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Pulsed laser deposition of piezoelectric ZnO thin films for bulk acoustic wave devices

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ABSTRACT

Piezoelectric properties of ZnO thin films have been investigated for micro-electro-mechanical systems (MEMS). Wurtzite ZnO structure was prepared on different substrates (Si (1 0 0), Pt (1 1 1)/Ti/SiO_2/Si and Al (1 1 1)/SiO_2/Si) at different substrate temperatures (from 100 to 500 °C) by a pulsed laser deposition (PLD) technique. X-ray diffraction (XRD) characterization showed that the ZnO films were highly *c*-axis (0 0 2) oriented, which is of interest for various piezoelectric applications. Scanning electron microscopy (SEM) showed evidence of honeycomb-like structure on the surface and columnar structure on the cross-section. In the case of ZnO on Al, ZnO exhibited an amorphous phase at the ZnO/Al interface. The XRD measurements indicated that the substrate temperature of 300 °C was the optimum condition to obtain high quality (strongest (0 0 2) peak with the biggest associated grain size) of crystalline ZnO on Pt and on Al and that 400 °C was the optimum one on Si. ZnO on Al exhibits smallest rocking curve width than on Pt, leading to better crystalline quality. The ZnO films were used in bulk acoustic wave (BAW) transducer. Electrical measurements of the input impedance and *S*-Parameters showed evidence of piezoelectric response. The electromechanical coupling coefficient was evaluated as K^2_{eff} = 5.09%, with a quality factor Q_r = 1001.4.

1. Introduction

Zinc oxide (ZnO) is well known as a material having notable and stable piezoelectric properties. Owing to their large electromechanical coupling coefficient, ZnO thin films became of interest for various micro-electro-mechanical systems (MEMS) applications such as high-frequency acoustic transducers, actuators and sensors. In telecommunication devices, they are used as bulk acoustic wave (BAW) and surface acoustic wave (SAW) resonators and filters [1–5]. Several techniques are used for ZnO elaboration. Pulsed laser deposition (PLD) is considered as one of the best techniques to obtain high quality thin films. However, the use of PLD is restricted to research purposes because of its limitation to small area thin films [6,7]. Due to its simplicity combined with its flexibility in the choice of processing parameters, it has been applied to the synthesis and the deposition of many compound films [8].

To adopt ZnO thin films in BAW and SAW devices, it is important to enhance their piezoelectric characteristics. These later are intimately linked to the microstructural features of the above-mentioned thin films [9–12]. In this paper, piezoelectric characteristics of ZnO thin films have been investigated in the perspective of their use in BAW devices. The work aims to show that these piezoelectric properties are improved by a good control of the texture, microstructure, and crystalline quality of piezoelectric ZnO films by optimizing the operating conditions for their growth (substrate type and temperature). To elaborate ZnO thin films, PLD technique is used. The experimental conditions, such as the target-substrate distance and the oxygen pressure, were previously optimized [13,14]. First, the substrate temperature is swept from 100 to 500 °C on different types of substrates; Si (1 0 0), Pt (1 1 1)/Ti/SiO_2/Si and Al (1 1 1)/SiO_2/Si. The scanning electron microscopy (SEM) characterization and X-ray diffraction (XRD) measurements are performed in order to find out the optimal temperature of the substrate which permits to obtain the best crystallinity of ZnO. Then, from the XRD rocking curves measurements (at the optimal temperature) we deduce the optimum substrate candidate corresponding to the higher crystalline quality of the deposited ZnO. Finally, electrical

