AlN THIN FILMS GROWN BY REACTIVE MAGNETRON SPUTTERING FOR MICROELECTRONICS APPLICATIONS

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The growth of AlN by different deposition methods is frequently reported, because of its optoelectronic, thermal and acoustic properties providing a potential for application, i.e. as metal-insulator-metal (MIM) structures, electro-acoustic and electro-optical devices. The substrates mostly used are Al_2O_3, SiC, Si. Silicon is of special interest because of its importance in the contemporary device technology and the possibility to integrate different functions, e.g., UV-detection or emission and Si-ICs on a common substrate. Reactive dc-magnetron sputter deposition has shown promising results for deposition of monophase wurtzite AlN. We report on AlN wurtzite-type layers deposited by reactive magnetron sputtering on different substrates - Si and Al. The dependence of the electrical, dielectric and structural properties on nitrogen partial pressure was studied.

Keywords: Nitrides, AlN, dc-magnetron sputtering, Structural defects

1. INTRODUCTION

Growth of high-quality epitaxial wurtzite AlN on different substrates is a subject of intensive investigation, because of its optoelectronic, thermal and acoustic properties and corresponding potential applications [1]. It is thermally and chemically stable and has a high electrical resistivity. The combination of these characteristics makes AlN thin films suitable for protective optical coatings and surface pasivating layers. The characteristics of the films are still far from the requirements of device applications despite the various deposition techniques and substrates that have been employed in an attempt of achieving high quality growth. The most frequently used substrates are Al_2O_3, SiC, Si(111) and Si(001). The latter is of special interest because of the possibility to integrate with the contemporary Si device technology different functions, e.g., UV-detection or emission and Si-ICs on a common substrate. Studies of AlN deposition on Si substrates by plasma-assisted molecular beam epitaxy [2] and by magnetron sputtering [3] were previously reported, where epitaxial relationship, microstructure and phase evolution was investigated. In particular, the process parameters of reactive dc magnetron sputtering such as reactive gas pressure and sputtering pressure strongly influence the physical, optical and electrical properties of AlN thin films.

2. PROBLEM STATEMENT

We report on AlN wurtzite-type layers deposited by reactive dc magnetron sputtering on different substrates - Si (111) and Al foil. The synthesis was performed in Ar(99.99%)-N_2(99.99%) gas mixture. A 99.95% purity Al disc with 100 mm in diameter was used as a target. The base vacuum was $7x10^{-6}$ mbar. The films were deposited at $1x10^{-3}$ mbar total pressure and three different values of the nitrogen partial pressures were used (Table 1). The substrates were kept at room temperature during deposition.

The dependence of the electrical, dielectric and structural properties on nitrogen partial pressure was studied. The initial nucleation, atomic structure and texturing of the layers were studied by transmission electron microscopy in plan-view and cross-section and X-ray diffraction methods. Spectroscopic ellipsometry was applied to determine the refractive index and the thickness for the set of samples.

In order to probe the electrical and transport properties of the films metal-insulator-semiconductor (MIS) and MIM structures were formed by evaporating Al circular contacts on AlN/Si and AlN/Al structures. Current-voltage (I-V), capacitance-voltage (C-V) and frequency dependent C-V-f measurements were performed. Electrical properties such as the dielectric constant, leakage current, dielectric losses were measured.

3. Results

The structure of the films varied depending on the particular substrate, being polycrystalline (on Al) or c-axis wurtzite [0001] textured (on Si). Cross-sectional transmission electron microscopy (TEM) image (fig. 1a) of AlN grown on Si (111), reveals crystalline columnar grains, with flat tops of (0001) planes and no well defined faceting of the surface. The diameters of the particular crystallites are of comparable dimensions from 34 nm to 65 nm, and the aspect ratios (diameter/height) are in the range ~ 0.4-0.7. The plan-view TEM image (fig. 1b) of AlN grown on Al shows polycrystalline structure. Most of the films on Al reveal increased oxygen content depending on the growth conditions. Also, XRD measurements show that samples deposited at the lowest nitrogen partial pressure reveal oxygen content (Fig.2). Further, only characteristics of layers deposited on Si will be presented because of the better structural quality.

