Optica Applicata, Vol. XXXII, No. 3, 2002

Photoreflectance study of AlGaN/GaN heterostructures grown by MOCVD process

ANNA WÓJCIK, TOMASZ PIWOŃSKI, TOMASZ J. OCHALSKI, EMIL KOWALCZYK, MACIEJ BUGAJSKI

Institute of Electron Technology, al. Lotników 32/46, 02–006 Warszawa, Poland.

ANDRZEJ GRZEGORCZYK, ŁUKASZ MACHT, SOUFIEN HAFFOUZ, POUL K. LARSEN

Experimental Solid State Physics III, RIM, University of Nijmegen, Toernooiveld 1, 6525 ED Nijmegen, The Netherlands.

In this paper we report the results of photoreflectance (PR) spectroscopy of GaN/AlGaN heterostructures used for realisation of high electron mobility transistors (HEMTs). For the proper operation of such structures a triangular quantum well created at the interface between GaN and AlGaN is required. Due to quantum confinement in this area 2DEG is created. The data obtained from PR technique allow to estimate a real shape of 2DEG confinement potential, what is necessary for verification of design and correctness of the growth process.

1. Introduction

GaN and its alloys are wide band-gap semiconductors. Their optical and electrical properties allow implementing these materials in modern optoelectronic devices, like light emitters and detectors operating in the blue and ultraviolet wavelength range. Among the electronic devices for high-power and high-temperature operation, one of the most active research fields is AlGaN/GaN high electron mobility transistor (HEMT).

The essential element of an HEMT is formation of the two-dimensional electron gas (2DEG) at the heterointerface (Fig. 1**a**). As suggested by some theoretical studies [1], [2] the existence of 2DEG is due to the piezoelectrically induced charges at the AlGaN/GaN interface. The electrons are ionised from the top of AlGaN layer and then are collected in the potential well at the heterojunction. The two-dimensionally confined electrons can have a high mobility, up to $\sim 10^4$ cm^2/Vs (at 1.5 K) [2]. This value strongly depends on the Al concentration.

A very important aspect of the performance of GaN-based HEMTs is the quality of material. The reported AlGaN/GaN structures have been grown on sapphire. The large lattice mismatch between sapphire and GaN (13.8%) produces material with a high density of threading dislocations. Optical measurement techniques may be used

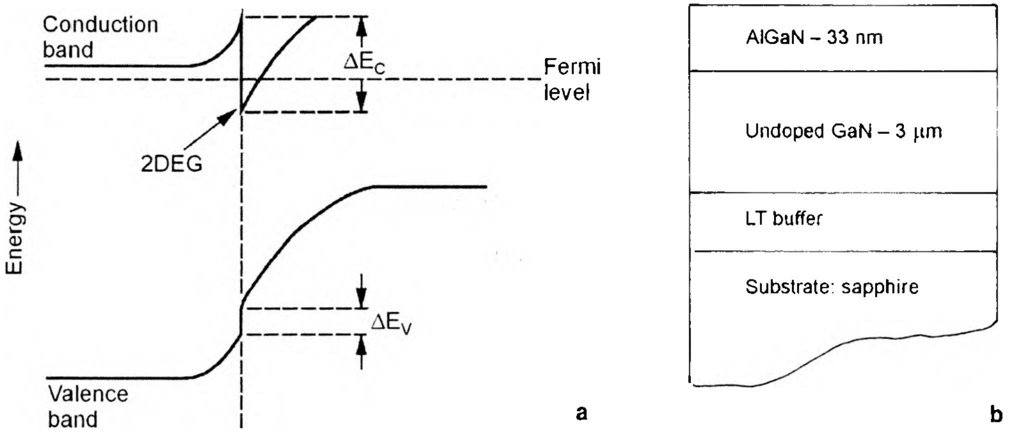

Fig. 1. Energy band diagram of the HEMT showing the 2DEG quantum well channel (**a**) and scheme of investigated AlGaN/GaN structures (**b**).

to characterise the quality of the AlGaN/GaN systems. In this paper we present some results of room temperature photoreflectance [3]. PR technique involves the measurement of reflectance changes induced by electric field, which is modulated by optically generated carriers. This technique is fast and easy to implement (no cooling system is required) and is very functional due to its non-contact and non-destructive character. PR is a method giving average values and that is why it can be used for control homogeneity of composition and thickness. Taking into consideration the fact that PR spectra are composed of derivative-like features, this spectroscopic technique is more pronounced than other optical techniques including PL.

