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Opto-electrical properties of sputtered AlN films

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AlN films were grown on silicon by DC reactive magnetron sputtering and Al/AlN/Si structures were fabricated to study the influence of post metalization annealing (PMA) and UV light. Thereafter, the samples were annealed at 350 ºC for 30 minutes in presence of argon gas. Reduction of hysteresis as well as interface state density was observed as a result of PMA. On the other hand, a ledge appeared in C-V curves, which became prominent with light intensity. The leakage current increased significantly as a result of photo generated charge carriers.

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1. Introduction

Aluminum nitride (AlN) films have received considerable interest as a promising candidate for acoustic, electro-optic, and metal/insulator/semiconductor (MIS)-based devices because of their excellent material properties such as wide bandgap, piezoelectricity, thermal, mechanical and chemical stability [1-5]. In addition, AlN is a promising insulator for microelectronic devices, because of its high dielectric constant i.e., around twice of SiO_2 [6]. Furthermore, one of the great advantages of AlN is its high thermal conductivity (~10^2 higher than SiO_2) that considerably reduces the self-heating effect in high power MOS devices [7]. The performance of these devices is dependent on the morphological and the electrical properties of the film. Hence, it is essential to investigate the electrical characteristics, specifically for MIS based device applications. Over the years, depending on its applications and device fabrication process compatibility, various techniques have been used to synthesize the AlN films. Among these, sputtering has advantages over the other conventionally used high temperature techniques because of its simplicity, low thermal budget and low cost [8, 9]. Herein, electrical properties of Al/AlN/Si structures were studied with PMA and UV light exposure.

2. Experimental

AlN films (2250 Å) were deposited by DC reactive magnetron sputtering (Model Alcatel SCM 450) from a pure aluminum target in high purity argon and nitrogen gas mixture (1:1) on p-type silicon wafers (<100>, 3-5 ohm.cm). Substrate temperature, working pressure and sputtering power were kept at 250 ºC, 3×10^{-3} mbar and 60 W, respectively. MIS structure was fabricated. Post metalization annealing of Al/AlN/Si structures was carried at 350 ºC for 30 minutes in presence of argon gas (3×10^{-3} mbar). Perkin Elmer Spectrometer (Lambda 900, UV/Vis/NIR) and Rigaku-350 equipments were used for optical and structural characterization. Electrical studies were conducted using HP 4280A C-V meter and an electrometer (Keithley 619).

3. Results and discussion

Fig. 1 represents the bandgap (5.8 eV) of the sputtered film, where the inset shows the optical transmittance. The lower bandgap (< 6.2 eV) in the AlN films may be due to the generation of shallow states caused by the formation of nitrogen vacancies and lattice distortion by interstitial Al atoms [10]. In addition, Joo *etal*. has reported that internal electric fields induced by charged defects, residual stress and inhomogeneous microstructure may also contribute to low bandgap energy [11]. Fig. 2 depicts the X-ray diffraction pattern of the films, where films are amorphous in nature. The refractive indices of the films were also found to be around 1.95.

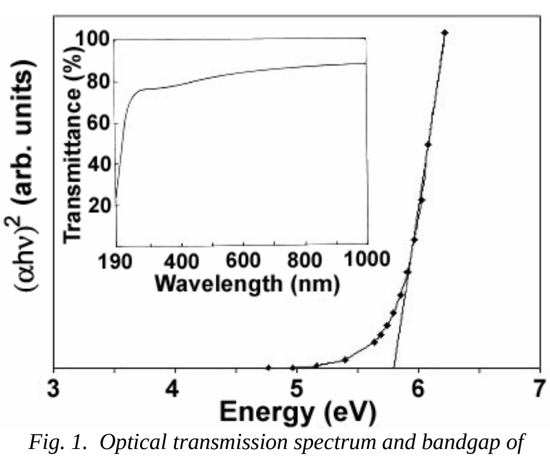

Fig. 1. Optical transmission spectrum and bandgap of DC sputtered AlN films.

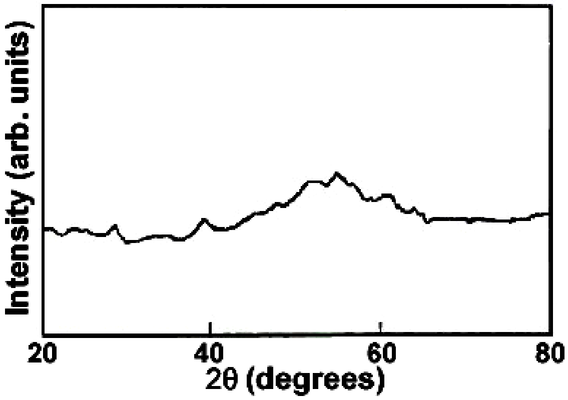

Fig. 2. XRD pattern of DC sputtered AlN films.

The C-V plot of both as-deposited and PMA samples are shown in Fig. 3. For the as-grown sample, the appearance of hysteresis may be due to the presence of trapped charges. The sources of these traps are interfacial trapped charges and the nitride equivalent of fixed oxide charges [12]. It is also reported that unsaturated bond defects distributed into the film may function as fast or slow border traps, depending on their distance from the interface [13]. The reduction of hysteresis for PMA samples can be attributed to significant decrease in slow traps inside the film. Interestingly, there is no change in the dielectric constant of the film after PMA. It is found that flatband voltage of the annealed sample shifts toward the positive voltage side, which indicates the reduction of positive insulating charges in comparison with unannealed samples. Lower stretch out of the curve in case of PMA, may attribute to the reduction of interface defect density and/or structural relaxation at interface. In addition, impurities such as water molecules may dissociate into ions and diffuse to the AlN/Si interface, thereby saturating the dangling bonds [14].

