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AlN FILMS OBTAINED BY A BROAD ENERGY NITROGEN ION IMPLANTATION AND RAPID THERMAL ANNEALING PROCESS

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The paper describes structural, morphological and electrical investigations of thin AlN films. The films were obtained by broad energy range ion bombardment (BERIB) of aluminium, with doses ranging from 1.5×10^{17} cm^{-2} to 6×10^{17} cm^{-2}. This technique, to our knowledge, has not been described previously in the literature. The ion implantation was carried out with two species - nitrogen atoms with energies from 50, 30, and 20 keV and nitrogen ions with energies of 50 and 30 keV. These energy values were chosen in order to ensure a continuous and wide nitride layer, at least of 150 nm thick.

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1. Introduction

Aluminium nitride has been widely investigated as a promising electronic and optoelectronic material, because of its wide bandgap (E_g ~ 6 eV) as well as its favourable thermal, acoustic, optical and electrical properties [1]. It has been produced by a variety of methods including reactive sputtering [2,3], ion beam assisted deposition, plasma enhanced CVD and nitriding [4]. As an alternative technology to conventional ion implantation, plasma immersion ion implantation has been developed.

2. Experimental procedures

Films of aluminium were thermally evaporated on (100) oriented p-type silicon wafers with specific resistances of 42-60 Ω cm. The ion implantation was carried out with two species - nitrogen atoms with energies of 50, 30, and 20 keV and nitrogen ions with energies of 50 and 30 keV. Three different irradiation doses were chosen for each of the three wafers, denoted hereafter as “A”, “B” and “C”. Table 1 lists the conditions under which the implantation was carried out.

The nitrogen species were implanted at normal incidence. The mean projected ranges for energies of 50, 30, 20 keV are 120, 74, and 52 nm with a straggling of 40, 30, and 20 nm respectively, according to the SRIM code [5]. In the case of bombardment by nitrogen ions, the N-N bond is broken on impact with the solid surface. Two energetic particles (atoms) sharing the energy of the ion are created. The mean projected range for 30 keV accelerated atoms is estimated to

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be the same as for 15 keV implantation, and amounts to 40 nm with a 17 nm straggling. The ion current during the implantation was such that the substrate temperature did not exceed 180 ^{o}C. The chosen energy ranges provide a relatively thick implanted zone, nearly 160 nm thick.

Table 1. Conditions under which the implantation was carried out.

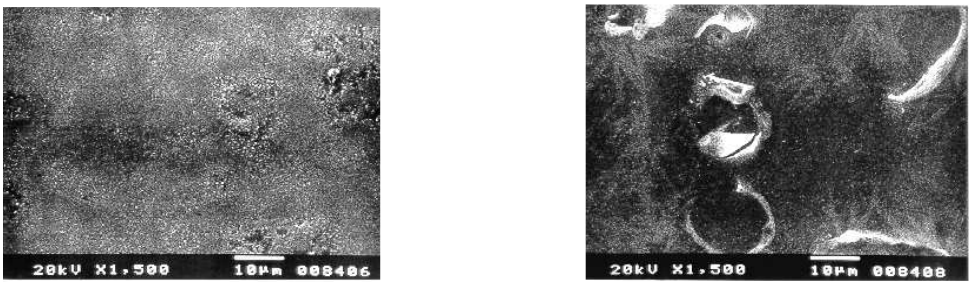
Batch A N^+ implantation	Energy [keV]	Dose [at/cm^2]	Total Dose [at/cm^2]
	50	5×10^{16}	1.5×10^{17}
	30	5×10^{16}	
	20	5×10^{16}	
Batch B N^+ implantation	Energy [keV]	Dose [at/cm^2]	Total Dose [at/cm^2]
	50	2×10^{17}	6×10^{17}
	30	2×10^{17}	
	20	2×10^{17}	
Batch C N_2^+ implantation	Energy [keV]	Dose [at/cm^2]	Total Dose [at/cm^2]
	50	3×10^{17}	6×10^{17}
	30	3×10^{17}	

3. Results and discussion

In spite of the appreciable energy supplied in the material by the bombarding particles, which considerably exceeds the energy for Al-N bond formation, we are aware that this energy is not supplied during the film growth and the formation of chemical bonds in the bulk material, which is less feasible. To provide favorable conditions for aluminium diffusion from the bulk toward the surface, a Rapid Thermal Annealing procedure was applied. In Table 2, the sheet resistance is given for N^+ implanted with a dose of 1.5×10^{17} at/cm^2 for batches A and B, and N_2^+ ions with a dose of 6×10^{17} at/cm^2 for batch C.

Table 2. Sheet resistances of Al implanted with N^+ atoms with doses of 1.5×10^{17} at/cm^2 and 6×10^{17}at/cm^2 for batch A and B respectively, and implanted with N_2^+ ions with a dose of 6×10^{17} at/cm^2 for batch C.

Procedure	**Batch A**	**Batch B**	**Batch C**
AlN – Ref.	448 *mΩ*/□	5.95 *Ω*/□	753 *mΩ*/□
AlN - RTA 800° 15”	399 *mΩ*/□	3.6 *Ω*/□	794 *mΩ*/□
AlN - RTA 800° 30”	978 *mΩ*/□	3.35 *Ω*/□	1.36 *Ω*/□
AlN - RTA 800° 1’	2.07 *Ω*/□	3.13 *Ω*/□	2.54 *Ω*/□
AlN - RTA 800° 2’	451 *mΩ*/□	2.48 *Ω*/□	4.54 *Ω*/□
AlN - RTA 1000° 15”	1.94 *Ω*/□	3.7 *Ω*/□	80.2 *Ω*/□



(a) (b)

Fig. 1. Morphology of samples from batch “A” (a) and batch “B” (b) treated with RTA at 800 ^{o}C for 120 sec.

