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Optical properties of AlN layers obtained by magnetron sputtering

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The growth of AlN layers on glass substrates using magnetron sputtering method was performed and the grown layers were subjected to optical measurements. Transmission spectra of the layers grown at different content of N_2 in the atmosphere were obtained. The transmission spectra as well as energy gap depended on N_2 content. The annealing of the layers in air led to transmission changes and influenced energy gap and refractive index values.

Keywords: *optical properties; thin films; AlN*

1. Introduction

Aluminum nitride (AlN) films have promising physical and optical properties, including high thermal conductivity [1, 2], high breakdown dielectric strength, high breakdown voltage, good chemical stability, high electrical resistivity [3], excellent piezoelectricity [4], fast acoustic velocity [5] and a wide band gap [6, 7]. Owing to the aforementioned material properties, AlN is suitable for applications in UV-Vis detectors and emitters, optoelectronic displays, surface acoustic wave devices, high temperature devices, thin film resonators, and dielectric passivation layers [8–10]. Thermal conductive AlN films with moderate dielectric constant are considered for metal-oxide-semiconductor (MOS) applications [11]. Also AlN films are used for optical applications in corrosive and high temperature environments [12, 13].

AlN films can be relatively easily obtained by a number of methods. The AlN films have been deposited by various techniques, such as molecular beam epitaxy (MBE), chemical vapor deposition (CVD), pulsed laser deposition (PLD), reactive magnetron sputtering and electron shower method [14–22]. Therefore, the study of the properties of AlN layers is very important. Unfortunately, there is little research work regarding the optical properties of AlN layers. In this work, optical properties of AlN layers obtained by magnetron sputtering method and the influence of annealing on their optical properties has been studied.

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2. Experimental

The AlN layers on the glass substrates were obtained by magnetron sputtering using modular platform PREVAC, in Rzeszow University. The films were deposited on microscope glass (borosilicate) substrates (25 mm × 25 mm × 0.1 mm). For optical measurements, we used two samples prepared by magnetron sputtering at glass substrate temperature of 25° with 13.04 % (AlN-30-40) and 14.89 % (AlN-35-40) content of N_2 in N_2/Ar atmosphere. An aluminum target for the film deposition was used. The substrates were mounted on a sample holder and the chamber was evacuated to a pressure of $\sim 10^{-5}$ Pa. The target surface was sputter etched by Ar for 20 min to avoid contamination before deposition. After sputter cleaning, Ar/N_2 gas flow was used and a working pressure of $\sim$2 Pa was maintained during the deposition.

Optical transmission spectra were measured in the wavelength range of 190 nm to 3300 nm using CARY 5000 spectrometer. After measurements, the samples were isochronously annealed (15 min) in air in NABERTHERM LH04 furnace at temperatures of 200 °C, 300 °C and 400 °C. After each step of annealing, the transmission spectra were recorded.

The additional absorption (AA) value ΔK induced by external influence was determined as:

$$\Delta K = \frac{1}{d} \ln \frac{T_1}{T_2} \qquad (1)$$

where d is the sample thickness, T_1 and T_2 are the sample transmission coefficients before (as grown) and after heat-treatment (each step of heating), respectively. The transmission spectra of annealed samples were measured after their cooling to room temperature.

3. Results and discussion

Transmissions spectra of the as-grown AlN layers are shown in Fig. 1.

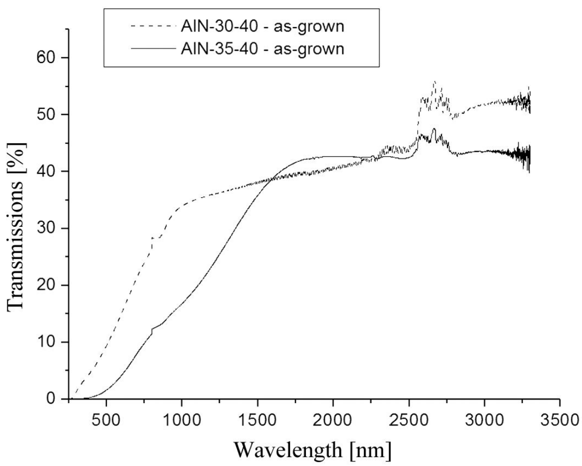

Fig. 1. Transmission spectra of AlN-30-40 and AlN-35-40 layers.

