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Distinctions of the growth and structural-spectroscopic investigations of thin AlN films grown on the GaAs substrates

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ABSTRACT

Using X-ray diffraction analysis, atomic force microscopy, IR and UV spectroscopy, the properties of thin aluminium nitride films (< 200 nm) that were obtained by ion-plasma reactive sputtering on GaAs substrates with different orientations were studied.

The films of aluminium nitride can have a refractive index within the range of 1.6–4.0 for the wavelength band around ~250 nm and an optical band-gap of ~5 eV. It was shown that the morphology, surface composition and optical functional characteristics of AlN/GaAs heterophase systems can be controlled owing to the use of misoriented GaAs substrates as well choice of the technological parameters used for the film growth.

1. Introduction

Currently, researchers and technologists developing materials for dielectric coatings that are optically transparent in a wide wavelength range most often focus on aluminium nitride [1–4], and there are certainly a lot of reasons to accept this idea. AlN is a wide gap semiconductor (E_g ~ 6 eV) with a high thermal conductivity and a small coefficient of thermal expansion. It is characterised by excellent thermal and chemical stability, very good piezoelectric properties and high-speed propagation of acoustic waves. Moreover, it exhibits good compatibility with the other III–V compounds chosen as substrates, making aluminium nitride the most promising material for production of optical, optoelectronic, high-frequency electroacoustic devices and sensors in solar power engineering as well as in sensor design [5–8]. Moreover, in the last 15 years there have been a number of works where oxidised aluminium nitride (AlNO) is widely used in various medical applications [9].

There are numerous methods for obtaining aluminium nitride. Many reports in the scientific literature are concerned with the growth of AlN using chemical deposition methods, epitaxy from organometallic compounds, molecular beam epitaxy, laser ablation, reactive ion-plasma sputtering and reactive magnetron sputtering. It has been demonstrated in many publications that the growth of polycrystalline films of aluminium nitride on substrates of a large area is possible using different methods at rather low temperatures (< 200 °C). It should also be noted that the main material used as a substrate in the processes of AlN deposition is silicon (Si), which is not surprising [7,8,10–12].

It is well known that the physical properties of aluminium nitride films considerably depend on the crystallographic orientation. This parameter, in turn, depends on the parameters and growth modes of these films. Furthermore, aluminium nitride can be crystallised in two different modifications (crystal structures): cubic one (sphalerite) and hexagonal one (wurtzite). The atomic structure of the end material is dependent on dimensional factors (thick or ultra-thin film, nanowires/columns, nanoclusters, etc.) [13–17], which means that by decreasing the dimensions towards the nano range, as well as by using different methods of growth, one can obtain different and important/useful physical properties of AlN [10,11]. Although textured and/or crystalline thin films of aluminium nitride with wurtzite symmetry can be obtained rather easily by applying different methods, synthesis of cubic aluminium nitride in the form of thin nanocrystalline films is much more difficult. According to our research, there are very few reports concerning the growth of AlN in the form of thin films with a zinc blende structure. Besides, we could not find any work related to the changes of the structural, morphological and optical properties of nitride aluminium films as a result of the growth on differently oriented substrates. In our opinion, this seems to be very interesting since the growth of AlN just as of Al_2O_3 deposited as dielectric antireflecting coatings on the mirrors of the Fabry–Perot resonator in the powerful semiconducting lasers proves to be very prospective way of application for aluminium nitride. Taking into account that misoriented substrates are often used in epitaxial

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growth technology for production of the devices that are used as optoelectronic component bases, investigations of the physical properties of aluminium nitride depending on the method of production as well as on crystallographic orientation of a substrate are rather important [18].

Thus, the purpose of the work is to investigate the features of the growth of nano-profiled AlN thin films on differently oriented GaAs substrates as well as the changes in their physical properties using structural-spectroscopic methods.

2. Objects, technology and methods of investigations

Thin films of aluminium nitride were obtained on GaAs (100) substrates with the use of ion-plasma sputtering technique. In this case, the aluminium target was pounded by nitrogen ions in the plasma of ultrapure (99.999%) nitrogen without the addition of argon. To deposit a dielectric film of AlN on the sample, optimal ratios between the potentials of cathode, anode, target and substrate of the sample were chosen as well as the pressure of nitrogen within the working chamber of the installation in order to get a stable burning plasma. The operating pressure in the chamber varied within the range of 3–5 $\times 10^{-3}$ Torr. The substrate of the sample during the deposition process was warmed up to 200–250 °C.

