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Fabrication of IDT/AlN/DLC/Si Structured SAW Device by Pulsed Laser Deposition
パルスレーザー堆積によるIDT/AlN/DLC/Si SAW装置の作成

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Preferentially-oriented aluminum nitride (AlN) films are grown directly on diamond-like carbon by pulsed laser deposition (PLD) for IDT/ALN/DLC/Si structured SAW device. The AlN preferential orientation changes from (002) to (100) with increasing N_2 pressure. Such different behaviors are discussed in terms of deposition-rate-dependent preferential orientation, kinetic energy of depositing species and confinement of laser plume. Finally, sample deposited at 0.9 Pa is proved to have the highest (002) peak intensity, the lowest FWHM value, the highest deposition rate and a relatively low RMS roughness (1.138 nm), showing the optimal growth condition for c-axis-oriented AlN growth at this N_2 pressure.

1. Introduction

Aluminum nitride (AlN), with a high acoustic propagation rate and a low transmission loss, offers tremendous potential for surface acoustic wave (SAW) devices. In SAW devices, the central frequency (f_0) is related to the spacing between the interdigital transducer (IDT) fingers (λ/4) and the propagation velocity on the substrate V_p by the simple formula: $f_0 = V_p/\lambda$. In this sense, increased operation frequency of SAW devices can be achieved by using high-resolution IDT lithography (shorter λ) and/or high acoustic wave velocity materials as bottom layer. Amorphous diamond-like carbon (DLC) is believed to be a good choice for bottom layer because of its highest propagating velocity among all materials [1]. To our knowledge, there is no report on the deposition of AlN film on amorphous substrate. In this study, we investigate the preferentially-oriented growth behavior of AlN film on amorphous substrate (silicon substrate with amorphous native oxide) and optimize the parameter of N_2 pressure for c-axis-oriented AlN growth.

2. Experimental

A second harmonic Q-switched Nd:YAG laser (Continuum, Surelite III-10M), operating at 532nm with 5 ns pulse duration, delivers a chosen energy of 380 mJ (corresponding to an energy density of 2 J/cm^2) at a repetition rate of 10 Hz. After two reflections, the laser beam was focused on a rotating sintered AlN target (99.999%) at 45° with respect to the normal direction of the target. The AlN target was polished before every experiment by mechanical abrasion. P-type Si (100) with a few nm thickness of native oxide layer was chosen as the substrate. 6000 pulses were chosen for AlN film deposition. In the present experiment, for the sake of studying the influence of N_2 pressure on AlN films growth, AlN films were deposited in a vacuum (evacuated up to ~10^{-4} Pa) and at N_2 pressures of 0.2 ~ 10 Pa, with fixed target-to-substrate distance of 50 mm and substrate temperature of 600℃.

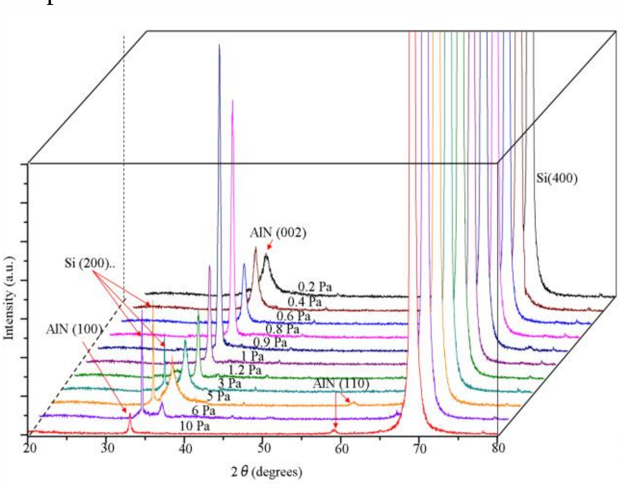

Figure 1. XRD patterns of as-deposited AlN films.

