ELECTRICAL AND PHOTOELECTRICAL CHARACTERIZATION OF DEEP DEFECTS IN CUBIC GaN ON GaAs

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Abstract

Nominally undoped cubic GaN epilayers deposited by rf-plasma assisted molecular beam epitaxy on semi-insulating GaAs substrates were investigated by electric and photoelectric spectroscopical methods. As a consequence of the existence of deep levels in the GaAs-substrate itself, special care has to be taken to separate the contributions of the substrate from that of the cubic GaN epilayer in the various spectra. Two different contact configurations (coplanar and sandwich structures) were successfully used to perform this separation. In the cubic GaN epilayer a trap with a thermal activation energy of (85±20)meV was found by thermal admittance spectroscopy and thermal stimulated currents. Optical admittance spectroscopy and photocurrent measurements furthermore revealed defects at E_G-(0.04-0.13) eV, E_G-(0.21-0.82) eV and two additional deeper defects at 1.91 Ev and 2.1 eV, respectively. These defect related transitions are very similar to those observed in hexagonal GaN.

Introduction

Cubic GaN layers grown on GaAs are of high interest for production of devices such as cleaved fabry perot type blue cavities using the substrate facets /1/. Furthermore, reaching very high p-type doping levels is feasible for cubic GaN /2/. However, for all applications based on cubic GaN the exact knowledge of defects in the layers is essential for optimization of devices. Therefore, intensive investigations on defects in GaN grown with MBE on semiinsulating (SI)-GaAs substrates were made with photoluminescence (PL), cathodoluminescence (CL) and temperature dependent Halleffect measurements (TDH). Some donor-acceptor-pair transitions were found in PL at 3.15eV /3/ involving a donor at 25meV and an acceptor at 130meV, as well as at 3.178eV and 3.056eV /4/. An acceptor bound exciton transition at 3.088 /4/ involves an acceptor at an activation energy of 212meV. In p-type undoped c-GaN grown under N-rich conditions an acceptor at an activation energy of 0.445eV was observed with TDH /5/, whereas in n-type undoped c-GaN-layers grown under Ga-rich conditions a shallow donor at an activation energy of 26meV and an deep donor at an activation energy of 0.6eV were found /5/. A further deep CL peak was observed at 2.4eV in undoped c-GaN /1/.

However, the electrical and photoelectric characterization of cubic GaN /SI-GaAs involves some principle problems. SI-GaAs itself contains many deep levels which must be isolated in the GaN/GaAs heterostructure spectra, complicating the analysis of the GaN layers.

The aim of our works is the detection and isolation of deep levels in n- and p-type GaN layers and to separate them from the defects in the SI-GaAs substrate using thermal and photoelectric techniques by using different contact arrangements and different excitation energies.

Experimental

Cubic GaN (c-GaN) films with a phase purity better than 99.9% (estimated by both X-ray diffraction and Raman measurements) were grown on SI-GaAs substrates orientated in (001) direction by rf-plasma-assisted molecular beam epitaxy (MBE) at a substrate temperature of 720°C. Details of the nucleation process and growth parameters were described in /6/. All samples were nominally undoped. However, in c-GaN the type of conductivity can be influenced by the growth conditions and both p- and n-type GaN layers with low carrier concentrations were obtained /5/. Three different kinds of GaN- layers were investigated. 1.) The first group were nominally undoped p-type GaN-layers with carrier concentrations of (1-5)x10^{16}cm^{-3} and Hall mobilities between 220 and 300 cm^2/Vs (samples signed as P1 and P2), 2.) an nominally undoped, p-type GaN- layer on top at a p-type GaAs buffer layer (signed B1), and 3.) n-type GaN layers, nominally undoped or slightly Si-doped with carrier concentrations below 10^{14}cm^{-3} and mobilities of a few 100cm^2/Vs (signed as N1 and N2). The SI-GaAs substrate is identical for all heterostructures investigated.