Table 1

#	p_{total} mbar	p N_2 mbar	n	ε_∞	tgδ	d nm
1	$7.1x10^{-4}$	$9x10^{-5}$	1.85	6.3	0.1	467
2	$1.1x10^{-3}$	$1.1x10^{-4}$	2.09	7.1	0.075	306
3	$1.1x10^{-3}$	$5.1x10^{-4}$	2.2	8.55	0.065	256

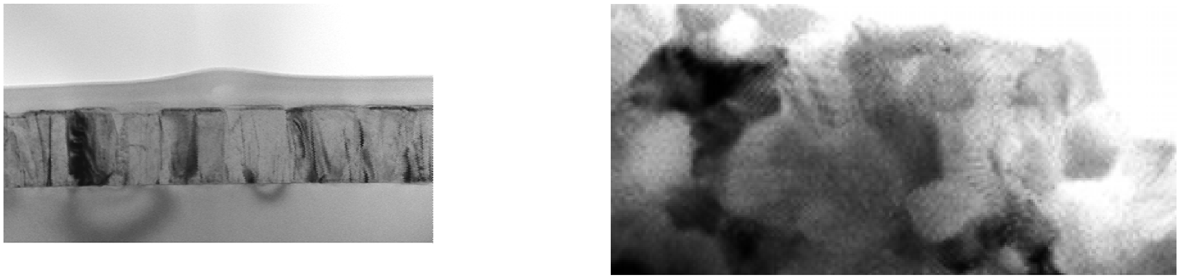


Fig.1. Cross-section low-magnification image of the AlN/Si(111) structure imaged along the Si (1-10) zone axis (a), and high resolution plan-view image of the AlN layer grown on Al.

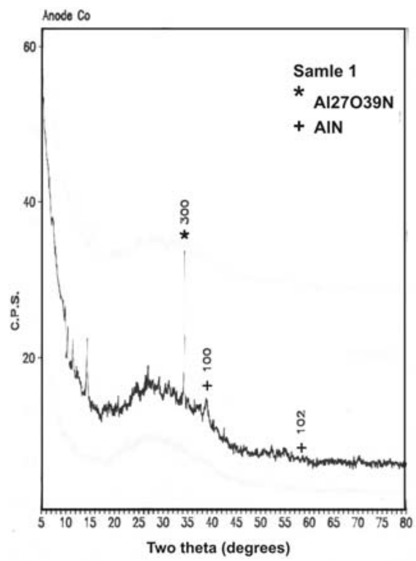


Fig.2. XRD 2Θ scan of sample 1.

