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Enhanced c-axis orientation of aluminum nitride thin films by plasma-based pre-conditioning of sapphire substrates for SAW applications

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ABSTRACT

Aluminum nitride (AlN) on sapphire has been investigated with two different pretreatments prior to sputter deposition of the AlN layer to improve the orientation and homogeneity of the thin film. An inverse sputter etching of the substrate in argon atmosphere results in an improvement of the uniformity of the alignment of the AlN grains and hence, in enhanced electro-mechanical AlN film properties. This effect is demonstrated in the raw measurements of SAW test devices. Additionally, the impulse response of several devices shows that a poor AlN thin film layer quality leads to a higher signal damping during the transduction of energy in the inter-digital transducers. As a result, the triple-transit signal cannot be detected at the receiver.

1. Introduction

Surface acoustic wave (SAW) devices have been investigated for several decades, leading to several commercially successful applications [1,2]. SAW devices are commonly used as band pass filters and resonators in the communication industry [3] or as wireless sensors for physical quantities such as pressure or temperature [4,5]. Such wireless devices need a rather large bandwidth to operate and only a few license-free frequency bands can be used [6]. 2.45 GHz is one of the suitable frequencies. Existing temperature sensors are operating up to 1000 °C and up to 200 MHz using langasite (LGS) as a piezoelectric substrate [7]. A disadvantage of this system is the low phase velocity of around $v_p = \sim 2700$ and the high propagation losses at higher operation frequencies [8]. Aluminum nitride (AlN) on sapphire substrates on the other hand promises SAW devices with very high operating frequencies in the GHz range, due to the high phase velocity $v_p = \sim 5700$ m/s of the surface acoustic wave [9]. In addition, these materials promise a high robustness even for harsh environments applications, like in pure oxygen atmosphere [10]. Most recently, an *in situ* surface pretreatment of silicon substrates prior to sputter deposition proved to be most beneficial to improve the piezoelectric coefficients of AlN [11]. However, this effect and the impact on the SAW performance has not yet been reported for AlN on sapphire substrates.

2. Experimental details

In this study, the enhanced quality of DC reactively sputter-deposited AlN thin films at low deposition temperatures (i.e. $T_{max} = 110$ °C) by pure plasma-induced self-heating is demonstrated for SAW applications. The temperature was measured at the backside of the wafer holder using a pyrometer. The focus is on the influence of the pre-treatment of the sapphire surface prior to AlN layer deposition. AlN thin films (thickness h = 500 nm) were deposited onto two 4 in. c-plane sapphire α-Al_2O_3 substrates applying the same DC reactive magnetron sputter parameters (800 W power, 2 μbar chamber pressure in pure nitrogen plasma, 65 mm target substrate distance) in an equipment from "Von

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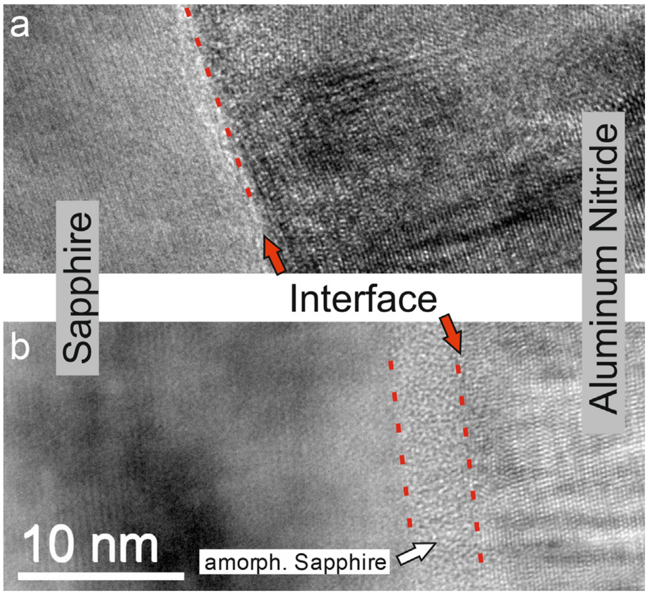

Fig. 1. HRTEM images of AlN on top of sapphire substrates exposed to different pre-treatments before AlN deposition, (a) T1 (ultrasonic cleaning) and (b) T2 (*in situ* ISE cleaning).

Ardenne" (LS730S). The substrates were conditioned with two different surface pre-treatments. One wafer (T1) was placed in acetone and isopropanol ultrasonic baths for 5 min each. The other wafer (T2) was exposed to an inverse sputter etch (ISE) process at 500 W for 5 min in pure argon atmosphere at a pressure of 6 μbar and a target substrate distance of 65 mm *in situ* prior to AlN thin film deposition.

