Epitaxial ZnO Films on $LiNbO_3$ Substrates for Surface Acoustic Wave Applications

S. Kuprenaite, S. Margueron, C. Millon, and A. Bartasyte
Institute FEMTO-ST
UBFC, ENSMM, CNRS UMR 6174
Besançon, France
sabina.kuprenaite@femto-st.fr

L. Arapan
Senseor
Besançon, France

P. Boulet
Institute Jean Lamour
University of Lorraine, CNRS UMR7198
Nancy, France

***Abstract*— Epitaxial Z-ZnO, Y-ZnO, and X-ZnO films with high crystalline quality were grown epitaxially on Z- /X-, Y- , and 41°Y-/36°Y- cuts of $LiNbO_3$ substrates, respectively. Good acoustical performance of single port resonators on ZnO films on Y-$LiNbO_3$ and Y-41° $LiNbO_3$ substrates was demonstrated.**

***Keywords*— ZnO; epitaxy; lithium niobate; SAW**

I. Introduction

Zinc oxide thin films, as a multi-functional material, many years have been widely studied for various applications, such as transparent electrodes, solar cells, sensing materials of gas sensors, etc. Recently, ZnO renewed the interest as growth technologies are being developed to fabricate high quality single crystals and epitaxial layers to be applied in ZnO-based acoustic, electronic and optoelectronic devices. Notably, ZnO exhibits remarkable piezoelectricity, good electromechanical coupling coefficient, low dielectric constants, easily controlled crystal structure and stoichiometry. All of the above makes ZnO films one of the most optimal ones for surface acoustic wave (SAW) device applications. High frequency and low loss SAW devices can be obtained when ZnO films are deposited on top of a high-velocity substrate, such as sapphire and $LiNbO_3$. The performance of these devices is critically dependent on orientation and quality of ZnO films.

The preferential growth direction of ZnO thin films is along the Z-axis and the textured growth of this orientation can be easily obtained on any substrate. Therefore, this orientation is highly studied for the SAW applications. X-axis oriented ZnO film are very interesting due to possibility to excite pure shear mode waves [1], while ZnO films with oblique C-axis have found a major interest in SAW sensor applications, due to exploitation of longitudinal and shear waves. The integration of ZnO films with ferroelectric $LiNbO_3$ substrates opens the new perspectives for the next generation acostic/optic devices [2] through the possibility to control interface charge density [3] and to increase the electromechanical coupling significantly [4,5]. These advanced devices require extremely high quality of the film orientation and very well controlled interface quality. However, there are only few studies in literature on epitaxial ZnO films on $LiNbO_3$ substrates and especially on the films oriented not along Z-axis. The SAW device performanceof such films was little studied experimentally, as well.

In this work we present structural characteristics and growth mechanisms of different epitaxial orientations of ZnO – (0002) or Z-axis, $(10\bar{1}0)$ or Y-axis, $(11\bar{2}0)$ or X-axis on different cuts of $LiNbO_3$. Moreover, the performance of single-port SAW resonators fabricated on ZnO/$LiNbO_3$ heterostructures was studied experimentally.

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II. Methods/Results

ZnO thin films were fabricated using radio frequency magnetron sputtering technique. The deposition process was carried out at 0.60 – 1.25 W/cm² power with gas composition of 40% Ar + 60% O_2 under a total working pressure of 2.5 mTorr. Substrate temperature during depositions was varied from RT to 650°C with a growth rate of 1.6 nm/min and 2.7 nm/min at lower and higher sputtering power, respectively.

ZnO films were structurally characterised by X-ray diffraction (XRD), either with conventional Bragg-Brentano diffractometers or with a four circle diffractometer, in order to estimate the epitaxial quality of the films (rocking curves, ϕ-scans). Surface morphologies were observed by atomic force microscopy (AFM) and optical microscopy. Film thicknesses were measured by profillometer.

Single-port resonators were fabricated using deep UV lithography (Fig. 1). Al electrodes were deposited by e-beam evaporation with a thickness of 200 nm. The resonators were characterized by admittance measurements, using a Rohde & Schwarz Vector Network Analyzer (VNA). The frequency response was investigated in the range from 1 MHz to 1 GHz.

