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AlN Deposited by OMVPE and PLD Used as an Encapsulate for Ion Implanted SiC

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Abstract

AlN deposited by either organometallic vapor phase epitaxy (OMVPE) or pulsed laser deposition (PLD) can be used as an encapsulate for SiC when heated in an argon atmosphere for temperatures at least as high as 1600°C for times at least as long as 30 min as the coverage of the AlN remains complete and the AlN/SiC interface remains abrupt as determined by Auger electron spectroscopy (AES). However, there is considerable atomic movement in the AlN at 1600°C, and holes can form in it as the film agglomerates if there are large variations in the film thickness. Also, the SiC polytype near the surface can in some instances be changed possibly by the stress generated by the epitaxial AlN film. Using x-ray diffraction (XRD) measurements, we also found that, during the 1600°C anneal, grains with non-basal plane orientations tended to grow at the expense of those with basal plane orientations in the OMVPE films, whereas grains with the basal plane orientation tended to grow in the PLD films. However, there is no indication that the type of grain growth that is dominant affects the film's ability to act as an encapsulate.

There is considerable interest in being able to ion implant SiC because the rate of diffusion in it is extremely low even at temperatures as high as 1600°C [1]. Moreover, being able to create FET structures, as is done with GaAs, would have considerable economic benefits, and being able to heavily dope a region before forming an ohmic contact to it can considerably reduce the contact resistance. This is particularly true for devices such as gate turn-off thyristors where the layer that is contacted is by necessity lightly doped.

One important reason that ion implant technology has not been developed for SiC is that very high temperatures are required to activate the implant. From their electrical measurements, Kawase et al [2] showed that an annealing temperature of 1600°C is required for a significant amount of activation to occur. At this temperature the preferential evaporation rate of Si is high enough to destroy the surface quality [3]. Samples can be annealed at this temperature by using a second SiC wafer to cover the implanted surface, but this is expensive, and some damage occurs because a hermetic seal

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is not formed. The usual encapsulates, SiO_2 and Si_3N_4, cannot be used at this temperature because their vapor pressures are too high. With a vapor pressure that is more than two orders of magnitude less at 1600°C, AlN [4] could possibly be used as an encapsulate. In this paper we show that under certain conditions it can be when it is deposited by organometallic vapor phase epitaxy (OMVPE) or pulsed laser deposition (PLD). The films are examined by observing the morphology of the AlN films with scanning electron microscopy (SEM), recording variations in the film thickness using energy dispersive x-ray (EDX) analysis, determining the abruptness of the AlN/SiC junction from the Auger electron spectroscopy (AES) depth profiles, and studying changes in the orientations of the AlN film and changes in the structure of the SiC near the interface by x-ray diffraction (XRD). Films were grown on Al_2O_3 as well as SiC for comparison.

4H-SiC substrates used for the OMVPE growth were chemically cleaned in an HF:H_2O 1:10 solution then thermally cleaned in situ by a 900°C anneal for 3 min. The Al_2O_3 substrate was chemically cleaned in an acetone/methanol/H_2O solution and thermally cleaned in H_2 as the temperature was ramped up. The film grown on SiC was deposited at 1300°C, the film grown on Al_2O_3 was deposited at 1180°C, and they both had a nominal thickness of 200 nm. The 6H-SiC substrate for PLD growth was also chemically cleaned in an HF solution, while the Al_2O_3 substrate was thermally cleaned during the heating up process. Both samples were deposited at a base pressure of 1×10^{-7} Torr using a KrF excimer laser emitting at 248 nm. The growth temperature for the SiC substrate was 800°C, the growth temperature for the Al_2O_3 substrate was 900°C, and both films were nominally 10 nm thick. The samples were annealed in a resistively heated furnace in an argon atmosphere at temperatures of 1200°C, 1400°C and 1600°C for 30 min, and then were cooled down at an initial rate of 20°C/min. The film and substrate were then examined by SEM, EDX, AES and XRD.

For the OMVPE samples no changes in the morphology were observed for the samples annealed at 1200 and 1400°C. However, significant morphological changes occur for both substrates when the samples are annealed at 1600°C indicating there is considerable atomic motion. Similar observations were made for the PLD films. There was so much atomic movement in the film grown on SiC and annealed at 1600°C the AlNagglomerated in some regions and left holes in others. Work with other samples suggests that the agglomeration is not associated with the deposition method. Rather, it is a result of the large variation in the thickness of the AlN layer that was primarily due to its low deposition temperature. It is possible that agglomeration would not occur in thicker films, but they are more likely to contain cracks.

That the film thickness varied from point to point in this PLD film was demonstrated by comparing the EDX peak heights of Si and Al in the as grown sample. This was also confirmed by observation of cleaved cross sections in the SEM. The as grown OMVPE film showed little variation, and this, too, was verified with cleaved cross sections. The ratio of the Si peak height to the Al peak height was much smaller in the OMVPE sample confirming it was thicker than the PLD film. This, too, was seen in the cleaved cross sections.

