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Growth of preferentially-oriented AlN films on amorphous substrate by pulsed laser deposition

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ABSTRACT

Preferentially-oriented aluminum nitride (AlN) films are grown directly on natively-oxidized Si (100) substrate by pulsed laser deposition (PLD) in nitrogen (N_2) environment. 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.
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1. Introduction

Aluminum nitride (AlN), with a wide direct band-gap (6.2 eV at 300 K) [1], high electrical resistance (10^9–10^{11} Ωm) [2], high thermal conductivity (up to 320 W/mK at room temperature) [3], a high acoustic propagation rate and a low transmission loss [4], offers tremendous potential for microelectronic devices, such as surface acoustic wave (SAW) devices [5], thin-film bulk acoustic resonators (FBARs) [6], contour mode resonators [7] and Lamb wave resonators [8,9]. Compared to zinc oxide (ZnO), AlN films show a higher SAW velocity (5607 m/s instead of 2682 m/s), better mechanical properties (18 GPa instead of 5 GPa in Vickers hardness) [10], resistance to humidity, and better endurance to chemical etching [11].

In SAW devices, the central frequency (f_0) is related to the spacing between the interdigital transducer (IDT) fingers ($\lambda/4$) and the propagation velocity on the substrate V_p by the simple formula: $f_0 = V_p/\lambda$ [12,13]. 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. The first solution is highly required in terms of fabrication costs and precision; the second one is attractive if high-quality fast materials can be grown by standard thin film deposition techniques [14]. Amorphous diamond-like carbon is believed to be a good choice for bottom layer because of its highest propagating velocity among all materials [15].

Various techniques have been reported for the synthesis of AlN films, such as chemical vapor deposition [16], molecular beam epitaxy [17], ion-plating deposition [18] and reactive magnetron sputtering [19], etc. Most of these works report the epitaxial growth behaviors of AlN films on single-crystal substrates, few works can be found regarding the deposition of AlN on amorphous substrate. Pulsed laser deposition (PLD) is believed to be a good choice to grow high quality preferentially-oriented film on amorphous substrate. It is generally known that owing to the non-equilibrium nature of the process in PLD, the energetic species in the laser ablation plasma have a much higher kinetic energy (in the range of 10–100 eV) than that of conventional methods, like thermal evaporation process (∼ 0.1 eV) [20]. Such energetic species would enhance the mobility of deposited adatoms and increase the film crystallinity on amorphous substrate.

To our knowledge, there is no report on the deposition of AlN film on amorphous substrate by PLD and the scope of this work is to fill this gap. As known, different crystal orientation of AlN films show different thermal expansion coefficient (c-axis parallel: 5.3×10^{-6}/K, a-axis parallel: 4.2×10^{-6}/K) [21] and different elastic constant ($c_{11} = 345$ GPa and $c_{33} = 395$ GPa) resulting in a different phase velocity [22]. 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. AlN films were later characterized by the X-ray diffractometer (XRD, RINT-2200, Rigaku), surface profilometer (Surfcom 1500DX, Tokyo Seimitsu), field-emission scanning electron microscopy (FE-SEM, JSM-6700F JEOL), and scanning probe microscope (SPM 9500 J2, Shimadzu).

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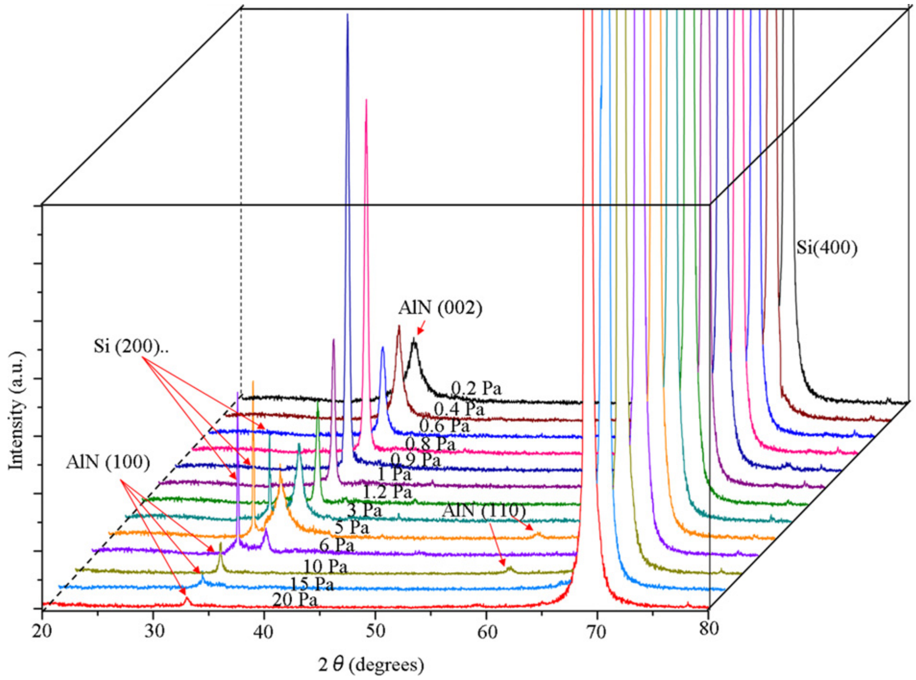