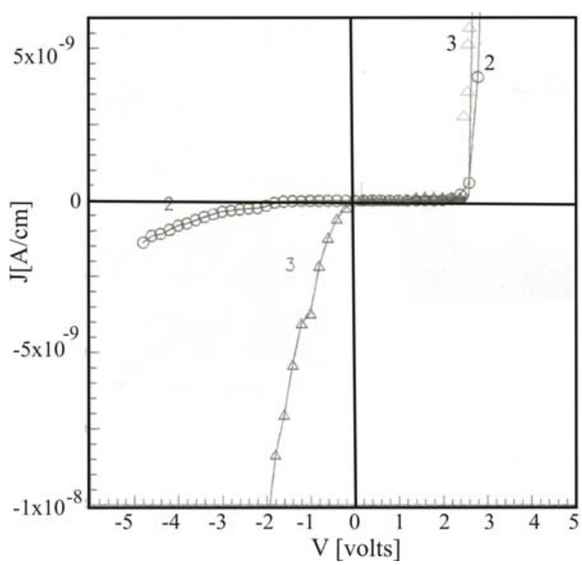
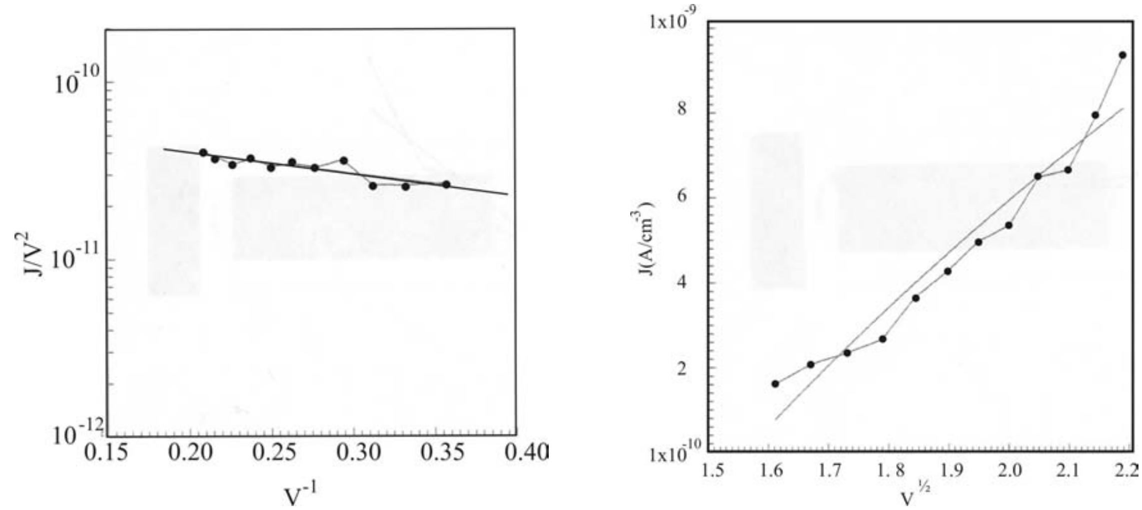


Fig.3. I-V characteristics of samples 2 and 3.

The electrical and optical characteristics are strongly dependent on crystallinity, oxygen contamination and structural defects at different nitrogen partial pressures. The refractive index is in the range typical for AlN ranging from 1.9 to 2.2 for the set of samples. These are typical values for polycrystalline AlN thin films. The values of the dielectric constant are lower than that for high quality AlN being 8.5-9 [1]. Also, for non-oriented AlN films the value of 7 is found [4]. The dissipation factor is also relatively high. These parameters are strongly dependent on the exact composition and stoichiometry of the films. A possible reason could be the presence of different amount of nitrogen vacancies and/or impurities in the AlN lattice. Both reftractive index and dielectric constant improve their values with increasing nitrogen partial pressure.

For the purpose to clarify the conduction mechanism through the AlN layer I-V characteristics are measured and typical diode behavior is shown in Fig.3. The conduction mechanism was modeled by assuming metal/AlN and AlN/Si interface quality limited electron injection upon forward/reverse biasing and field induced thermal ionization of defects in the AlN layer. Two types of conduction mechanisms are revealed in the two samples at forward biasing that are modeled by Fowler-

Nordheim (Fig.4a) and Poole-Frenkel (Fig.4b) analysis. When negative field is increased in the presence of defects in the AlN layer the field changes, redistributes and the current could be localized in very small areas. This leads to local increase of the temperature and creation of new defects. Thus a conduction channel could be created. If this mechanism is involved (Poole-Frenkel effect) the plot of the current density J vs $V^{1/2}$ should show linear dependence [5]. Actually it is the case observed in Fig.4b (sample 2). Another conduction mechanism (Fowler-Nordheim) is observed in sample 3, namely the tunneling injection through triangular potential barrier formed at the metal/AlN interface. The experimental I-V dependence in this case is plotted as J/V^2 vs V^{-1} and is approximated with linear dependence (Fig.4a). The results need further examination to determine the exact nature of the defects responsible for the different conduction mechanisms.



(a) (b)

Fig.4. Fowler-Nordheim (a) and Poole-Frenkel (b) model analysis of the conduction mechanism.

4. Conclusions

AlN wurtzite-type layers were deposited by dc reactive magnetron sputtering on different substrates - Si and Al. The structural and optical properties of the films were characterized as a function of the deposition conditions. Evidence for different types of traps mostly appearing in AlN was provided. Controlling the preferred growth orientation by the substrate used and the deposition conditions proofed better optical parameters and insulating properties.

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5. References

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