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COMMUNICATIONS

DETERMINATION OF CARRIER PROFILES ON BEVELLED GaAs STRUCTURES BY PCIV METHOD

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Determination of free charge carrier profiles of GaAs on a bevelled surface by the PCIV is presented. The bevelled structures were prepared by chemical etching. The results are compared with the electrochemical capacitance-voltage technique. Some specific problems concerning of measurement of carrier profiles and calibration PCIV method are discussed.

K e y w o r d s: PCIV, ECV, GaAs, free carrier concentration, bevelled structure

1 INTRODUCTION

The spreading resistance (SR) is the resistance associated with the divergence of current from the probe tips. Shallow bevel angels and lightly loaded probes allow a depth resolution down to 1 nm. The SR method was applied to III-V compounds using the point contact methods. SR measurements (which use the low voltage proportion of the I-V curve) have a limited resolution for III-V materials. An alternative technique was developed for GaAs and compound semiconductors based on analysis of the non-linear regions of the point contact current voltage (PCIV) curve. The PCIV measurements are performed by driving an appropriate current through a pair of point contacts and by monitoring the corresponding point contact voltage. Detailed information about PCIV technique is in [1]. The PCIV technique has found applications in a variety of III-V semiconductors, including $Al_xGa_{1-x}As/GaAs$ [2].

Of great importance for correct measurement of the free charge carrier concentration profile $N(x)$ with SR and probe methods is the quality of the bevelled structures prepared by chemical etching. In contrast to mechanical bevelling, there is neither intermixing of layers during the chemical bevelling process nor damage to the surface and to the interface. Bevelling techniques have been used for sample preparation also in other analytical techniques such as photoluminescence spectroscopy, SR analysis, and Raman spectroscopy. Many authors prepared bevels on III-V structures using a bromine-methanol solution. The bevel angles were mainly in the range of 10^{-3} rad. For GaAs based structures also $NH_4OH/H_2O_2/H_2O$ etchant was used [3, 4, 5, 6].

Carrier concentration profiling with the PCIV method involves calibration of the probes at a preselected current using samples of known carrier concentration. The $N(x)$ profile in the unknown sample is determined by measuring the point contact voltage at the same current used during calibration. The point contact voltage is then converted to carrier concentration using a proper calibration curve. For calibration we used sample with five steps in concentrations of Si in GaAs and measured by ECV technique.

For the measurement of the $N(x)$ profile the electrochemical capacitance-voltage (ECV) method can also be used. This technique is an interesting alternative to more conventional methods because of quick and accurate evaluation of the concentration and depth distribution of carriers in GaAs, Si, InP and in other compound semiconductors. Successful application of this method to a given semiconductor material depends on the availability of an electrolyte which supports a well defined electrochemical dissolution process and forms a Schottky contact. The anodic dissolution behaviour of GaAs in the 0.1 M Tiron depends on a number of factors such as the stripping potential, illumination level, *etc* [7, 8].

This paper describes the determination of $N(x)$ profiles of practically important bevelled GaAs structures by the PCIV method. The bevelled structures were prepared by chemical etching. Optimum measurement conditions for the PCIV method are established. The $N(x)$ profiles obtained by PCVI method are compared with ECV.

2 EXPERIMENTAL

The apparatus for chemical bevel preparation was constructed at the Department of Microelectronics at the Slo-

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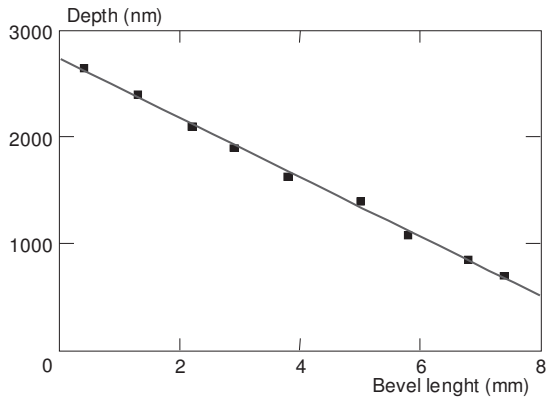