2. Experiment

The investigated structures (Fig. 1**b**) were grown by metalorganic chemical vapor epitaxy (MOCVD). Because of the large lattice mismatch between sapphire and GaN a thin low-temperature buffer layer is deposited on sapphire substrate. The growth of a main GaN layer of a 3-μm thickness was proceeding at the temperature higher than 1100 °C. The designed composition of Al in 33-nm AlGaN layer averages to 20%.

Photoreflectance spectra were collected at room temperature. The monochromatically dispersed light of a quartz-tungsten halogen lamp shined the samples. As a pump light source we used a monochromator equipped xenon 250 W lamp. Such set-up offers certain advantages over laser pump beams. Luminescence, inevitably generated in PR measurements, is always an undesirable effect. Thus, by reducing the power density of the pump beam, the luminescence is limited and we can observe even weak PR features. Additionally, a possibility of continuous tuning of the pump beam wavelength allows finding the maximum of modulation strength adequately for each

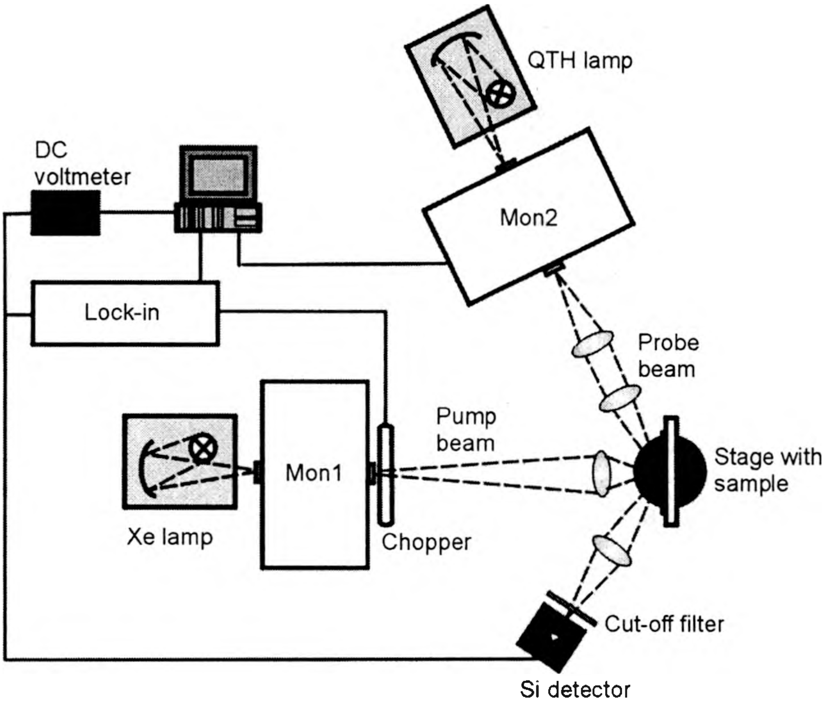

Fig. 2. Scheme of a room temperature photoreflectance set-up.

sample. The reflected light is focussed on a Si-detector and the measured signal is amplified by using a lock-in amplifier. In the same time a constant reflection signal was measured by a digital (DC) voltmeter. The data are collected with a PC as normalised $\Delta R/R$ curves. The transition energies are determined as a fit using Aspnes' first derivative functional form model.

