THE EFFECT OF THE SECOND CONDUCTING CHANNEL IN ALGAN/GAN TYPE HEMT HETEROSTRUCTURES ON THE HALL MEASUREMENTS

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Abstract *This article describes AlGaN/GaN type HEMT (High Electron Mobility Transistor) heterostructures, in which the second conducting channel exists, which exhibits unique dependence of both electron mobility and concentration on temperature. The transverse electric field associated with the classical Hall effect is the source of different electromotive forces in each layer. When a conductive path between 2DEG (two dimensional electron gas) and the GaN layer is created, the current between the layers starts to flow, changing the values of mobility and concentration acquired from Hall measurements. The classical Hall measurements in wide range of temperatures in AlGaN/GaN type HEMT heterostructures provide significant information about conductivity and the influence of the GaN layer.*

Keywords mobility, heterostructures, AlGaN/GaN, HEMT, 2DEG

1. INTRODUCTION

Simplified AlGaN/GaN type HEMT heterostructures [1] fabricated by use of MOVPE (Metal Organic Vapor Phase Epitaxy) in the laboratory of Wroclaw University of Science and Technology are show in Figure 1 [2]. The pressure during the epitaxy of each layer in samples #193 and #194 was the same and equal to 100 mbar, while the pressure during deposition of GaN layer in samples #267 and #273 was changed to 800 mbar and 300 mbar, respectively.

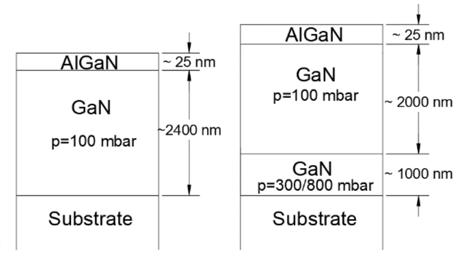

Fig. 1 Simplified AlGaN/GaN type HEMT heterostructures grown on sapphire substrate [2].
On the left - samples #193 and #194, on the right - samples # 267 and #273.

Using a Hall measurement setup, the sheet resistivity, the mobility and the sheet carrier concentration in the heterostructure were determined for each examined heterostructure. The measurements were performed in wide range of temperatures from 77 K to 420 K, what enabled to distinguish two kinds of characteristics. The first one corresponds to samples grown with pressure equal to 100 mbar and the second one corresponds to samples grown at higher pressures of 300 mbar and 800 mbar, respectively. The values of aluminium content in the barrier for each sample was the same and was equal to about 25%, that clearly proved that the the difference is caused mainly by the pressure difference during the growth of GaN layer of the heterostructure.

2. THE FUNDAMENTALS OF VAN DER PAUW AND HALL MEASUREMENTS

The sheet resistivity R_s of each sample was determined using the van der Pauw method [3]. The 2-inch samples were cut into 10 mm x 10 mm square samples, (Fig. 2). On the AlGaN/GaN surface in each corner an indium point contact was deposited and annealed to form an ohmic contact to the semiconductor.

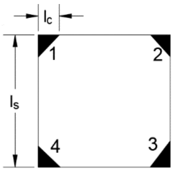

Fig. 2 A van der Pauw structure for the sheet resistivity, sheet carrier concentration and mobility measurements.

A point contact has the shape of a triangle. The length of a contact is l_c, and the length of the sample side is l_s. To obtain sheet resistivity without error, the length of sample side must be at least three times greater than the length of contact size, $l_s > 3l_c$ [4]. The sheet resistivity, R_s, was calculated by solving the van der Pauw equation (1):

$$\exp\left(-\frac{\pi R_v}{R_s}\right) + \exp\left(-\frac{\pi R_h}{R_s}\right) = 1 \tag{1}$$