Fig. 1. Depth profile of the bevelled sample

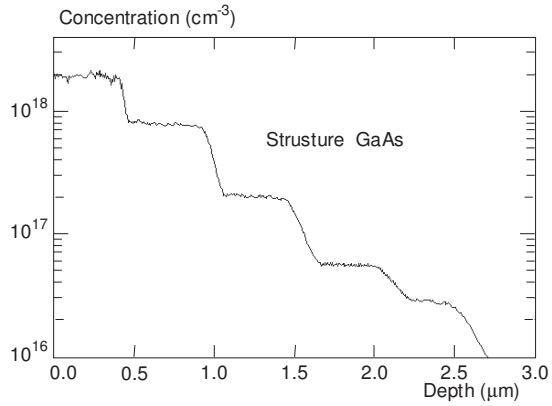

Fig. 2. The $N(x)$ profile step-like GaAs structure by ECV technique measured

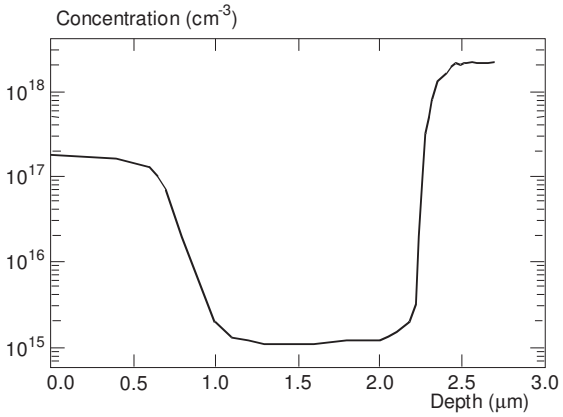

Fig. 3. The profile $N(x)$ by PCIV method measurement

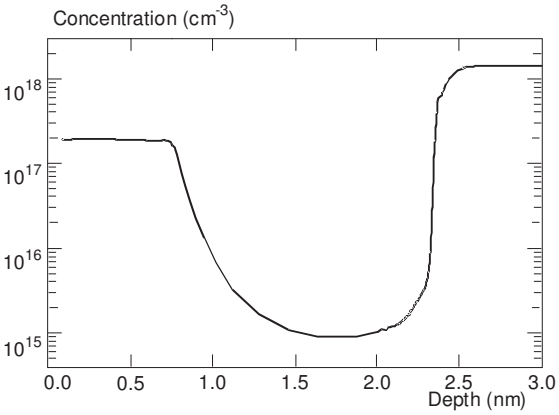

Fig. 4. The $N(x)$ profile by ECV measured

vak Technical University of Bratislava. The rate at which the sample moves is computer controlled, and can be varied depending on the etchant, sample composition and the final shape of the bevel. The sample with the bevelled surface of GaAs structures for PCIV measurements was prepared with this apparatus. The etching bath is prepared and deionized water is dripped slowly onto it until a 10 mm deep layer floats on top of the etching solution. The water layer removes the meniscus from the surface of the etchant where it is in contact with the sample. The experiments were carried out at room temperature using a solution of $H_3PO_4/H_2O_2/H_2O$ [4]. Each sample was prepared first by splitting a section of approximately 4×8 mm, although sizes as small as 3×5 mm have also been used. A part of the sample surface was protected on the long side by either black wax or by a photoresist stripe. The time of bevelling was usually in the range 10–100 s. The bevel profile was evaluated by measuring the step height between the etched and non-etched surfaces in various positions along the bevel using a Talystep profilometer and by 3D-profilometer ZYGO.

For our study by the PCIV method a lightly loaded tungsten carbide probe with diameter $\approx 12\,\mu$m was used which was tracked by a motor down the bevel of a small piece of heterostructure. The probe forms a Schottky barrier in the measured material. The current I^+ or I^- passing through the probe and a broad area back contact can be measured at a voltage plus or minus 0.8 V on the probe. The current was displayed on a chart recorder as a function of distance at the bevel. The current I^+ depends on the doping of individual layers and in each layer of the GaAs structure the currents vary with carrier concentration. They characterize the doping level of each layer. Determination of the carrier concentration directly from the I-V curve is not possible. The carrier concentration of the sample used to develop the calibration curve should be characterized using an independent technique. Therefore, the doping level in our case was obtained from the measurement by ECV technique on calibrated samples with a step-like structure.