Fig. 1. XRD patterns of AlN films deposited at various N_2 pressures.

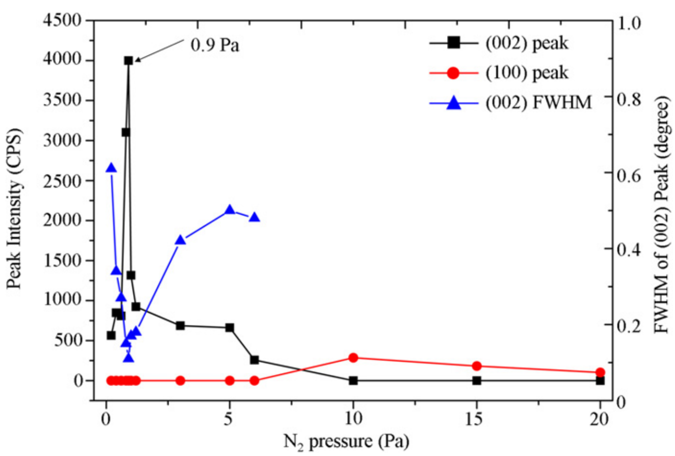

Fig. 2. Variation of XRD peak intensities of AlN films deposited at various N_2 pressures.

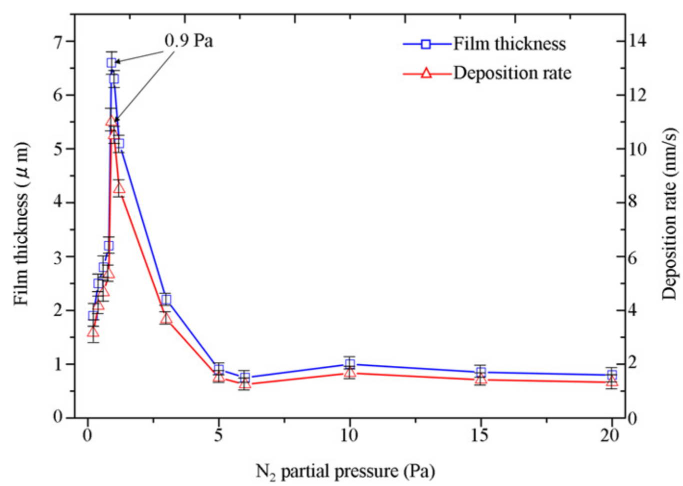

Fig. 3. Film thickness and deposition rate vs. N_2 pressure for AlN films.

2. Experimental details

A second harmonic Q-switched Nd:YAG laser (Continuum, Surelite III-10M), operating at 532 nm 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. During deposition, the target was continuously rotated around its center to ensure a complete elimination of stress and a fresh location for each incident laser pulse. The AlN target was polished before every experiment by mechanical abrasion, removing the topmost layer to preserve the target stoichiometry [23] and reduce the density of droplet often observed on PLD films. P-type Si (100) with a few nm thickness of native oxide layer was chosen as the substrate, because the (100) silicon is used in all CMOS electronics and is inexpensive. Prior to deposition, substrates were alternately cleaned in ultrasonic baths of deionized (DI) water and ethanol for several rounds to remove organic impurities and eventually dried with N_2 duster.

Target surface pre-ablation is necessary to remove impurities and to prevent droplets incorporation in the growing film. Thus, we block the first 3000 pulses by using a shutter between target and substrate. Afterwards, the shutter was removed and 6000 pulses were chosen for AlN film deposition. The physical properties of AlN films prepared by PLD mainly depend on the processing parameters such as substrate temperature, N_2 pressure, target substrate distance, laser pulse energy and pulse repetition rate. 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 $\sim 10^{-4}$ 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 °C.

3. Results and discussion

X-ray diffraction (XRD). The crystalline structure and preferred orientation of the as-deposited films were characterized by XRD. Fig. 1 shows the XRD patterns of AlN films deposited under var-

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