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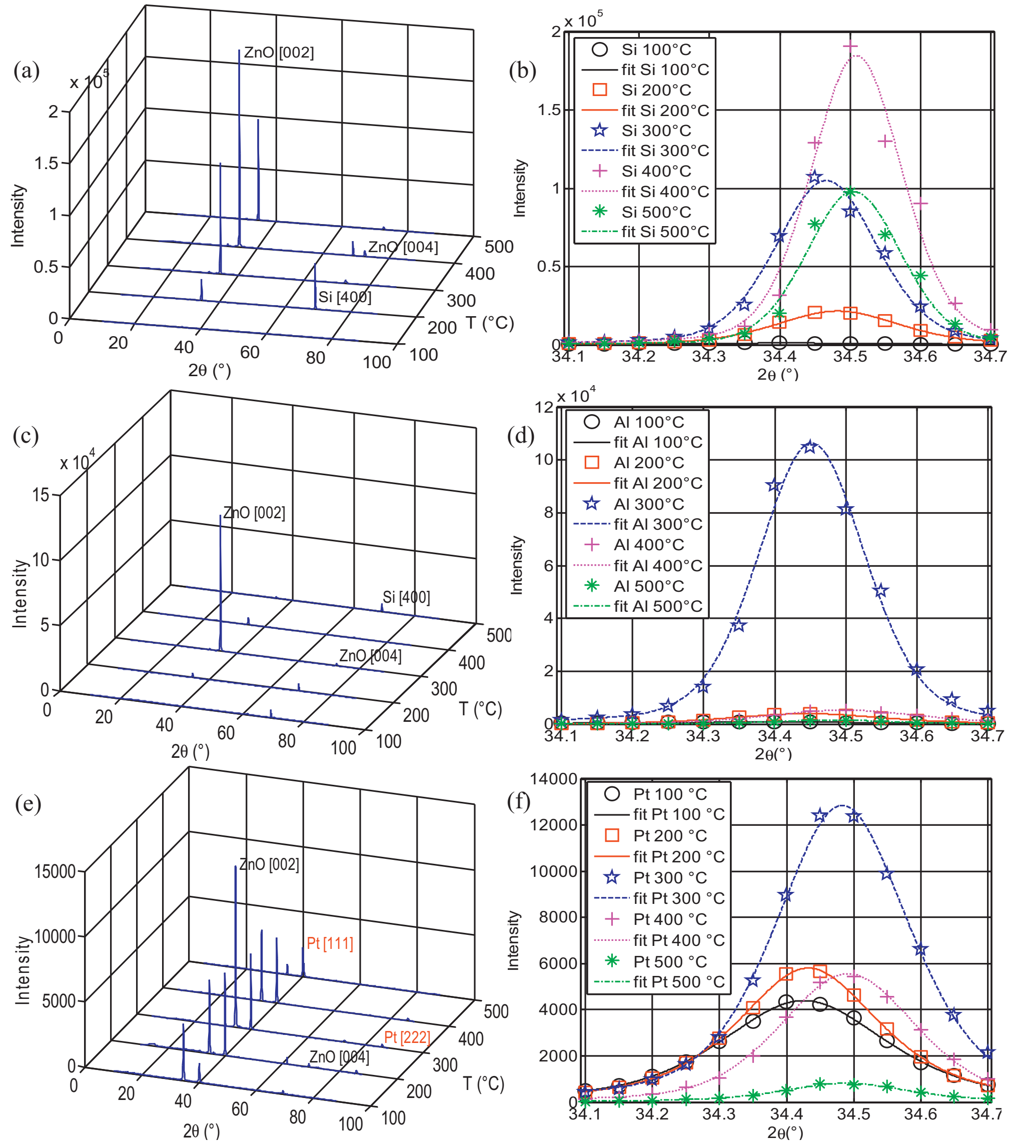

Fig. 1. XRD patterns of ZnO thin films gown at different temperatures on Si (1 0 0) substrate (a), on Al (1 1 1) (c) and on Pt (1 1 1) (e). Fit of (0 0 2) peak by pseudo-Voigt function on Si (b), Al (d) and Pt (f).

measurements of the input impedance and the *S*-parameters of the realized BAW transducers are done to evaluate their piezoelectric performances.

2. Experiment details

In the chamber of the PLD system, three substrates, which have been previously thoroughly cleaned, are disposed on the holder. These are a Si (1 0 0) substrate of 500 μm thickness, an Al (1 1 1)/SiO_2/Si (1 0 0) substrate of 0.25 μm/2 μm/500 μm respective thickness and a Pt (1 1 1)/Ti/SiO_2/Si (1 0 0) of 0.2 μm/0.02 μm/2 μm/500 μm respective thickness. The SiO_2 film is performed by a silicon wet oxidation step, under ($H_2 + O_2$) (5 slm + 3.5 slm) gas flows at a temperature of 1100 °C for 9 h10 min. All metals are deposited by an electron beam evaporation (EBE) system. The Ti is flash-deposited to favor the adhesion of Pt (the bottom electrode) on SiO_2. The substrates are, then, mechanically attached to a heating block of the PLD system. The temperature is monitored by means of a power generator which keeps the current and the voltage at constant values. The target, a sample of compacted and sintered ZnO powder, is fixed on a holder located at 4 cm far from the substrate holder [13]. During laser irradiation, the target is rotated to avoid crater formation. The beam of a 5 Hz pulsed KrF laser (λ = 248 nm, τ = 25 ns), is directed at 45° with respect to the target normal and is focused on its surface at a fluence fixed at 2 J/cm^2. Before starting the deposition, the chamber is previously evacuated to attain a vacuum of 10^{-6} mbar. It is, then, filled with oxygen up to 2.10^{-2} mbar [14]. We proceed, first, with a pre-ablation for 5 min to clean the target. The deposition of ZnO is performed during 90 min at different substrate temperatures (100, 200, 300, 400 and 500 °C). The surface morphology of the grown films and their cross sections are analyzed by scanning electron microscopy (SEM-JOEL 6400) and the films structure is determined by using a Bruker D8 Advance X-ray diffractometer ((θ,2θ), Cu $K\alpha$ and λ_0 = 1.5406 Å).

For the realization of the BAW transducer, a circular top electrode is made on the surface of ZnO by thermal evaporation of Aluminum through a mask. The piezoelectric film is confined in circle of 1.5 mm radius. The measurements of the *S*-parameters and electrical input impedance are performed by means of a HP8753ES network analyzer.