The measurement of GaAs structure with a staircase carrier profile was performed by ECV techniques (PN 4100 and PN4300). ECV measurements were conducted using carrier and modulation frequencies of 3 kHz and 30 Hz, respectively. The electrochemical cell with a rubber sealing ring (3 mm in diameter) is generally used in ECV investigations. The measurement parameters are determined by measuring the current-voltage (I-V) and conductance/capacitance-voltage (G/C-V) curves. These curves contain information about the volt-

age magnitudes for etching, V_{etch}, and measuring, V_{meas}. The electrolyte used was a 0.1 M Tiron solution (1,2-Dihydroxybenzene - 3,5 disulphonic acid, disodium salt — $C_6H_2(OH)_2(SO_3Na)_2.H_2O = 332.22$). The values of V_{meas} and V_{etch} voltages were deduced from G/C-V and I-V curves.

Experimental determination of the N(x) profiles with ECV equipment and PCIV method was performed on a sample with n-doped and undoped (buffer) GaAs layers on an n^+ GaAs substrate. The structure was grown by Metal Organic Chemical Vapor Deposition (MO CVD). A 1400 nm thick undoped GaAs buffer layer ($8\times10^{14}\,\mathrm{cm}^{-3}$) was first grown on an (100)-oriented Si-doped GaAs substrate ($2\times10^{18}\,\mathrm{cm}^{-3}$). On this layer, an 800 nm thick layer of Si-doped GaAs ($2\times10^{17}\,\mathrm{cm}^{-3}$) was then grown. The carrier concentration of the layers was determined from the growth conditions of the layers. For calibration measurement of the $N(x)$ profile by the PCIV method, a staircase structure was deposited.

3 RESULTS AND DISCUSSION

Figure 1 shows the depth profile of a bevel prepared on the studied structure. The bevel angle is $\varphi = 2.7\times10^{-4}$ rad. This corresponds to a magnification of 3700 times. The magnification is defined as a ratio of the length along the bevel and corresponding depth into the surface. Surface topography observed using a ZYGO 3D profilometer revealed a good linearity of the bevel slope along the whole bevel length.

The $N(x)$ profile of the staircase structure measured by ECV technique is shown in Fig. 2. The measured $N(x)$ profile is in the range concentration from $1\times10^{16}\,\mathrm{cm}^{-3}$ to $2\times10^{18}\,\mathrm{cm}^{-3}$ and was used for calibration the PCIV method.

The I^+ current profile by PCIV method was on the bevelled surface of the sample measured at voltage +0.8 V. The depth of the bevel profile was evaluated by the above-mentioned procedure. The point contact current is then converted into carrier concentration using the calibration curve. Thus, a positive sample bias (+0.8 V) allowed us to detect the staircase dopant profile and gave good correlation with the ECV data.

A carrier concentration profile of an n n^- n^+ GaAs structure was obtained by the PCIV method (Fig. 3). With the dopant concentration ranging from about $1\times10^{15}\,\mathrm{cm}^{-3}$ to $2\times10^{18}\,\mathrm{cm}^{-3}$, with uniformity ($1\times10^{15}\,\mathrm{cm}^{-3}$) of the n^- layer was clearly demonstrated. The concentration of n^- layer had advanced concentration compared to input technological ($8\times10^{14}\,\mathrm{cm}^{-3}$). The depth of the $N(x)$ profile approximately answered the input technological parameters. The measured PCIV data was found to be noisy on a variety of these structures. Therefore the $N(x)$ profile by PCIV method measurements was at first smoothed to remove the influence of noise. The noise may be due to material nonhomogeneities or to defects in GaAs. The $N(x)$ profile in Fig. 3 shows interfaces of the GaAs structure. By comparison of Figs. 2 and 3 we see good correlation between numerical values of concentration for the substrate and the n-doped layer, determined by ECV method. From Fig. 3 one can be see that the $N(x)$ profile corresponds with technological input parameters.

The carrier concentration profile measured with the ECV technique is shown in Fig. 4. The measured carrier profile corresponds approximately to the above-mentioned technological input parameters. The depth of the bottom of the etched crater was measured by Talystep. We note that the PCIV technique measures right up to the surface, while at the ECV the start of profile measurements depends on the height of the Schottky barrier created between electrolyte-GaAs interface and applied back voltage [9].

4 CONCLUSION

The PCIV method has been presented and it has been demonstrated that this technique can be used to determine the doping profile measured on a bevelled structure prepared by chemical etching. The results obtained by the PCIV method were comparable with the results obtained by ECV technique. The PCIV method offers significantly improved depth and spatial resolutions. Information about the heterojunction such as space charge width is also obtained from PCIV measurements.

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