The transmission spectra of investigated samples depend on growth conditions. The transmittance of sample AlN-30-40 is higher than that of AlN-35-40, except in the region of 1700 nm to 2300 nm.

Annealing of the samples in air led to the increase in their transmission, which increased with temperature (Fig. 2, Fig. 3). The lower transmittance of as-grown layers can be due to presence of Al particles in the AlN layer. The post-growth annealing led to the oxidation of Al and produced Al_2O_3 particles with good transparency.

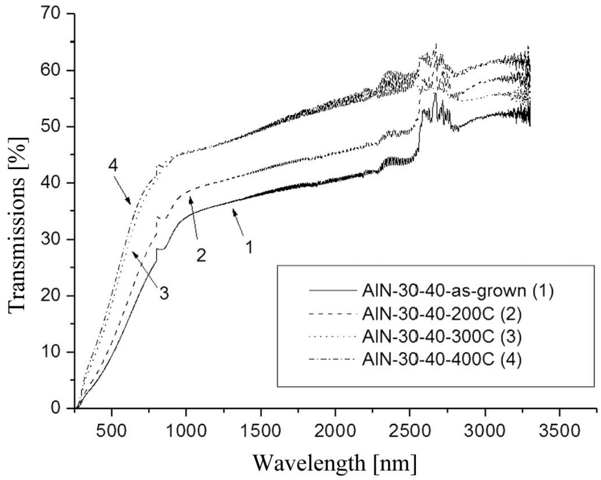

Fig. 2. Transmission spectra of AlN-30-40 layer before and after annealing.

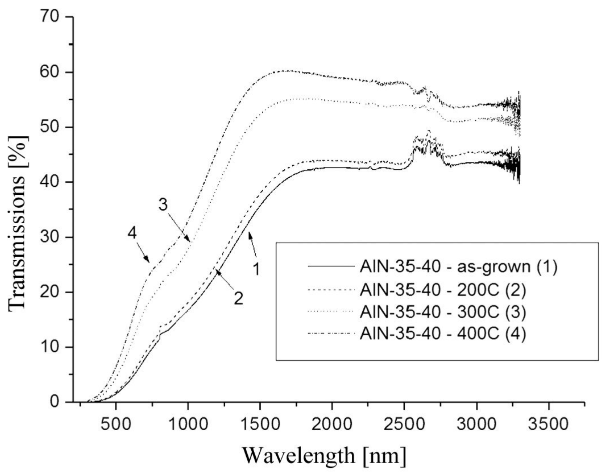

Fig. 3. Transmission spectra of AlN-35-40 layer before and after annealing.

A general form of an absorption coefficient α in the region of absorption edge can be described by the Tauc relation:

$$(\alpha h\nu)^{1/m} = A(h\nu - Eg) \qquad (2)$$

where E_g is the optical band gap energy, A is a proportionality constant and m takes different values which correspond to different transitions [23].

Since AlN is known to be a direct band-gap material, the value of m is taken to be 1/2 for the direct allowed transition. Thus, E_g was determined by plotting $(\alpha h\nu)^2$ as a function of photon energy $h\nu$ and extrapolating the linear region of these plots to the x-axis as shown in Fig. 4 and Fig. 5.

