Journal of ELECTRICAL ENGINEERING, VOL. 58, NO. 3, 2007, 165–168

COMMUNICATIONS

AN AUTOMATIC MEASUREMENT SYSTEM WITH SPREADING RESISTANCE AND PCIV PROFILING FOR CHARACTERIZATION OF SEMICONDUCTORS

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This article deals with the design and a control program of an automatic measuring system (AMS). The AMS allows to obtain the carrier concentration profile $n(x)$ from the spreading resistance (SRP, with single point probe) and point contact current voltage (PCIV) measurements on a bevelled structure. The software of the AMS contains the possibility of calibration needed for converting the measured data into a carrier concentration profile and graphical subroutines for conversion of the resistivity to concentration. The software of the AMS further permits monitoring of running measurements by SRP and PCIV by LAN networks. The attained results in designing and creating the control program were verified by measuring and determining the carrier concentration profile on selected structures. The experimental $n(x)$ profile has been compared with that calculated by program SUPREM.

K e y w o r d s: spreading resistance, PCIV, Si, SUPREM

1 INTRODUCTION

An organic part of the production technology of electronic components and integrated circuits is diagnostics of the technological process. One of important parameters in the research and development of semiconductor devices is reliable determination of the doping profiles in layered structures. Several methods are used for doping profile measurements. The various measurement techniques can be divided into two groups: analytical and electrical. The first group (doping profile $N(x)$ measurement) includes Secondary Ion Mass Spectrometry, Auger Electron Spectroscopy, Rutherford Back Scattering and others, while the second comprises carrier concentration $n(x)$ measurements, capacitance-voltage, four point probe, spreading resistance, electrochemical capacitance-voltage, differential Hall and others. The most widely used method for electrical profile measurement is the spreading resistance method.

The point contact current voltage (PCIV) method is a modification of SRP technique. This method was developed primarily due to the low resolution of SRP on III-IV semiconductors. The only difference is that these methods use different parts of the I–V curve. While SRP measures the current through the sample at a constant voltage 5 mV, PCIV uses a constant current ($0.5\,\mu$A) and measures the voltage drop between the contacts [1–7].

This paper describes an automatic measuring system. We present a modification of the SRP measuring equipment for PCIV measurements. The results obtained by PCIV method are compared with the results from SRP and with theoretical ones.

2 THEORY

The procedure for calculation of the n(x) profile from the spreading resistance by SRP or PCIV measurement is described in detail in [1–7].

In case the concentration changes with the depth rapidly, as it is the case of diffused and ion implanted structures, it is necessary to introduce a correction of the measured profiles. For one point method the correction factor F is given by equation [5]:

$$R_S = F\frac{\rho}{4a}\,, \tag{1}$$

$$F = \frac{4}{\pi}\int_0^\infty A_N(t)J_1(t)\frac{\sin(t)}{t^2}\mathrm{d}t = \frac{4}{\pi}\int_0^\infty G(t)\mathrm{d}t = \frac{4}{\pi}\sum_{i=1}^{n} Y_i A_N(t) \tag{2}$$

because

$$\int_0^\infty G(t)\mathrm{d}t \cong \sum_{i=1}^{n} w_i G(t_i) = \sum_{i=1}^{n} w_i A_N(t_i) C_i = \sum_{i=1}^{n} Y_i A_N(t_i) \tag{3}$$

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ISSN 1335-3632

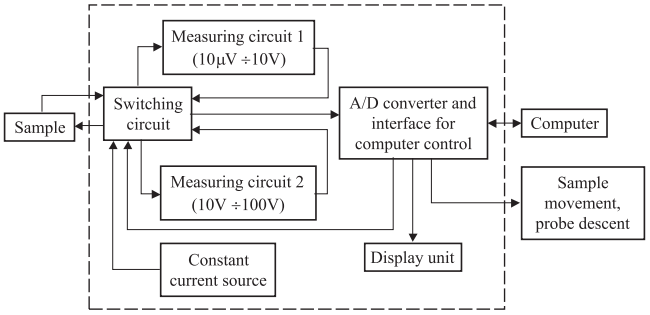

Fig. 1. Block diagram for measurement with SRP and PCIV methods [6].

where

$$C_i = J_1(t_i)\sin(t_i)/t_i^2 \tag{4}$$

and R_S is the spreading resistance, F is the correction factor, ρ is resistivity, a is the effective radius, $A_N(t)$ is an integration factor, $J(t)$ is the current density, t_i is the abscissa, i-th correcting layer, $G(t)$ is the conductivity of the correcting layer, Y_i, C_i, T_i are auxiliary variables, and w_i are weighted factors.

