HALL AND A FOUR POINT PROBE FOR CHARACTERIZATION OF SEMICONDUCTORS

***Rudolf Kinder*[1], *Miroslav Mikolášek*[1], *Jaroslav Kováč*[1], *Marek Tlaczala* [2]**

1. Slovak Technical University, Faculty of Electrical Engineering and Information Technology, Institute of Electronics and Photonics

2. Institute of Microsystems Technology, Wroclaw University of Technology, Faculty of Electronics, Janiszewskiego 11/17, 50 372 Wroclaw, Poland

E-mail: rudolf.kinder@stuba.sk

Received 30 April 2011; accepted 5 June 2011.

1. Introduction

An important part of the production technology of electronic components and integrated circuits is the diagnostics of the technological process. Hall effect and electronic transport measurements are invaluable to understanding and characterization the physical properties in semiconductors such as Si, GaAs, ZnO, and nanocrystal diamond as well as other electronic and magnetic materials [1]. This paper describes a Hall system with the four-point-probe method and optimization of measurement conditions for determination of concentration n and mobility μ of different semiconductor layers and structures [2].

2. Design of equipment and measurement routine

The measurements and calculations were carried out on a set-up tool designed at the DSLab. s.r.o., in collaboration with Institute of Electronics and Photonic, STU in Bratislava. The measurement system (MS) provides measurements of sheet resistivity and Hall coefficient to evaluate specific resistivity (R_s), carrier concentration (n), Hall mobility (μ) and type of semiconductor (n-type or p-type). Two different ways were used to measure resistivity (i) Van der Pauw set-up being the part of the Hall measurement covering the sheet resistance in the range 0.1 to 10^{10} Ω/cm^2 and (ii) 4-point linear probe providing measurement in the range of specific resistivity from 10^{-3} to 20 Ωcm. A part of measuring system is the sample board allowing measurements at room and nitrogen temperature utilizing permanent magnet (0.55 T) or electromagnet (0.15 T). The sample is electrically contacted through Ecopia corporation sample holder. The block diagram of complete measuring system is shown in Fig. 1.

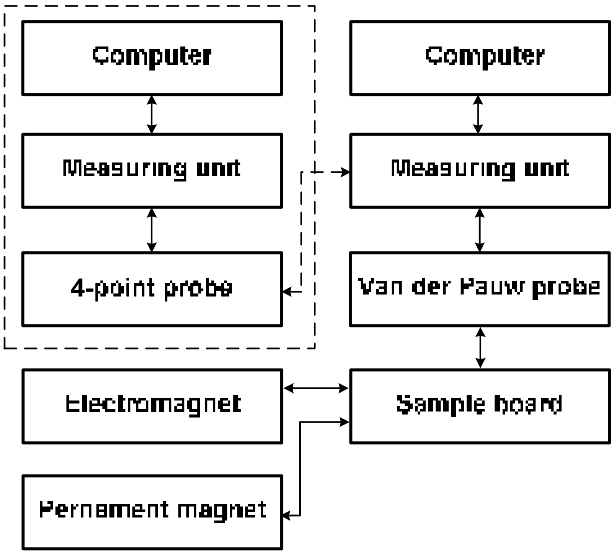

Fig.1: *The complete measuring system.*

The switching field of MS was used for linear 4-point probe method measurement. The calculation of R_S and ρ values as well as conversion of ρ to n for p- or n-type Si can be performed by a conversion code. For determining R_S, ρ and n it is needed to know following parameters: type of 4-point probe, type of semiconductor, thickness of sample or layer, correction factor value, given current (max. 100 mA) and number of measurements. Then from the number of measurement the average values of R_S, ρ and n are calculated [2].

The value of sheet resistance required for evaluation of Hall mobility and concentration is measured using a Van der Pauw configuration. Various aspects are important to obtain a good sensitivity and accuracy using this method. The most critical role by the measurements plays the ohmic contacts created on the different samples. The quality of ohmic contacts in the Van der Pauw configuration is controlled via the measurement of resistivity linearity between neighbouring contacts, where four leads labelled 1, 2, 3, and 4 are connected to the four contacts on the edge of the sample. The technology of ohmic contacts formation differs from semiconductor sample and is described elsewhere [3]. Other aspects influencing the accuracy of the measurement, sample homogeneity (symmetry) and power dissipation during the measurements are automatically controlled by software as well.

The Hall system together with the Van der Pauw resistivity configuration was primary designed for high resistance sample measurement, covering the sheet resistivity from 0.1 Ω/cm^2 up to 10^{10} Ω/cm^2. For this kind of measurement the voltage source was used to feed the sample, so the current through sample is limited only by semiconductor resistivity. The current measurement is provided with currents ranging from 100 pA to 10 mA with the highest sensitivity of 0.02 pA.