The formation of the dielectric film has several steps: a) formation of aluminium nitride on the surface of a target with the subsequent knocking out of nitride molecules from the surface of the target with gas ions (nitrogen), and, next, deposition of the nitride molecules on the surface of the sample; b) knocking-out of the target atoms with gas ions followed by their binding with the gas atoms within the inter-electrode space; c) deposition of the target atoms on the substrate of the sample followed by interaction with the gas molecules on the substrate surface; and d) deposition of the target atoms in the form of metallic aluminium. One can change the ratio between the contributions of ≪ a ≫ , ≪ b ≫ , ≪ c ≫ and ≪ d ≫ in the resulting process, thus changing composition and properties of the deposited dielectric film, by varying the following process parameters: cathode current, potentials of the anode, target and substrate of the sample, temperature of the substrate, pressure of the working gas in the chamber, and purity and composition of the plasma-forming gas. The main difference in the considered technological processes is the concentration level of residual oxygen at the initial time of deposition of the dielectric film on the substrate of the sample.

Technological distinctions in the growth of samples as well as the calculated values are presented in Table 1. One should note that in our work we applied two types of GaAs substrates to obtain aluminium nitride. Three samples were obtained on GaAs (100) with a precise orientation in the [100] direction, while one more sample was obtained on a misoriented GaAs (100) substrate (misorientation was 4° relative to the [110] plane).

The concentrations of the elements in the films were determined by X-ray microanalysis technique with the use of Oxford Instruments attachment on the JEOL JSM-6510LV electron microscope.

Structural diagnostics of the obtained AlN/GaAs samples was performed by X-ray diffraction with the use of a DRON 4-07 diffractometer using the characteristic radiation of cobalt. To get higher counts by detector of the XRD machine, the incidence angle (α) of primary beam was set as 4° with respect to film surface. At the secondary side, along soller slit was used to limit the radial divergence to 0.15°. The study of the surface quality of the structure was performed with the use of an atomic force microscope produced by NtMDT Company.

The optical properties of AlN/GaAs heterophase structure were studied within the range of 190–900 nm by UV-spectroscopy using a LAMBDA 650 spectrometer produced by Perkin Elmer Company, supplied with a universal reflection attachment URA, which makes it possible to obtain reflection spectra within the range of the incidence angles from 8° to 80°. In addition, the operating scheme of the attachment allows the absolute reflection to be obtained. Reflection spectra were obtained at different incident angles within the range of 8–67°.

The properties of the obtained films of aluminium nitride in the IR range of spectrum were studied with the use of a Vertex-70 Bruker IR-spectrometer with total reflection and attenuated total internal reflection attachments.

Table 1
Technological distinctions in the growth of samples as well as the calculated values.

Sample	Substrate type	Technological distinctions
190	GaAs (100)	Calculated refractive index – 1.941 Pretreatment of the sample – non Clean environment for Al target- Ar (99.999%) (only) The working gas – N_2 (99.999%) Sputtering stages – 1 The deposition rate – 4.6 nm/min. Film thickness – 113.8 nm $\pm$ 10 nm The size of crystalline (calc. using XRD data) – 3.5 nm
191	GaAs (100)	Calculated refractive index – 2.500 Pretreatment of the sample – non Clean environment for Al target- Ar (99.999%) (only) The working gas – N_2 (99.999%) Sputtering stages – 1 The deposition rate – 6.6 nm/min. Film thickness – 190.0 nm $\pm$ 10 nm The size of crystalline (calc. using XRD data) –3.5 nm
192	GaAs (100)	Calculated refractive index – 1.782 Clean environment for Al target- Ar (99.999%) (only) The working gas – N_2 (99.999%) Sputtering stages–1 The deposition rate – 6.6 nm/min. Film thickness – 131.5 nm $\pm$ 10 nm The size of crystalline (calc. using XRD data) – 3.5 nm
145	GaAs (100) with 4° misorientation toward [110]	Calculated refractive index – 2.016 Clean environment for Al target- Ar (99.999%) (only) The working gas – N_2 (99.999%) Sputtering stages – 1 Pre-heating the sample up to the 350 °C, 50 minutes annealing at 350 °C. The deposition rate – 5.5 nm/min. Film thickness – 109.0 nm $\pm$ 10 nm The size of crystalline (calc. using XRD data) – 2.7 nm

3. Experimental results and discussion

3.1. Phase analysis

Using an X-ray microanalysis attachment to the electron microscope, the concentrations of the elements in the films were determined for the studied samples. For analysis, a voltage of 20 kV was applied to accelerate the electrons in the beam and the investigated areas of the samples were 0.75 $\times$ 0.75 mm. Experimental data demonstrated that the film was composed of aluminium ($\sim$50 at.%) and nitrogen ($\sim$50 at%). It should be noted that according to the experimental data, a small amount of oxygen (<1 at%) was observed. It means that the the presence of oxygen