The values of the concentration profile n(x) from the measured values $\rho(x)$ can be obtained from conversion graphics (Irvin curves, for n- and p-type Si). The curves express the mutual dependence between resistivity ρ, mobility μ and concentration n, according to formula:

$$n(x) = \frac{1}{\rho(x)\mu(x)q} \tag{5}$$

For automatic calculation of ρ or n, the value of μ is used as given by empirical formula

$$\mu = \mu_{\min} + \frac{\mu_{\max} - \mu_{\min}}{\left(1 + \frac{n}{n_{\text{ref}}}\right)^{\alpha}}. \tag{6}$$

Here $\mu_{\min}$ and $\mu_{\max}$ are the values of minimal and maximal mobility, n_{ref} is the reference concentration and α is an exponential factor [7].

3 EQUIPMENT AND MEASUREMENT ROUTINE

The SRP measuring system was developed at the Department of Solid State Engineering, Czech Technical University. The system was primarily designed for SRP measurements. The probe is loaded by a weight of 5 g and slowly lowered onto the surface of the sample as gently as possible, using thermal expansion of an electrically heated wire. The probe material (tungsten carbide) is harder than silicon and fractures the silicon surface, leaving visible probe marks. The SRP in term of construction uses single point contact. The ohmic contact with the sample is created by applying GaIn on the both sides of the sample [5]. The modification of this measuring system for PCIV measurements and calculations were carried out on an automated set-up designed and constructed at the Department of Microelectronics, Slovak Technical University, Bratislava [6]. In the collaboration with FIIT STU, Institute of Computer Systems and Networks, the operating program was designed and modified [7].

The automatic measuring system consists of a PC and spread resistance and PCIV equipments. The complete AMS with SRP and PCIV methods are seen in Fig. 1.

The designed and realized operating program for AMS is tailored to experimental specification. The body is the main program, which provides calibration, measurement and processing function of the measured data. Further, it contains a library of user's control, which controls communications with the measuring equipment. The last part is an export library, which carries out the export of the measured data into an arbitrary format for further processing or customized presentation. The detail look at the solution and functions provided by the main program is shown in Fig. 2 [7].

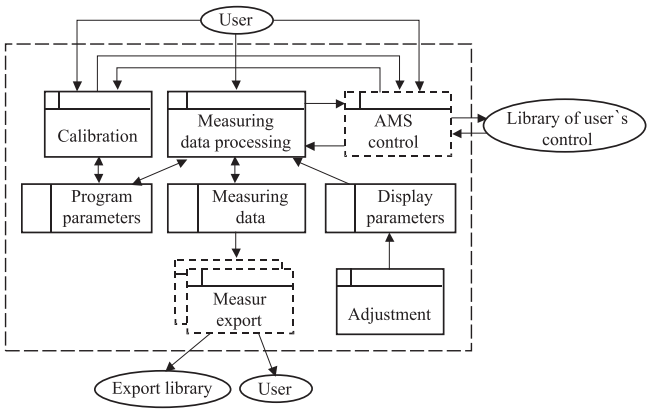

Fig. 2. Flow chart of the main code.

The measurement consists of four steps: start-up of the measuring tip on the sample, measurement of the voltage drop on the sample by choice of PCIV or SRP method, tip up, shift the tip into the next point of measurement. This period is repeated along the bevelled surface of the sample. The measuring data of voltage drops are used for further processing and calculation of the n(x) profile. When calculating the n(x) profile, it is necessary to carry out conversion of the measured data of the voltage drop to spreading resistance data (SRP or PCIV), further conversion of spreading resistance to resistivity, and of the resistivity to the carrier concentration (by Irvin curves, for n- and p-type). In the case of an implanted sample it is necessary to use a correction of resistivity for volume sampling effects. All relations for calculation of the parameters and corrections are described in detail in [5, 6].

The menu driven software AMS insures communication with the measuring equipment, commands its single parts, measurement of the required parameters and

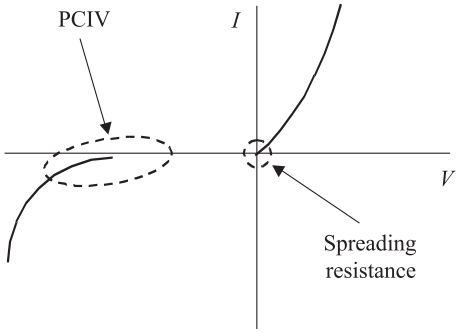

Fig. 3. Comparison of I–V range for SRP and PCIV [2].