To investigate the microstructure of the AlN thin film, high-resolution transmission electron microscopy (HRTEM) analyses were performed using a TECNAI F20 from FEI at an acceleration voltage of 200 kV. Furthermore, X-ray diffraction (XRD) measurements in Bragg-Brentano configuration and a Rocking curve were measured using an X'Pert MPD Pro and Empyrean (PANalytical) powder diffractometer in θ-θ geometry, equipped with a Cu anode operating at 45 kV, 40 mA providing a wavelength of λ = 1.5406 Å (CuKa1) and λ = 1.5444 Å (CuKa2), respectively.

To analyze the influence of the different pre-conditioning steps on device level, test structures based on SAW delay lines with a wavelength between 8 μm and 24 μm, 40 finger pairs and an aperture of 1400 μm with distances of 2175 μm, 4350 μm and 6525 μm were fabricated. The 100 nm thin aluminum electrodes were patterned using standard lithography and a lift-off process. The characterization of the delay lines (i.e. S_{21} parameter measurements) was performed at room temperature using a standard network vector analyzer HP8753E from Hewlett Packard.

Additionally, the influence of a slight misalignment of the c-axis oriented grains relative to the surface normal direction was simulated for the same structure, using full finite element method (FEM) applying a perfectly matched layer (PML) approach[12]. The AlN-related material parameters such as compliance matrix used

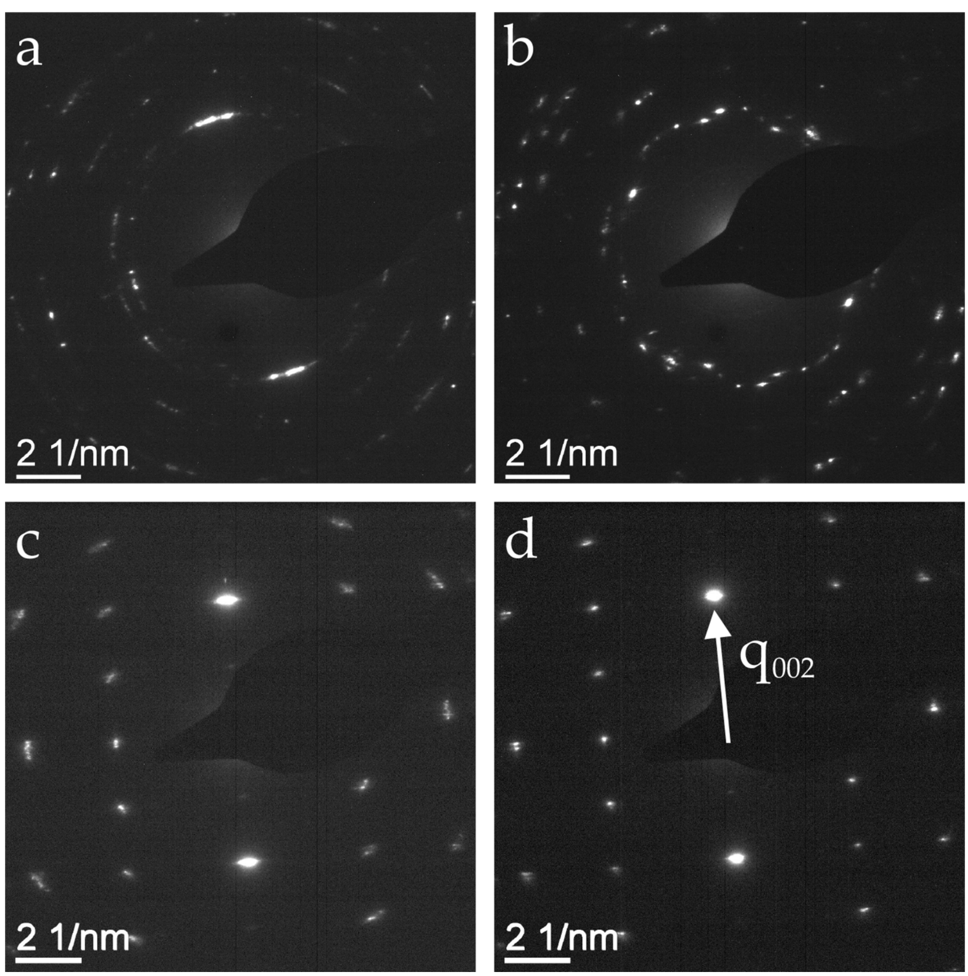

Fig. 2. AlN diffraction pattern of T1 (a) and T2 (c) near the interface (~40 nm) and T1 (b) and T2 (d) in a distance of 400 nm from the interface.