3. Results

Figure 3 illustrates the PR spectra for two samples. Open circles represent experimental data, while the solid line shows results of the fitting procedure. For the first investigated sample (Fig. 3**a**) a photoreflectance GaN signal is found at 3.3987 eV. Higher in energy a signal from AlGaN is visible (3.7645 eV). These values correspond with energy gaps of our alloys. Between these energies we found a signal from 2-dimensional electron gas at two energies of an oscillator, 3.5 eV and 3.6388 eV, which may be interpreted as transitions between 2DEG and the valence band. Data taken on a second sample are shown in Fig. 3**b**. The photoreflectance signals are found at 3.3979 eV and 3.7638 eV, for GaN and AlGaN respectively, and at 3.4951 eV and 3.6333 eV for two levels of 2DEG. The values of AlGaN energy gaps were determined due to the results of the

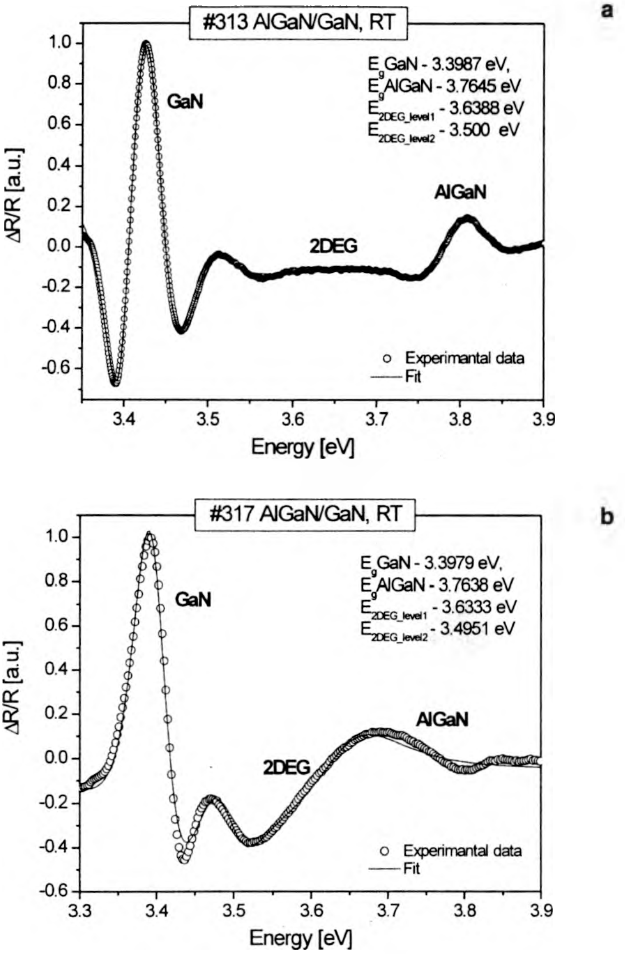

Fig. 3. Experimental data (circles) and results of the fitting procedure (solid line) for two samples (**a**, **b**) of AlGaN/GaN.

fitting procedure. In both investigated samples these values indicate lower (~15%) composition of Al in AlGaN layer than designed [4].

4. Conclusions

The undoped AlGaN/GaN heterostructures grown by MOCVD on sapphire substrate were investigated by the photoreflectance technique. The results confirmed the existence of the 2-dimensional electron gas at the interface of AlGaN and GaN. The values of GaN and AlGaN energy gaps were determined due to the results of the fitting procedure. These values correspond with the data reported in literature. The investigated structures are of a sufficient quality to be implemented in electronic devices.

References

[1] HSU L., WALUKIEWICZ W., Appl. Phys. Lett. **73** (1998), 339.

[2] HO KI KWON, EITING C.J., LABMERT D.J.H., SHELTON B.S., WONG M.M., ZHU T.G., DUPUIS R.D., J. Appl. Phys. **90** (2001), 1817.

[3] POLLAK F.H., *Modulation spectroscopy of semiconductors and semiconductors microstructures* [In] *Handbook of Semiconductors*, [Ed.] T.S. Moss, Elsevier, Amsterdam, Oxford 1994.

[4] OCHALSKI T.J., GIL B., LEFEBVRE P., GRANDJEAN N., LEROUX M., MASSIES J., NAKAMURA S., MORKOC H., Appl. Phys. Lett. **74** (1999), 3353.

Received May 13, 2002