Ohmic contacts were prepared on SI-GaAs after cleaning and chemically etching by evaporating the layer system Ni(5nm)/Ge(20nm)/Au(50nm) and subsequent annealing (see also /7/). On the GaN-surface the contacts was realized by evaporating of Al and followed by annealing for ohmic and a sputtered Pt layer for Schottky contact. In coplanar contact arrangement the ohmic as well as the Schottky-contact are on the GaN surface whereas the sandwich measurements were performed between the ohmic contact on the GaAs substrate and the Schottky contact on the GaN side. All Schottky contacts show rectifying behavior up to a frequency of 100kHz. The contacts on the GaN layer have a diameter of 1 mm.

The samples were characterized by thermal admittance spectroscopy (TAS), thermal stimulated currents (TSC), by DC-photocurrent spectroscopy (PC) and by optical admittance spectroscopy (OAS). The measurements were made in the temperature range from 80K to 450K. The admittance investigations were realized in the range of modulation frequency between 20Hz and 1MHz. The optical excitation in TSC measurements was performed with a laser at a wavelength of 675nm and a mercury-tungsten-lamp with an optical band pass filter ((330±30)nm).

OAS and PC investigations were performed in the wavelength region from 300nm to 3000nm using monochromator systems with Xe-lamp and W-lamps. The OAS and TAS experimental technique and the evaluation methods are described in detail elsewhere /8/. Furthermore, the use of OAS and PC to evaluate defect transitions in hexagonal GaN layers is described in /9/. Details for the investigation of defects in hexagonal GaN using TAS are given in /10/ and in /7/ for TAS and TSC investigations of GaAs.

Results and Discussion

Fig. 1 shows TAS spectra of the sample P2 measured in sandwich and coplanar contact arrangements. The main defect L1 with E_A=(530±30)meV in the spectrum of the sandwich arrangement is probably the well known deep level EL3 in the GaAs substrate /7/.

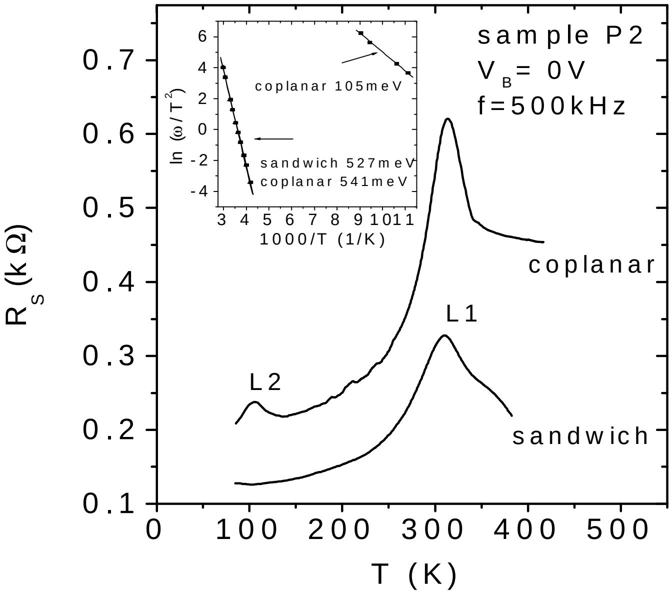

Fig. 1 : TAS spectra of the sample P2 in coplanar and sandwich contact arrangement. The corresponding Arrhenius plots are shown in the insert.

However, a further peak L2 at 100K with a thermal activation energy of (105±15) meV exclusively shows up in coplanar contact arrangement. Thus, we conclude that this defect L2 is located within the GaN layer. In another sample a level with an activation energy of (89±20)meV was observed by TAS in coplanar contact arrangement in the same temperature range.

For the separation of the deep levels we also performed TSC measurements with different excitation energies while the GaN layer is excited by UV-light with a wave length of (330±30) nm, a laser at 675nm mainly stimulates the GaAs substrate (low absorption coefficient in the GaN-layer). A comparison of both TSC spectra in Fig. 2 shows, that the defect level at about 120K with E_A= (85±15) meV only appears after UV-excitation. Therefore, we conclude that this level is located within the GaN layer and is the same trap L2 found with TAS as mentioned above.