In Fig. 1, one can see a sizeable grain increase and also some agglomerations of the grains with increasing dose. It can be distinguished that knob-like structures unify the grains, which probably have an increased hardness and are more resistant to re-sputtering erosion.

The X-ray diffraction spectra were measured in the θ-2θ scan mode (15 sec/step, 0.05°) with Cu Kα using a Siemens D-5000 spectrometer. In Fig. 2, we show XRD spectra of two samples from batch "C"; one annealed at 800 °C for 60 seconds, and one annealed at 1000 °C for 15 seconds. Batch "C" was implanted with the same dose as batch "B"; the only difference was the implanted species – nitrogen ions. This profile more clearly exhibits the aluminium-nitride phase formed at higher temperature. Here, AlN peaks (101) and (200) appear at 2θ values of 38° and 44° respectively. The latter show the temperature factor to be an important one. It has been shown that the re-sputtering zone of batch "C" is around 100 nm, due to the relatively high dose and the nature of the implanted species. The nitrogen ion dissociates near the surface and two atoms share the energy. In this energy range, the sputtering coefficient increases by nearly a factor of two. The surface in this case should be oxygen and carbon free, which facilitates the nitridation process.

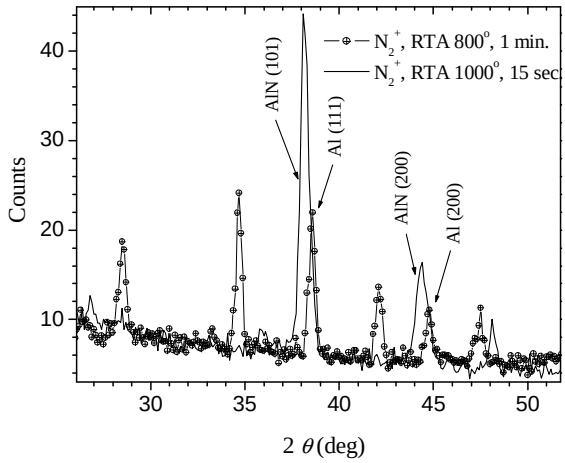


Fig. 2. A zoomed XRD spectrum of two samples from batch "C"; sample annealed at 800 °C for 60 seconds - circles, and sample annealed at 1000 °C for 15 seconds – solid line.

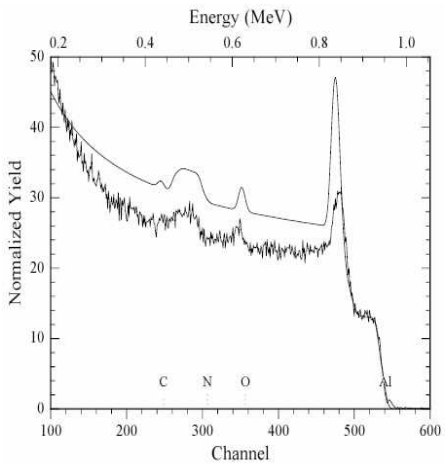


Fig. 3. Rutherford backscattering spectra, batch C 1000° 15 sec. The smooth line is the simulated spectrum.

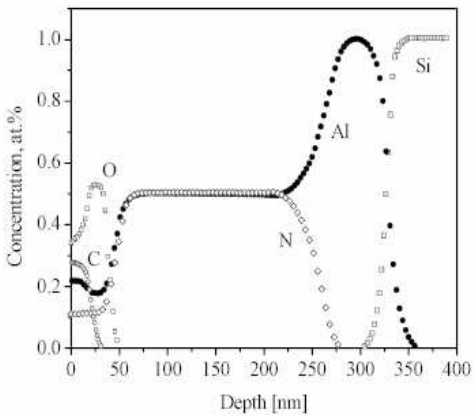


Fig. 4. Elemental depth distribution of batch "C" – sample annealed at 1000 °C, for 15 seconds as deduced from RBS, (Fig. 3).

Rutherford backscattering spectra using 1.7 MeV $^4He^+$ were taken in a random geometry. The relative elemental atomic ratios were simulated using the RUMP code [6]. A simulated RBS

spectrum of as-deposited aluminium gave thicknesses of 200 to 210 nm, from Al with a very oxygen contaminated surface layer of around 30 nm. Fig. 3 displays the measured and the simulated (the smooth line) spectra for batch "C" annealed at 1000 ^{o}C for 15 seconds. In Fig. 4, the elemental depth distributions for this sample are shown.

4. Conclusions

It has been shown that ion implantation without annealing leads to a mixed composition of disordered grains of aluminium and incorporated nitrogen. Implanted doses higher than 1.5×10^{17} at/cm^2 lead to a sizeable increase in the presence of AlN grains, and to some agglomerations of the grains in knob-like structures with increased hardness and greater resistance to re-sputtering erosion. The use of nitrogen ions instead of nitrogen atoms increases the re-sputtering rate and diminishes the time of radiation exposure. It has been shown that the best results are achieved when a rapid thermal annealing process occurs at 1000 ^{o}C for 15 seconds. This suggests that aluminium diffusion from the bulk to the surface takes place. Thus, the aluminium nitride layer grows from the near surface to the bulk, assisted by the diffusion of aluminium from the nitrogen rich regions.

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