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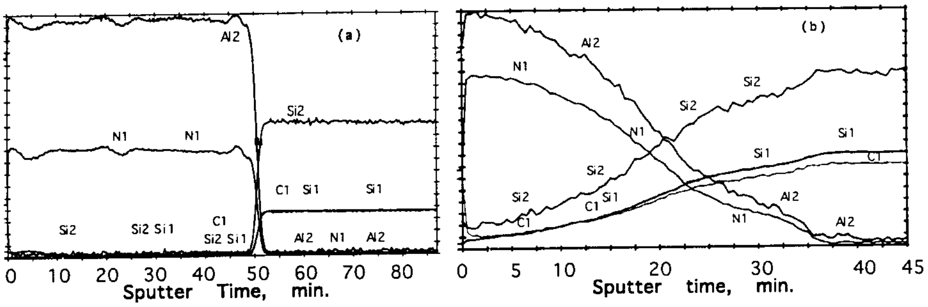

Fig. 1 AES depth profiles for the AlN film grown on SiC by (a) OMVPE and (b) PLD and annealed at 1600°C for 30 min.

The films grown on Al_2O_3 also show no discernable changes when annealed at 1200 and 1400°C, but there is considerable atomic movement after the 1600°C anneal. However, both the OMVPE and PLD films retain their complete coverage of the substrate, and cleaved cross sections show that there is little variation in the thickness of the as grown films. The most likely reason that the PLD film for this substrate had a more uniform thickness is that it was deposited at a higher temperature.

In the AES depth profiles in Fig. 1 for both of the samples deposited on SiC and annealed at 1600°C one sees that the profile is very abrupt for the OMVPE sample. However, the PLD sample has a gradual profile indicating a considerable in-diffusion. It is likely that the enhanced diffusion was due to Si preferentially evaporating through the openings in the film leaving vacancies behind that assist in the diffusion process.

The x-ray diffraction pattern for the OMVPE as deposited film shown in Fig. 2a has a second basal plane reflection suggesting that a polytype other than the original 4H polytype is present. This could possibly have been caused by stress created by the lattice and/or thermal coefficient mismatch. The second polytype peak is not present in the OMVPE 1600°C annealed sample, as shown in Fig. 2b, but the (002) AlN peak has been greatly reduced while at the same time the (100) and (101) peaks increase in intensity. Once again this shows that there is considerable atomic motion at 1600°C, but given the strong tendency for wurtzite crystals to grow in the [001] direction, it is surprising that in this case strong c-axis growth did not occur. However, this considerable amount of grain growth did not appear to affect the film's ability to act as an encapsulate. Some AlN grains were deposited on Al_2O_3 with the (100) and (101) orientations, but their peaks were not increased in intensity by the 1600°C anneal as they were for the AlN film grown on SiC. Why the grain orientation changes for films grown on the SiC are larger than those grown on Al_2O_3 is not understood at this time.

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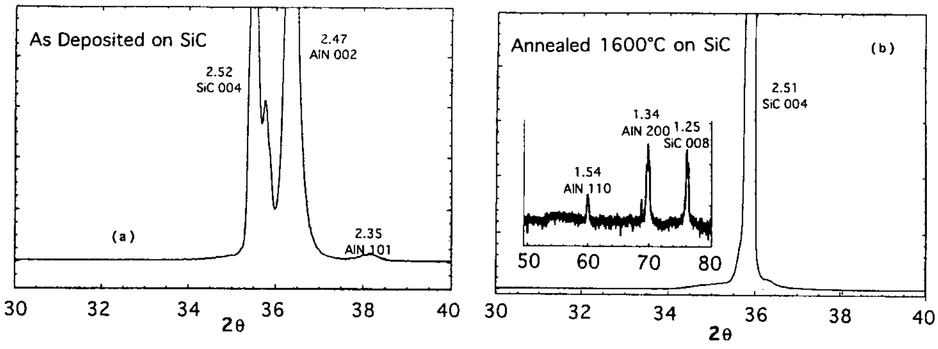

Fig. 2 X-ray diffraction spectra for the (a) as grown and (b) annealed OMVPE films deposited on SiC.

The diffraction pattern for PLD as grown AlN on SiC had no (002) AlN peak because it was amorphous. This was probably caused by the low deposition temperature. On annealing at 1600°C the film showed only grains with a preferred (001) orientation. However, it also showed that some of the 6H-SiC had been converted to another polytype as there were two basal plane SiC peaks. For the PLD films deposited on Al_2O_3 both the as grown and the annealed films showed only the (002) peak.

It has been shown that AlN films deposited on SiC by either OMVPE or AlN can act as an encapsulate for temperatures at least as high as 1600°C for 30 min annealing times in that they can retain their coverage of the substrate. With the complete coverage there is little in-diffusion from the AlN into the substrate as there are only a limited number of Si vacancies since the Si cannot preferentially evaporate. However, the film should have a uniform thickness as there is considerable movement of the atoms at this temperature that can lead to the formation of holes if the thickness varies. The AlN films have the disadvantage that they can create SiC with a polytype different than the original polytype; this is probably due to stress created by the lattice and/or thermal mismatch between the epitaxial film and its substrate. Even if it does not have a bearing on the quality of the encapsulate, it is interesting to note that OMVPE grown AlN has some grains with an off-axis orientation that continue to grow at the expense of others when the films are annealed. This, however, is not true for the PLD deposited films.

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