In our photoelectrical measurements (OAS, PC) the deep levels in the GaAs substrate were detected also. However, the spectral ranges of the transitions in GaAs and GaN were well distinguishable as shown in Fig. 3. The relative signals from the GaAs substrate and from the GaN layer could be changed by using sandwich or coplanar contact arrangement similar as in the case of TAS measurements. The OAS spectrum of a sandwich arrangement were dominated by the near band gap peak (NBG) of the GaAs substrate. But using coplanar contacts the GaN spectrum exhibited more features and some additionally transitions stemming from the GaN layer, which were hardly observed in the sandwich structure.

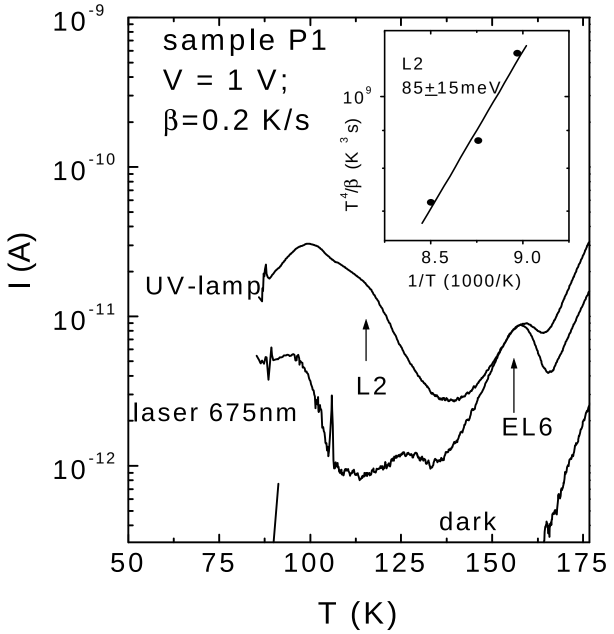

Fig. 2 : TSC spectrum of sample P1 with different light excitations (UV-lamp and 675nm laser). The inset shows the Arrhenius plot of the UV-induced trap.

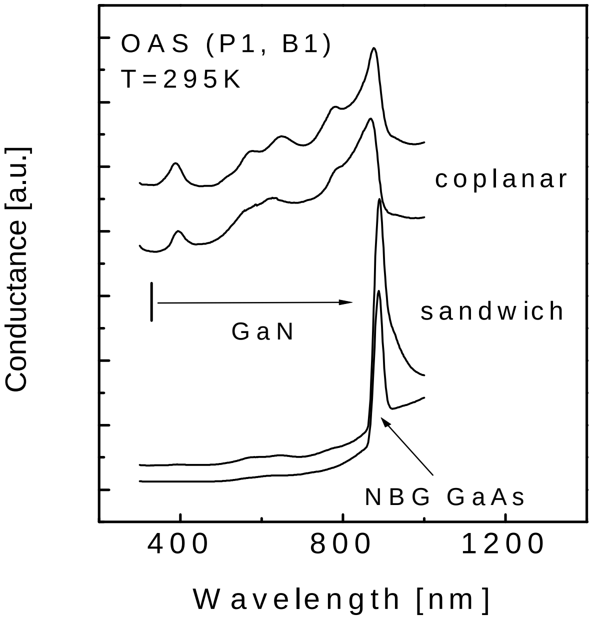

Fig. 3 : OAS spectra of the samples P1 and B1 in sandwich and coplanar contact arrangements.

Fig. 4 gives an example of the OAS spectrum of the sample P2. For the GaN samples P1, P2 and B1 all defect-band-transitions found were summarized in Table I.

In the near band gap region transitions involving shallow levels up to E_G-130meV appear which are comparable with the defects measured by TAS and TSC. Furthermore, the band between 3.0 and 2.2eV consist of deep level-opposite band- transitions and is adequate to the “blue band“ in hexagonal GaN /9/. Some of these deep levels were also detected by PL - measurements (see /4/ and /5/). The yellow band at 2.1eV and the 1.9eV band show the existence of very deep levels.