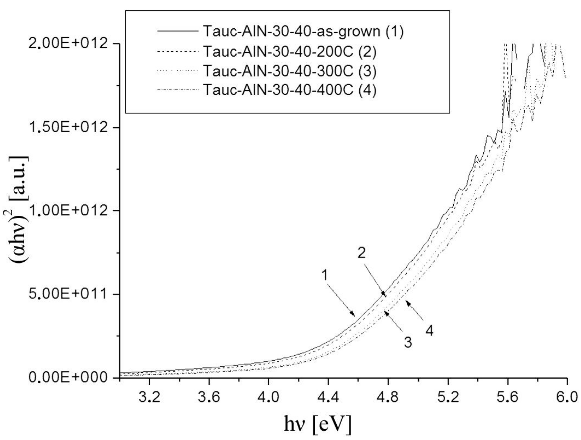

Fig. 4. Absorption spectra of AlN-30-40 layer before and after annealing in Tauc coordination.

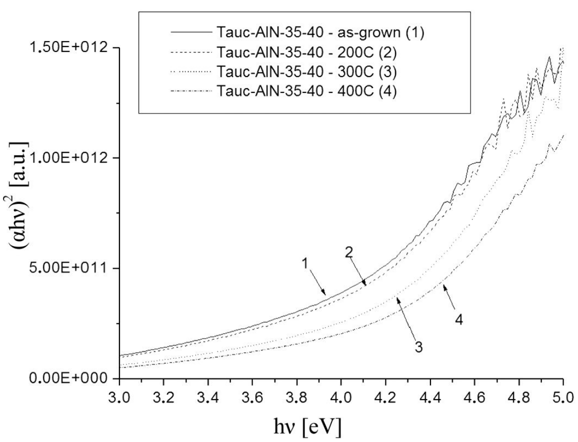

Fig. 5. Absorption spectra of AlN-35-40 layer before and after annealing in Tauc coordination.

The determined optical energy gap of not annealed samples are 4.45 eV and 3.81 eV for AlN-30-40 and AlN-35-40, respectively. We noticed that the glass substrate becomes transparent above 250 nm (below 4.96 eV). Theoretical calculations and experimental absorbance studies in the UV range revealed that AlN has a direct band gap between 5.8 eV and 6.2 eV [24–26]. This values are higher than our results, but Strassburg et al. [27] reported a bulk AlN sample grown by physical vapor transport method with the absorption edge near 4.1 eV that corresponds well with our results.

The lower E_g of our layers in comparison to the reported value for a single crystal AlN, can be elucidated by the concept of Urbach tails [28].

The annealing of the samples in air led to the shifting of absorption edge to the high energy values for both samples that resulted in the increase of energy gap value. The values of E_g after each step of annealing are given in Table 1. The lower E_g value for the sample before annealing can be due to the presence of Al particles in the films, which are oxidized during annealing. It was shown in the literature [29] for zinc nitride films that an oxidized film has higher energy gap than non-oxidized, due to the formation of $ZnO/Zn(OH)_2$ phase.

In Fig. 6 and Fig. 7 the dependences of additional absorption as a function of wavelength are presented. It can be seen that irradiation leads to a significant reduction of the layers absorption in the short and medium wave range of the spectrum (below 800 nm).

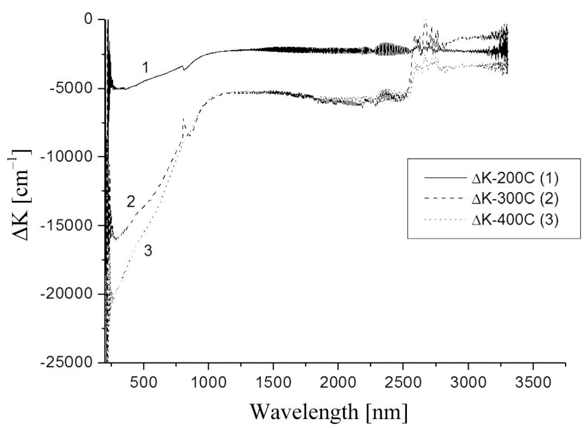

Fig. 6. Additional absorption spectra of AlN-30-40 layer.

The refractive index of the deposited films have been determined from their normal incidence transmission spectra by Swanepoel method [30].

Table 1. The energy gap of AlN samples before and after annealing.

