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Influence of doping level on shift of the absorption edge of gallium nitride films (Burstein-Moss effect)

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ABSTRACT

In this ellipsometric study it was revealed possibility of observation of the absorption edge shift and changing of its slope for gallium nitride films doped by silicon. It seems to be attractive to connect specific features of Burstein-Moss shift with structural and electrical properties of films of gallium nitride in future. As well known the Burstein-Moss effect occurs when the carrier concentration exceeds conduction band edge density of states, which corresponds to degenerate doping in semiconductors.

1. Introduction

Last several decades, the study of physical properties of thin films of nitrides is a hot topic for many investigators over the world and there are lots of publications in this field. GaN and related III–V nitride materials have been investigated for various applications in electronic and optoelectronic devices and high-power and high-temperature electronic devices. When doped with a suitable transition metal such as manganese, GaN becomes a promising spintronics material (magnetic semiconductors). The mixtures of GaN with indium (InGaN) or aluminium(AlGaN) with a band gap dependent on ratio of Indium or Aluminium to GaN allows the manufacture of light-emitting diodes (LEDs) with colors that can go from red to blue [1]. Second generation technology with shorter gate lengths will be addressing higher frequency telecommunication and aerospace applications.

The main aim of present study is to focus on possibility of contactless ellipsometric measurements for characterization changing of zone structure doped semiconductors thin films used in today electronics. Earlier for doped semiconductor thin films, correlation dependences on band gap were already obtained for the following electrical parameters: carrier concentration, its mobility and resistivity [2]. Therefore in future, it would be possible to prognosticate electrical properties if the optical measurements have been got only. Ellipsometry is proposed as method involved in this problem. In this paper technological features of thin film deposition by ammonia MBE are not discussed because these questions will be considered in next publication where obtaining of high level of doping in GaN:Si will be described in details. The equipment and technique were used the same as mentioned in [3–5].

2. Actuality of study. Experimental structures

Gallium nitride is a binary III–V direct bandgap semiconductor. The compound is a very hard material that has a Wurtzite crystal structure. Its wide band gap of 3.4 eV affords it special properties for applications in optoelectronic, high-power and high-frequency devices. Its sensitivity to ionizing radiation is low, making it a suitable material for solar cell arrays for satellites. GaN is a very hard, mechanically stable semiconductor material with high heat capacity and thermal conductivity. Because GaN transistors can operate at much hotter temperatures and work at much higher voltages than gallium arsenide (GaAs) transistors, that make them ideal material for power amplifiers at microwave frequencies.

Effect of shift of absorption edge due to doping of semiconductor was simultaneously revealed by E. Burstein and T. Moss in 1954 year [6]. In nominally doped semiconductors Fermi level lies above the donor states, just below the conduction band. As you increase the doping concentration, more and more donor states are produced which pushes Fermi level higher in energy and in the case of degenerate level of doping, Fermi level lies inside the conduction band above the occupied donor states as shown in Fig. 1.

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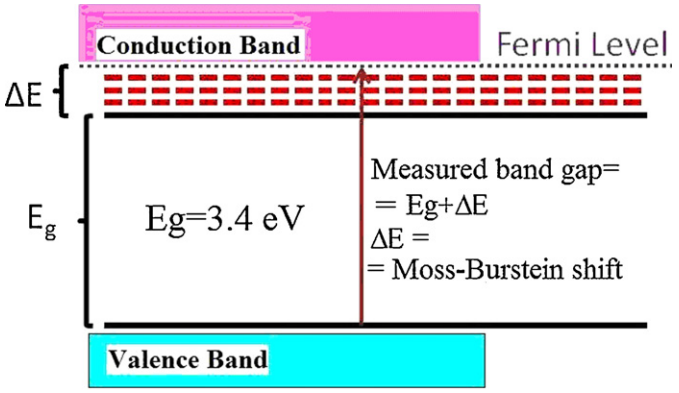

Fig. 1. Schematic diagram of the Moss-Burstein effect.

In the case of degenerate semiconductor measured band gap is equal to sum of actual band gap plus Moss-Burstein shift [7].Our structures were grown on sapphire substrates by ammonia MBE; thickness of layers and their composition are shown in Table 1. Back side of Sapphire substrate was specially ground to eliminate of reflecting of light. Gallium nitride layers have been doped by 10^{19} donor atoms of Si per cubic centimeter up to the following values: (1)–the intrinsic carrier (2)–0.3; (3)–1.2; (4)–5.5; (5)–12. The intrinsic carrier concentration for gallium nitride depends on temperature [8]. Ellipsometric measurements were carried out using UVISEL-Spectroscopic Phase Modulated Ellipsometer (JobinYvon-Sofie) in the range of photon energies 1.5–4.75 eV; incidence angle of light was constant and equaled to 69.3°.

