with variation in chip size that have on one side ohmic circle contacts.

In literature [1] there are informations regarding the size effect in Hall measurements with GaAs semi-insulating (SI) and GaAs crystals in a Van der Pauw configuration [2].

From the point of view of semiconductor properties evaluation, it is of interest to determine the effects due to the size and shape of finite contacts for representative sample configuration with reference to the ideal Van der Pauw situation [2]. The error due to the finite contacts was theoretically investigated and a correction factor was proposed. This is a parameter related to the ratio of contact area to area of the sample surface [2].

2. Experimental

Fifteen different chips of various size were analysed. The bar-configuration is presented in Fig. 1.

The n-GaAs samples, LEC type, (100) oriented, were prepared for Hall measurement in the following manner. Firstly, the ohmic contact Au(83%)-Ge(12%)-Ni (5%) on semiconductor wafer

[*]Corresponding author: ghitar@alpha1.infim.ro

was deposited in high vacuum (8×10^{-5} Torr). Thereafter, the samples with AuGeNi contacts were annealed at 450 °C for 5 min in low vacuum (10^{-1} Torr). For bar configuration the average dimensions were L = 5.4 mm, l = 2.3 mm and the contact diameter δ =1 mm. The third experimental step was the bonding in air of indium wires on AuGeNi contact at 260 °C using a indium based solder.

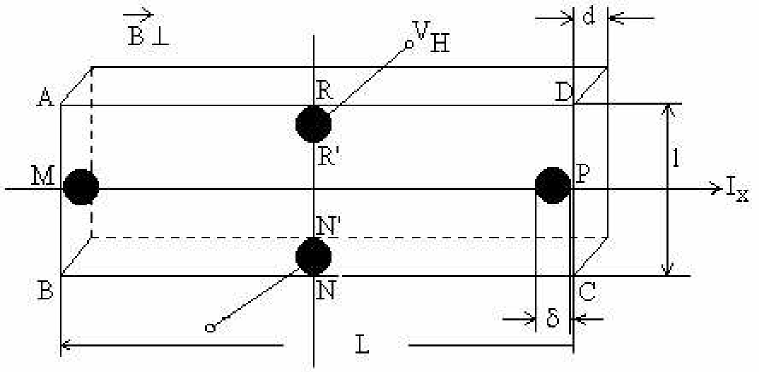

Fig. 1. Experimental contact configuration and the "standard" characteristics of the sample.

Every sample was fixed on a holder situated in a magnetic field (B = 5000 Gs), and a driving current in the range 0.1-10 mA was set at the edge of M, P electrodes. The Hall voltage in the range of (5-100) mV was measured perpendicularly to the driving current. The results allow for the computation of Hall resistivity and mobility. The final results are affected by an error factor due to the finite dimensions of the sample and contact.

3. Results and discussion

Under the influence of a magnetic field, $\vec{B}$, the current density J_y and the electric field $\vec{E}$ in a flat isotropic homogeneous semiconductor must satisfy the following relation [2]:

$$\vec{J} = \sigma\vec{E} + \sigma R_H\left(\vec{J}x\vec{B}\right) \tag{1}$$

where σ and R_H are the conductivity and Hall coefficient of the sample respectively. When the magnetic field $\vec{B}$ is applied perpendicular to the plane of sample as shown in Fig. 1, equation (1) can be rewritten in the following form:

$$E_x = \rho\left(J_x - tan\,\theta \cdot J_y\right) \tag{2}$$

$$E_y = \rho\left(tan\,\theta \cdot J_x + J_y\right) \tag{3}$$

where ρ is the resistivity and $\tan\theta = \dfrac{R_H B}{\rho}$ is defined as the Hall angle.