The vertical resistance R_v and the horizontal resistance R_h were obtained by measuring the voltage and the current in vertical and horizontal directions. It is assumed that the current in *y* direction is equal to zero, the carriers are electrons and all electrons move with the same velocity v. Moreover, it is assumed that the density of the current flow in y direction is independent of the magnetic field (no magnetoresistance is observed). Additional effects, like Nernst, Ettingshausen, Seebeck and others [4] also present in heterostructures, could be eliminated by performing the measurements in both directions of current flow. Comparing the electron velocity in the low electric field regime, $v_x = \mu_H E_x$, with the electron velocity in the presence of the magnetic field, $v_x = E_H B_z^{-1}$, the Hall mobility is therefore equal to (2):

$$\mu_H = \frac{V_H}{R_s I_x B_z} \tag{2}$$

The sheet concentration is derived directly from the definition of square resistivity i.e. (3):

$$n_s = \frac{1}{q R_s \mu_H} \tag{3}$$

3. RESULTS

The Hall voltage and sheet resistivity of AlGaN/GaN type HEMT heterostructures were measured using van der Pauw method in wide range of temperatures from 77 K to 420 K. On Fig. 4 the mobility in function of the sheet concentration is shown. Two characteristic areas of the carrier concentration can be distinguished: area A, where the mobility vs. sheet carrier concentration dependence is more linear, and area B, in which a more complex dependence can be observed. The concentration of electrons in the area A is less than in area B. Moreover, the mobility in low temperature part of area A is significantly higher than in area B. For higher temperatures the mobility in both areas are changing slightly.

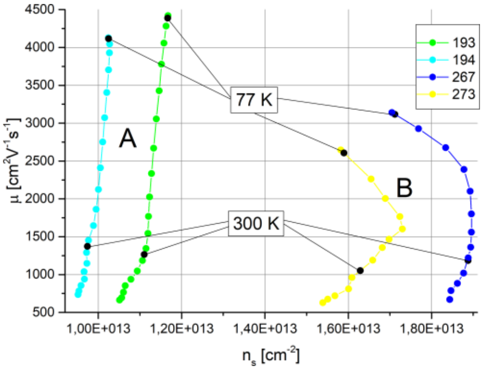

Fig. 4 Sheet carrier mobility in AlGaN/GaN heterostructure vs. sheet carrier concentration at different temperatures. The area A, where the relationship is half-linear, and area B with bend shape of curve, are distinguished.

The samples in area A exhibit one conducting channel of 2DEG forming at the AlGaN/GaN interface. The samples from area B have two conducing channels: first with 2DEG electrons and the second formed at GaN/GaN interface, as a result of the pressure change during the growth.

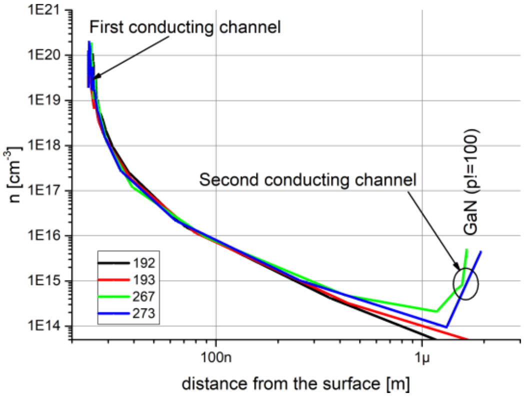

Fig. 5 Carrier concentration profiles measured by use C-V method.

The Capacitance-Voltage (CV) measurements (Fig. 5) showed higher values of electron concentration at GaN/GaNinterface, which are the result of the presence of the second conducting channel. The additional concentration of electrons at GaN/GaN interface is more than three orders of magnitude higher than the free carrier concentration in samples grown with no pressure changes during the GaN layer deposition. 2DEG concentration in the triangular potential well was around $10^{19}\ \mathrm{cm}^{-3}$ and subsequently decreases with the increase of the depth. However in samples #267 and #273 the electron concentration increased to about $10^{16}\ \mathrm{cm}^{-3}$at GaN/GaN interface, indicating the existence of the second conducting channel. The conductivity of the half-insulating GaN layers between channels remains the same for each sample.

4. CONCLUSIONS

In order to evaluate the appropriate values of 2DEG mobility it is essential to involve in the calculations not only the electron concentration n_1 and mobility μ_1, which exist in triangular quantum potential well at the AlGaN/GaN interface, but also the electron concentration n_2 and mobility μ_2, present in the second conducting channel (once it is formed). The Hall measurements of the heterostructures with second conducting channel resulted in lower values of the mobility measured in low temperatures. The basic physical quantities, obtained by the performed Hall measurements at samples in group B, provide the information on both 2DEG and the electrons in the second conducing channel.

Acknowledgement

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