Table I : Summary of defect -band-transitions of cubic GaN/ SI-GaAs heterostructures found with OAS and PC at room temperature. A value of 3.23eV was assumed as the gap energy at 295K /11/.

E_{ph} (eV)	designation	interpretation	references
3.1 -3.2	near band gap (NBG)	E_G-(0.04 - 0.13)	130meV acceptor /3/
3.3 - 2.5	blue band (BB)	E_G-(0.21±0.03)	212meV acceptor /4/
		E_G-(0.33±0.03)	
		E_G-(0.57±0.05)	0.6eV donor /5/
2.41 - 2.44 and 2.15 - 2.18	yellow band (YB)	E_G-(0.82±0.05) yellow band	2.4eV CL-peak /1/, /12/
1.9 - 1.94	deep defect-band transition (DB)	deep defect	

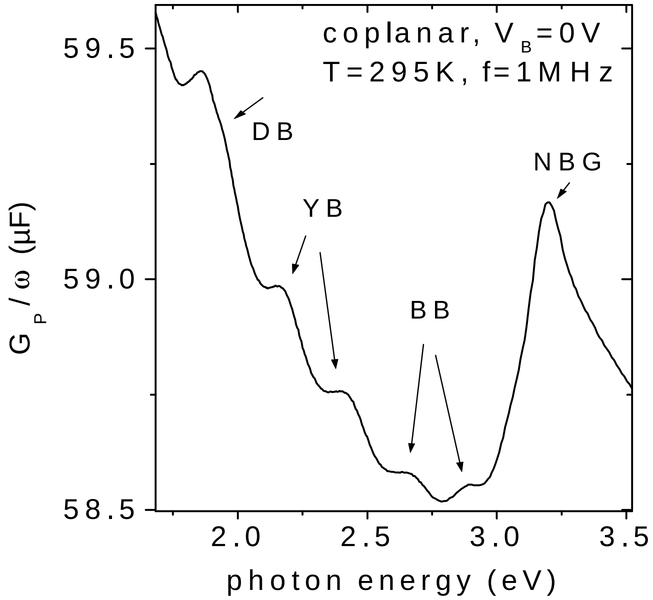

Fig. 4 : OAS spectrum of sample P2 in coplanar contact arrangement (the transition energies are listed in Table I). The meaning of the abbreviations is: NBG near band gap region: BB blue band region: YB yellow band region; DB deep defect-band transition.

It is important to note, that the OAS spectra of cubic GaN were very similar to those of hexagonal GaN as described in /9/. The spectral features in both crystallographic phases of GaN were nearly the same, only the optical transition energies were lightly shifted. We therefore conclude, that the origin and the formation mechanism of the deep defects in cubic GaN are similar to those in hexagonal GaN layers. This is further supported by DLTS measurements on hexagonal GaN by FANG et al. /13/ how reported DLTS traps similar to those seen here, especially in the 0.2eV range. However, due to the phase purity of our sample, which is better than 99.9% and the optical shift to lower energies, we can exclude that the traps are generated by the h-GaN component.

In conclusion, we have investigated nominally undoped cubic GaN layers grown by rf-plasma assisted MBE on SI-GaAs using thermal and optical admittance spectroscopy (TAS and OAS) and thermal stimulated currents (TSC) measurements. By comparing coplanar and sandwich contact arrangements we could separate the GaAs-substrate related defects from the defects in the cubic GaN epilayer. Although in TAS and TSC the deep levels of the GaAs substrate (EL2, EL3 and EL5) are observed in all spectra, a defect with a thermal activation energy between 85meV and 105 meV can clearly be located in the cubic GaN films. OAS measurements showed defect-to band transitions in a wide range of transition energies. Besides two deep defects at 2.1 eV and 1.9 eV, defects in the range of E_G-(0.21-0.82)eV and shallower defects at E_G-(0.04-0.13) eV were also observed. The OAS-spectra of cubic GaN layers were very similar to those of hexagonal GaN, indicating the same nature of defect formation mechanism.

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