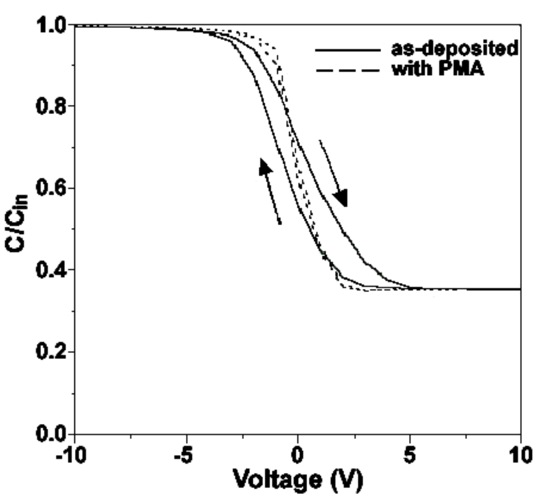

Fig. 3. Comparison of C-V plots of as-deposited and post-metalized annealed (PMA) samples.

Fig. 4 shows an unusual ledge in C-V curves with the UV exposure of 10 minutes, which becomes prominent at higher intensities. In addition, the light intensity plays a significant role for the ledge spreading. This abnormality can be attributed to the delayed evacuation of charge carriers [15], possibly due to the presence of trap levels. Apart from the ledge, it was also noticed that inversion region capacitance increases with increase in light intensity, probably this attributes to the generation of minority carriers at higher light intensity.

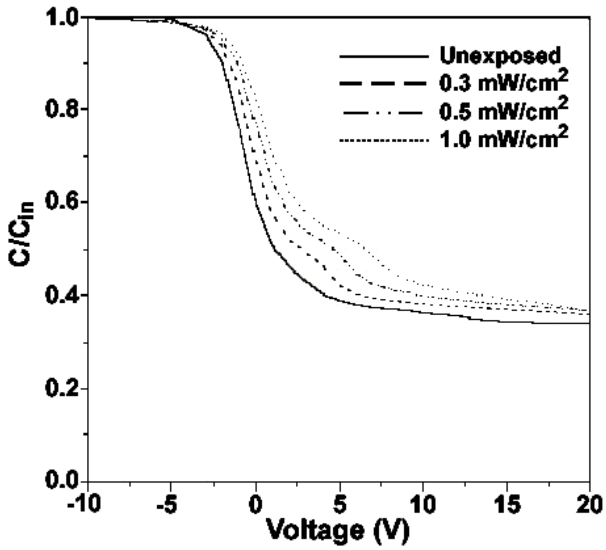

Fig. 4. In situ high frequency C-V plots of annealed Al/AlN/Si structures, exposed by UV light of different intensities.

Fig. 5 plots the I-V curve of Al/AlN/Si structures, where the leakage current initially increased rapidly and afterwards it became quasi-saturated. This non-linearity may be due to charge trapping leading to the creation of an internal electric field, which opposes the applied electric field and subsequently limiting the carrier conduction [16].

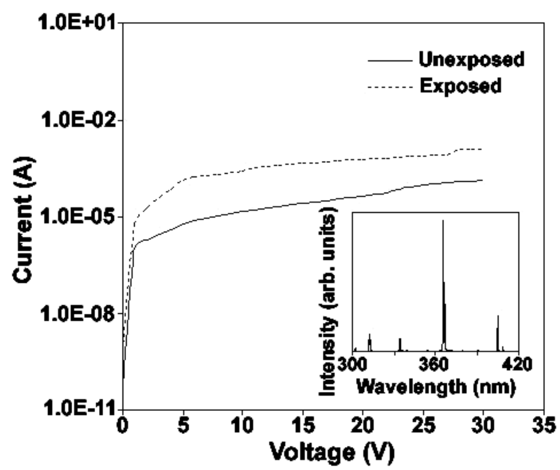

Fig. 5. I-V characteristics of annealed Al/AlN/Si structures during unexposed and exposed at 1 mW/cm^2 of UV light for 10 min.

On the other hand, the significant increase in leakage current as a result of UV exposure can be attributed to the photo-generation of charge carriers. The possible mechanism may due to the detrapping of charge carriers (charge carriers captured in traps within the bandgap of the insulator that releases due to photon excitation), rather than direct transition from band to band [17]. The applied photon energy is very low (~ 3.4 eV as shown in inset of Fig. 5) which is insufficient to generate electron-hole pairs across the forbidden gap of AlN. This is supplemented by our experimental results.

4. Conclusions

Amorphous AlN films with optical bandgap of 5.8 eV were obtained by DC reactive magnetron sputtering. Post metalization annealing and UV light exposure significantly affected the electrical properties of Al/AlN/Si structures. Reduction of hysteresis as well as interface state density was observed as a result of PMA. On the other hand, a ledge appeared in C-V curves, which became prominent with light intensity. The leakage current increased significantly as a result of photo generated charge carriers. Further investigation is required to analyze the ledge of C-V curves, which may lead a path for the new generation of UV sensors.

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