The Hall voltage V_H is measured between the infinitesimal Hall electrodes *R* and *N* when current I_0 is passing between inifinitesimal driving electrodes *M* and *P*. Therefore:

$$J_x = \frac{I_0}{(L-2\delta)\cdot d} \quad \delta \to 0 \tag{4}$$

$$E_y = \frac{V_H}{l} \qquad E_y = \rho\, tan\,\theta J_x = \frac{\rho\, tan\,\theta I_0}{(L-2\delta)\cdot d} \quad \delta \to 0 \tag{5}$$

$$V_H = \frac{\rho \tan\theta I_0}{d} \cdot \frac{l}{L} \tag{6}$$

where d is the thickness of the sample, L-the length and l the width of the sample, and I_0 is the total current injected into the sample. If both magnetic field and current are maintained constant, the Hall voltage one would measure with finite electrodes in the corresponding situation as shown in Fig. 1 will be (7):

$$V_H^{'} = \int_R^N E_y dy = \int_R^N \rho\left(\tan\theta J_x + J_y\right)dy = \int_R^{R^{'}} \rho(\tan\theta J_x + J_y)dy + \int_{R^{'}}^{N^{'}} \rho\left(\tan\theta J_x + J_y\right)dy + \int_{N^{'}}^{N} \rho\left(\tan\theta J_x + J_y\right)dy \tag{7}$$

Since the resistivity in the ohmic contact region is nearly zero, the first and the third integral on the right hand side of the equation (7) can be set equal to zero. In the situation:

$$J_x\left(L - 2\delta\right) = \frac{I_S}{d} \tag{8}$$

Here I_S is defined as the total current which passes through the semiconductor. Hence, the apparent Hall measured with finite contacts is:

$$V_H^{'} = \int_{R^{'}}^{N^{'}} \rho \tan\theta J_x dy + \int_{R^{'}}^{N^{'}} J_y dy = \frac{\rho \tan\theta I_S}{d}\frac{l}{L} - \rho\int_{N^{'}}^{R^{'}} J_y dy \tag{9}$$

The resulting error factor can be deduced from equations (6) and (9) as:

$$E_H = \frac{V_H - V_H^{'}}{V_H} = \frac{\frac{\rho \tan\theta I_0}{d}\frac{l}{L} - \frac{\rho \tan\theta I_S}{d}\frac{l}{L} + \rho\int_{N^{'}}^{R^{'}} J_y dy}{\frac{\rho \tan\theta I_0}{d}\frac{l}{L}} = \frac{I_0 - I_S}{I_0} + \frac{Ld\int_{N^{'}}^{R^{'}} J_y dy}{I_0 l \tan\theta} \tag{10}$$

Table. 1. The samples used in the experiments.

Sample	Growth procedure	Contact	Chip size (mm^2)	Contact size (mm^2)	Plane	δ/l	Thickness (μm)
S1	LEC	AuGeNi	6×1.5	1	(100)	0.667	500
S2	LEC	AuGeNi	4.5×2.3	1	(100)	0.435	900
S3	HB	AuGeNi	5.3×2.4	1	(100)	0.417	1100
S4	LEC	AuGeNi	4.5×2.3	1	(100)	0.435	900
S5	HB	AuGeNi	5.3×2.4	1	(100)	0.417	1100
S6	LEC	AuGeNi	5.4×3.9	1	(100)	0.256	1000
S7	HB	AuGeNi	5.9×2.4	1	(110)	0.417	1000
S12	LEC	AuGeNi	5.5×1.6	1	(100)	0.625	800

The first term on the right hand side of equation (10) represents a reduction factor in measured Hall voltage due to the loss of a part of the injected current that now flows around the edges of the finite Hall electrodes. The second term in equation (10) represents a bulk correction factor due to the shorting effects or current re-distribution due to the presence of finite current and voltage contacts. Thus, equation (10) provides us with a physical interpretation of the error induced when the electrodes in the bar-configuration measurement are not infinitesimally small.

The samples used in the experiments are shown in Table 1. They are characterized by different chip size with the same contact size, a situation that implies different ratios δ/l. In our case the contact shape is a circle and we approximated it for the sake of calculation simplicity with a square with the same area [1]. In the bar-configuration we established the expression of the error factor, E_H, when the ratio of AuGeNi contact diameter to sample width (δ/l) is that from Table 1.