	E_g [eV]			
Sample	Before annealing	200 °C	300 °C	400 °C
AlN-30-40	4.45	4.48	4.54	4.60
AlN-35-40	3.84	3.87	4.00	4.14

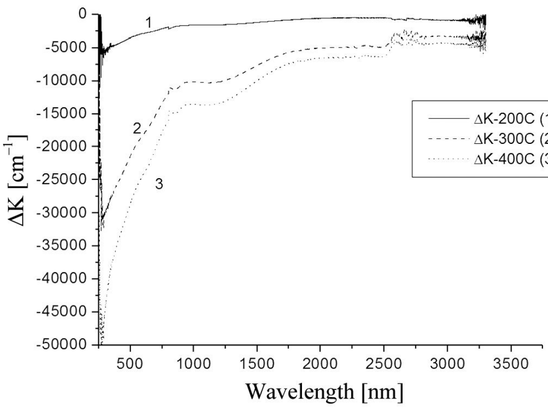

Fig. 7. Additional absorption spectra of AlN-35-40 layer.

In this method, the refractive index of the layer is given as:

$$n = \sqrt{H + (H^2 - s^2)^{1/2}} \quad (3)$$

where s is the refractive index of the substrate (taken as 1.5171 for glass), H is the Swanepoel coefficient and T is the transmittance (interference free):

$$H = \frac{4s^2}{(s^2 + 1)T^2} - \frac{s^2 + 1}{2} \quad (4)$$

The dependences of the calculated refractive index versus wavelength are given in Fig. 8 and Fig. 9. These dependencies have a normal dispersion excluding sample AlN-35-40 which exhibits a weak anomalous dispersion above 1800 nm. The refractive index of the layers is several times higher than that reported in the literature [14] (i.e. refractive index ranges from 1.79 to 2.12 for the sample obtained at DC power of 200 W). The n values decrease with the increase of annealing temperature. It is interesting that the weak anomalous dispersion above 1800 nm occurs but its presence is difficult to explain. Perhaps it is in some way related to the increased content of nitrogen, because it appears in the sample obtained at a higher N/Ar ratio.

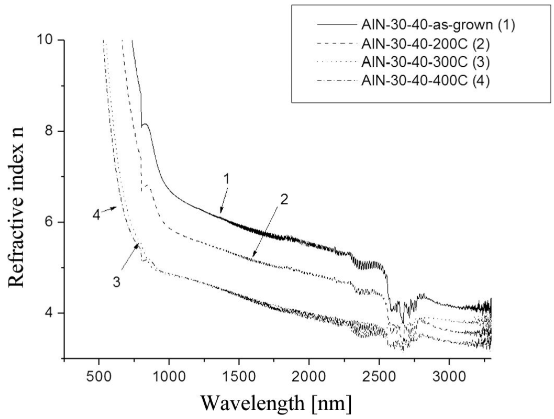

Fig. 8. Refractive index of AlN-30-40 layer as a function of wavelength before and after annealing.

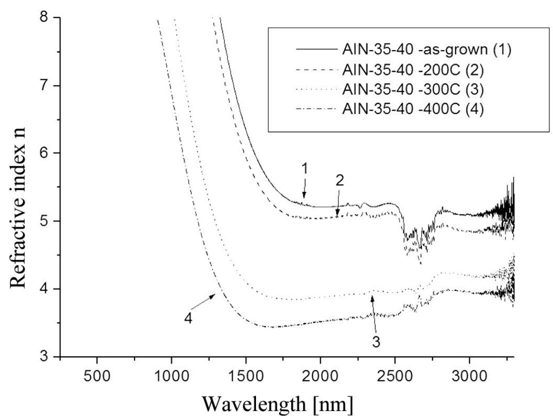

Fig. 9. Refractive index of AlN-35-40 layer as function of wavelength before and after annealing.

4. Conclusion

The AlN layers were deposited on glass substrates by magnetron sputtering method. The optical measurements showed that optical energy gap of the samples is smaller than that of the bulk crystal. The annealing of the layers led to the increase in the transmission of the samples and their energy gap.

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