3. Results and discussion

Figure 1 shows the XRD patterns of AlN films deposited under various N_2 pressures. The

Table I Evaluation of AlN surface energy and corresponding growth rate.

		(002)	(100)	(110)
No consideration of polarization	Dangling bond density [bonds/cm^2]	11.94×10^{14}	12.91×10^{14}	14.91×10^{14}
	Surface energy	Small	Medium	Large
	Expected growth rate	Small	Medium	Large
Consideration of polarization	Surface energy	Large	Small	Medium
	Expected growth rate	Large	Small	Medium

diffraction peaks located at 2θ = 33.216°, 36.041 °and 59.350 ° are corresponding to (100), (002) and (110) of hexagonal AlN respectively. The strong diffraction peak at 2θ = 69° belongs to (400) of Si substrate. In addition, very sharp peaks at 2θ = 32.958° that observed at 3, 5, 6 Pa, are attributed to the forbidden reflection of Si substrate which occasionally appear in XRD measurement. It was observed that all the films deposited below 10 Pa exhibited strong AlN (002) diffractions. At higher N_2 pressure (10 Pa), instead of (002) peak, the XRD patterns showed only AlN (100) diffraction. The preferred orientation changes from (002) to (100) at 10 Pa indicating the c-axis of AlN crystallites changes from perpendicular to parallel with respect to substrate surface. 0.9 Pa is found out to be the optimal crystal growth pressure for c-axis-oriented AlN.

The film thickness was estimated using a surface profilometer by measuring the step fabricated with a mask on the substrate during the deposition. The deposition rate keeps increasing with N_2 pressure and starts to decrease drastically after it reaches its highest value at 0.9 Pa, implying the fastest growth rate along c-axis. Surface morphology and surface roughness of AlN films have been examined by using the SPM in atomic force microscopy (AFM) mode. All the films display uniform and crack-free surface. Besides, it is observed that the surface roughness is drastically decreasing with the increasing N_2 pressure. The RMS roughness passes though a minimum value of 0.561 nm at 5 Pa, which is comparable to the substrate roughness.

The results until now suggest that the large deposition rate enhances the (002) preferential orientation. In general, this phenomenon is well known as the deposition-rate-dependent preferential orientation. Supposing there are two competitive growth planes with a large and a small surface energy, the large surface energy plane is dominant in a large deposition rate case while two planes are competitive in a small deposition rate case. However, the surface energy of AlN is quite controversial according to the published literatures. Most of the papers on growth of AlN nanostructures and AlN films are showing AlN (002), i.e. c-axis orientation, suggesting AlN (002) plane has the largest surface energy. The evaluation of AlN surface energy and the expected growth rate in terms of dangling bond density and consideration of polarization has been shown in Table I. The consideration of polarization is believed to be crucial to determine AlN surface energy. Actually, the top/bottom surfaces of the ± (001) dominated AlN films would be charged with positive and negative charges by polarization due to its noncentral symmetry structure. Hence, AlN (002) plane possesses larger surface energy than AlN (100) plane and is easier to be formed at low N_2 pressure with higher deposition rate. For more details, please refer to Ref. [2].

4. Conclusion

PLD can be utilized to grow highly c-axis-oriented AlN films directly on natively-oxidized Si substrate. N_2 pressure was found to be a crucial parameter in controlling preferred orientation. Low N_2 pressure was favorable to form (002) preferred orientation. With increasing N_2 pressure, it changed from (002) to (100) indicating the c-axis of AlN crystallites changes from perpendicular to parallel with respect to substrate surface. Sample deposited at 0.9 Pa is experimentally proved to have the highest (002) peak intensity, the lowest FWHM value, the highest deposition rate and relatively low RMS roughness (1.138 nm), showing the optimal growth condition for c-axis-oriented AlN growth. The deposition-rate-dependent preferential orientation was introduced to explain the evolution of preferred orientation and deposition rate.

References

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