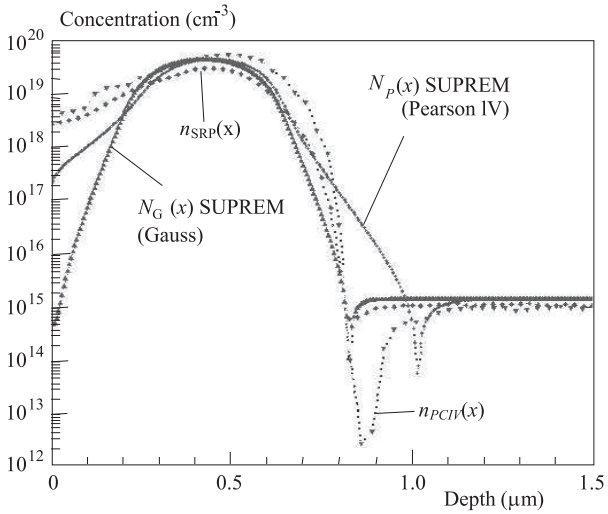

Fig. 4. Doping profile of implanted p^+n sample.

communication with the operating personnel. The operating personnel, by means of the driven software, enters the data needed for the measurement process and then can observe results of measurement in real time on the graph, drown on display. The AMS provides also cooperation with the external program SUPREM. The n(x) profile obtained experimentally can be compared with theoretical ones based on Gauss and Pearson IV distribution (SUPREM) using parameters gained from LSS theory. The software of the AMS permits also monitoring of the running measurement with SRP or PCIV in LAN networks. The program allows exporting the results of measurement into any format, which is defined by export library, giving operating personnel the possibility to present their results in any way (HTML page, picture, data sheet, ...), or to process measured results in another application. Hardware requirements on the control program are based on minimal requirements for used operating system (Windows 9X, 2000, XP) and one free LPT port.

4 EXPERIMENTAL RESULTS

The PCIV method uses the same point contact probes as the SRP technique. However, while SRP measures the resistance at a fixed 5 mV, PCIV measures either the entire I-V curve or the point contact voltage (PCV) at a user defined current. The relationship between I-V measurement ranges of SRP and PCIV is shown in Fig. 3.

PCIV measurements offer a high spatial resolution, a wide dynamic range and the ability to measure the profile right up to the surface. The PCIV method can be used for profiling of shallow structures such as ion implants.

For verification of our modified equipment we made measurements on a Si sample with an implanted layer. The sample was an n-type (100)-oriented substrate with concentration $N_B = 1.4 \times 10^{15}\,\mathrm{cm}^{-3}$. This sample was implanted with $^{11}B^+$ at the energy of 150 keV and dose $1 \times 10^{15}\,\mathrm{cm}^{-2}$. The sample was then activated in N_2 ambient at 930 °C for 30 minutes. The depth of the implanted layer was $0.8\,\mu$m. The bevel angle 0.286° was created using a diamond paste with $0.1\,\mu$m grain size. For PCIV, the measuring current was $0.405\,\mu$A and 70 points were measured on the sample. The measured resistance profiles were then corrected making use of the algorithm for implanted layers correction and converted to doping profiles [5, 6]. For comparison, the sample was measured also by SRP and the doping profile was calculated also by SUPREM. Results are shown in Fig. 4.

From Fig. 4 we see that the profiles measured by PCIV and SRP are almost the same. The depth of the implanted layer determined by both methods is $0.8\,\mu$m. The same depth and profile behaviour is indicated by theoretical results from SUPREM using the Gauss distribution, $N_G(x)$ profile. However, the near surface region of the implanted layer is better represented by Pearson IV distribution, $N_P(x)$ profile, in the theoretical profile. The obtained results with our SRP, $n_{SRP}(x)$ profile and PCIV equipment, $n_{PCIV}(x)$ profile, satisfy the technological parameters of sample.

5 CONCLUSION

Modification of our SRP equipment was presented to allow PCIV measurements. The control program provides the possibility of calibration needed for converting the measured data into a carrier concentration profile, exporting the results of measurement for their processing in Origin or another spreadsheet editor as well as other functions making the operation of the control program and measuring system more efficient. The software of the AMS contains graphical subroutines for conversion of resistivity to concentration and mobility. This technique was used for determination of the doping profile on bevelled silicon structures created using a diamond paste. This modified equipment was calibrated for measurements on silicon and GaAs structure [9, 10]. The results were compared with theoretical results from SUPREM and satisfy the technological parameters of the sample. We have observed good agreement between these results. Further, the advancement of our program compared to the commercial equipment from fy Solid State Measurements, Inc., SSM 150 is that the software of the AMS allows monitoring of

running measurements on the SRP and PCIV by LAN networks and the program allows exporting the results of measurement into HTML sites.

Acknowledgement

This work was supported by a grant of the Slovak Grant Agency Vega, Nos. 1/3111/06, 1/3108/06 and 1/3091/06.

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Received 22 November 2006

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