For Hall measurements a contact configuration perpendicular to each other is expected for current flow and voltage measurement. In real sample due to non perpendicular contact misalignment the voltage offset is measured also at 0 magnetic fields, which present a serious problem for measurements of low hall voltage. To overcome this problem Hall system contains a hardware compensation of this misalignment voltage and gives much better results on asymmetric samples as Hall systems without it. The range of hall voltage measurement goes from 5mV to 10V with the highest sensitivity 0.05 μV provided at the lowest voltage range.

3. Experimental results

By applying the measuring system with help of a linear 4-point-probe method (4PP) the values of ρ and n were measured and calculated. The results are described in detail in [2]. The accuracy of conversion of ρ to n and counter calculated by is 0.01%. The calculated results are identical with the results obtained from Irvin curves [2].

To demonstrate the potential of Hall measurement tool, measurement on four kinds of semiconductor samples with different resistance were carried out. For the experiment following samples were employed: 1.1 μm thick aluminium doped zinc oxide (ZnO:Al) prepared on glass substrate, high doped p-type silicon substrate (c-Si(p)) 450 μm thick, nanocrystal diamond (Diamond) layer of thickness 0.9 μm deposited on 1. 4 μm thick SiO_2 insulating layer on silicon substrate and Si doped GaAs epitaxial layer of thickness 1.25 μm (GaAs:Si) grown by molecular beam epitaxy on GaAs SI substrate. To overcome the leakage current caused by diamond layer, which during the deposition overlaps over the thin insulating SiO_2 layer and makes connection to the silicon substrate, the edges of the diamond layer were etched. In the first step of measurement, the samples were attached to the holder and four contact labels were placed on the corners of the sample. The quality of the ohmic contacts to the sample was controlled via the resistance linearity measurement between neighbour contacts. In case of the ZnO:Al sample, which has a high conductance, the good ohmic contact giving nonlinearity value bellow 0.5% was attained by direct placing of sample holder gold tips on the sample. Other samples required contact preparation. For samples with diamond layer and GaAs:Si layers an In contacts were first spread at the corners of the samples and than annealed in FGA (90% N_2 + 10% H_2) at the temperature 400 ºC for 1.5 minutes. The aluminium contacts were evaporated on the corners of c-Si(p) substrate to assure ohmic contact. From linearity of I-V curves between neighboured contacts and thus good ohmic contacts was achieved for all samples. The results of resistivity and Hall measurements for selected samples are summarized in Tab. 1. The obtained results are in good agreement with technological prediction and measurements carried out on other Hall measurements tool [3, 4]. The developed system proved the potential of providing resistivity and Hall measurements of various semiconductors with wide range of resistance.

Tab. 1: *Summarized results of Hall measurement, d is sample thickness, R_s is sheet resistivity, ρ is specific resistivity, U_H is Hall voltage, μ is mobility and n is carrier concentration.*

Sample	d (μm)	R_s (Ω/cm^2)	ρ (Ohm cm)	Contact nonlin. (%)	U_H (μV)	μ (cm^{2}Vs-^{1})	n (cm^{-3})
c-Si(p)	450	0.0438	1.97×10^{-3}	<1	0.25	49.2	6.4×10^{19}
ZnO:Al	1.1	5.3×10^{3}	5.9×10^{-2}	<0.5	87	0.348	3×10^{20}
GaAs:Si	1.25	6.24×10^{2}	7.8×10^{-2}	<0.2	33330	3.5×10^{3}	2.2×10^{16}
Diamond	0.9	3.6×10^{7}	3.3×10^{3}	<10	130	1.5	1.2×10^{15}

3. Conclusion

The classical Hall measurement system has been completed by a four-point-probe method by employing a relay network for measuring the sheet resistance and then the resistivity of semiconductor layers was calculated. The potential of developed tool was attested by measurement on various types of semiconductor samples and structures.

Acknowledgement

The work has been conducted at the Institute of Electronics and Photonics, FEI STU Bratislava, in the Centre of Excellence CENAMOST (VVCE-0049-07), supported by the grants, APVV-12-345678, project MSMS CR, No. 1M06031, Agency of the Ministry of Education of the Slovak Republic, projects No. VEGA 1/0507/09 and by the Project of International Research Collaboration, SK-PL-0017-09: TU Wroclaw/STU Bratislava.

References:

[1] P. Blood, J. W. Orton: The electrical characterization of semiconductor: Majority carriers and electron states, Academic press, (1992).

[2] R. Kinder et al.: *Journal of Electrical Engineering*, **56**, 268, (2005).

[3] www.ecse.rpi.edu/~schubert/.../A07-Specific-contact-resistance.pdf

[4] T. Ižák, M. Vojs, M. Veselý et al.: *Microelectronics Journal*, **40**, 615, (2009).