2.1. Technique of band gap measurements

As a rule the band gap of semiconductors can be measured using absorption spectroscopy. These measurements are based on Bouguer–Lambert law $I = I_0\exp(-\alpha d/\lambda)$ and knowledge of layer thickness is needed. However, Pino et al. [2] demonstrated calculation of the band gap obtained from the transmission measurements (using Fourier transform infrared spectrometer) as well as the calculated from the electron probe microanalysis data by using equation, which describes the band gap for triple alloy as linear function of sum of the band gaps with account of mole fraction, x, of every component, plus quadratic constant of $x: E_G[(GaSb)_{1-x}(InSb)_x] = (1-x)E_{G(GaSb)} + xE_{G(InSb)} - x(1-x)C$, where E_G means band gap of corresponding component noted in brackets.

2.2. Experimental finding of absorption edge position

In our case transmittance was measured for each of all multilayer structures, due to difficulties of the growth of more simple structure: gallium nitride-sapphire. Taking into account of above mentioned restrictions, the absorption edge positions (values close to band gap) inGaN: Si were extracted from transmittance spectra and are shown in Fig. 2. Donor concentrations of Si in the doped layers were determined by using Hall Effect in semiconductors. It needs to be noted that AlN layer is transparent in the range of transmittance measurements and itexerted negligible influence

Table 1
Composition and thickness of layers in the studied structures grown on the sapphire substrate by ammonia MBE.

GaN:Si	1000 nm
$Al_{0.28}GaN$	200 nm
AlN	200 nm
Al_2O_3	430 μm

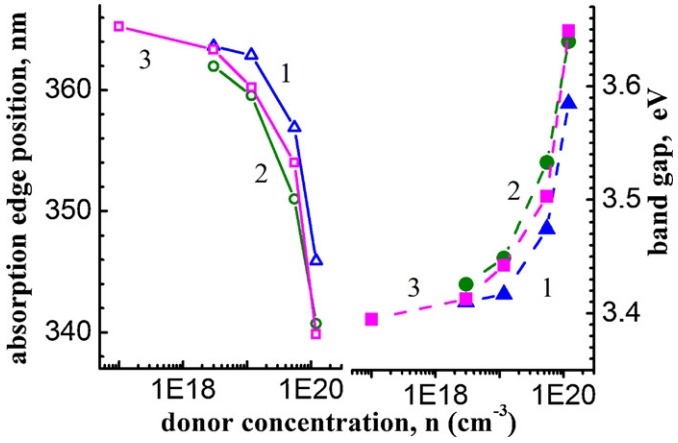

Fig. 2. Absorption edge position in GaN:Si via concentration of donor extracted from $T(\lambda)$ –transmittance spectra: (1)–as derivation of $\partial T/\partial\lambda$ and (2)–as wavelength at 0.01 T, i.e. as the wavelength at which the transmittance is reduced in 100 times; (3)–the same values extracted from imaginary parts of dielectric function (ellipsometric spectra) as middle of linear part of ε_i.

on our measurements. The $Al_{0.28}GaN$ layer is almost transparent and its influence was also insignificant as shown in Fig. 3. However, it should be noted that this effect increases with decreasing wavelength, in according with Fig. 3.

3. Results: ellipsometric spectra of doped gallium nitride

All ellipsometric spectra shown below are spectra of real and imaginary parts of pseudo-dielectric function. It means that dielectric functions were calculated without taking into account of multilayer structures of samples and by substituting on semi-infinite substrate instead of real samples. Obviously, that the light reflected from samples changes its intensities due to interference effect in region when all layers are almost transparent but they differ each from other in refractive indexand besides, the difference between AlN and GaN (as shown in Fig. 3) plays more important role.

Ellipsometric spectra of dielectric function of GaN: Si-Al_xGaN-AlN structures grown on Sapphire substrate clearly show modification of optical properties in transparent range of all of these films and shift of absorption edges as a result of n-type doping.

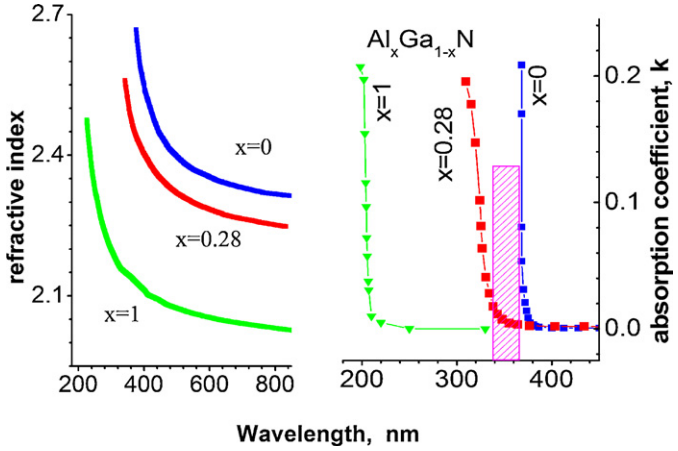

Fig. 3. Spectral dependences of refractive indices and absorption coefficients for GaN ($x = 0$), AlN ($x = 1$) and $Al_{0.28}GaN$ [9]. The range of found values of absorption edges positions of doped samples are noted by rectangle.

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