The results of Hall effect measurements, resistivity and mobility for different samples are presented in Table 2. In Fig. 2 is presented the mobility vs factor δ/l, supposing the effect of contact size on n-type GaAs samples. These results are relevant for contact-size effects as they are presented in the case of GaAs (SI), in the regular articles [1, 3]. The apparent Hall voltage measured with finite contacts is affected due to the orientation of the magnetic field $\vec{B}$ with Oz axis of GaAs unit cube, in a typical configuration, where the conventional unit cube for GaAs is four times larger than that of the primitive cell [4]. The next supposition is related to the results of Hall parameters in the case of (100) and (110) samples as they are affected by the type of crystal related to the growth procedures because the bulk defects in crystals depend on the growth methods: LEC or HB.

Table 2.

Sample	Substrate type	Proportion δ/l	Mobility μ(cm^2/Vs)	Resistivity ρ(Ωcm)
S2	N	0.435	279	0.538
S4	N	0.435	279	0.538
S7	N	0.417	1.76	0.632
S12	N	0.625	1147	0.233

We presented a calculation of Hall voltage on different n-GaAs samples with a bar-configuration. This sample geometry was considered as the first one suitable for measurements on GaAs semi-insulating [3]. The experimental set-up was an extension in case of bar-configuration sample geometry of the standard Hall suitable geometry proposed in ASTM library [5] designed as preferred (cloverleaf) or acceptable (square or rectangle contacts at the corners). In standard Hall measurements the relative error factor is δ/l [5] with a computed error factor on Hall voltage discussed by Chwang et al. in reference [2] related to the contact size effect. From this point of view we calculated the error factor on Hall voltage in bar-configuration as a function of geometrical parameters: L, l, d. The electrical and transport properties of GaAs crystals, obtained from effect Hall analysis, fit well the expected characteristics of semiconductor samples.

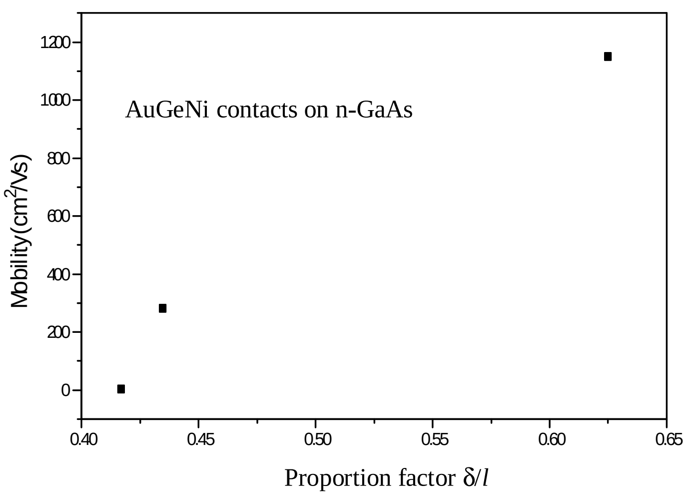

Fig. 2. Experimental effect of the factor δ/l on n-GaAs mobility.

4. Conclusions

An extended Hall measurement on n-GaAs samples at room temperature was performed. There were determined the effects introduced by the size and shape of finite contacts and finite bar-configuration. The AuGeNi ohmic contact was deposited on n-GaAs wafers grown by LEC and HB methods. The effect of the ratio δ/l on parameters, e.g mobility, was evidenced. The $\mu_H = f(\delta/l)$ variation is expressed by an experimental curve and a notable difference between (100) and (110) planes was remarked.

The error factor introduced when the electrodes are not infinitesimally small is expressed by a reduction factor in measured Hall voltage coupled with bulk correction factor due the shorting effects or current re-distribution determined by the presence of finite current and of voltage contact.

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