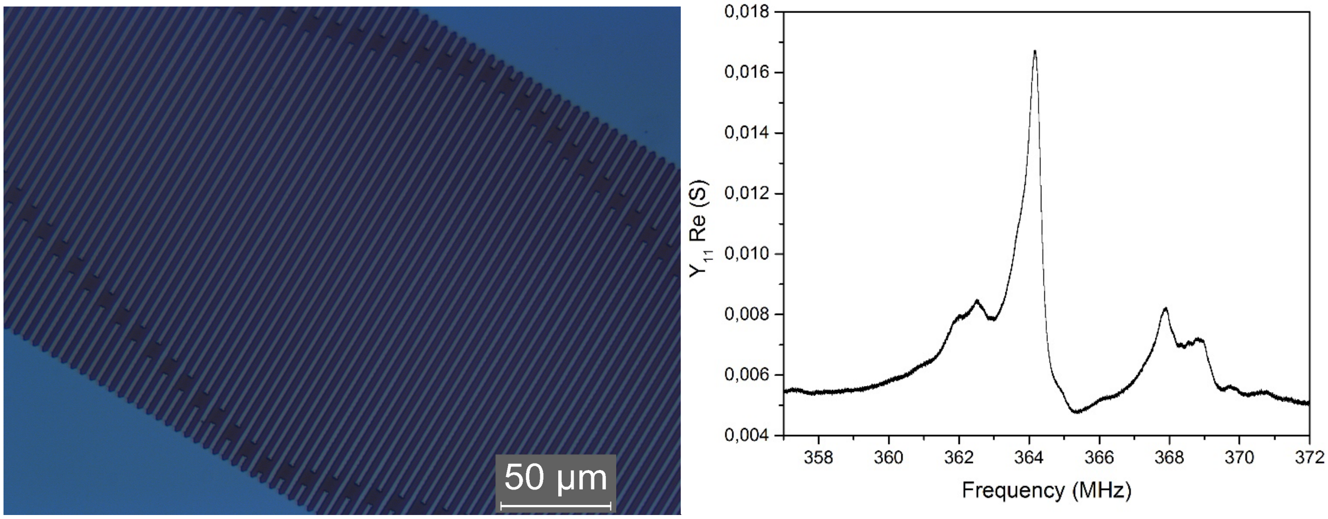

Fig. 1 Optical image of IDT/ZnO/Y-41°$LiNbO_3$ SAW resonator with wavelength of 10 µm (left). Conductance as a function of frequency of single port SAW resonator with wavelength of 10 µm and propagation direction along X-axis of $LiNbO_3$ in ZnO/Y-41°$LiNbO_3$ heterostructure (right).

Epitaxial ZnO films oriented (0002) or Z-axis, $(10\bar{1}0)$ or Y-axis, $(11\bar{2}0)$ or X-axis were grown epitaxially on the Z- /X-, Y- , and 41°Y-/36°Y- $LiNbO_3$ substrates, respectively. Epitaxial relationships between ZnO and $LiNbO_3$ were identified. The FWHM (full width at half maximum) of the XRD reflections in rocking curves and φ-scans were lower than 1.5 ° in all epitaxial structures.

Single-port SAW resonators with wavelength of 10 µm were fabricated on 150 nm thick ZnO films on Y-$LiNbO_3$ and Y-41° $LiNbO_3$ substrates. X(Z)-axis of ZnO was parallel to Z(X) of Y-$LiNbO_3$ and Y(Z)-axis of ZnO was parallel to X(Y-115°) of Y-41° $LiNbO_3$. The different modes were observed along X- and Y- propagation axis, especially for SAW resonators on ZnO/Y-$LiNbO_3$. The velocity of LSAW mode propagating along X-axis was higher by 280 m/scomparing to that of Rayleigh mode propagating along Z-axis. The k^2 of 2.06 % (Q=19.89) and 1.45 % (Q=102.28) were obtained for LSAW and Rayleigh modes in ZnO/Y-$LiNbO_3$, respectively. The highest Q (193.09) along with the relatively high velocity (3641 m/s) was obtained for SAW resonators on ZnO/Y-41°$LiNbO_3$ (Fig. 1).

III. DISCUSSION/INTERPRETATION

In this work, we have demosntrated a possibility to grow epitaxial ZnO films with high crystalline quality on different cuts of $LiNbO_3$ and the ZnO/$LiNbO_3$ heterostructures with new orientation combinations were proposed. In literature, SAW devices based on Y-ZnO/Y-$LiNbO_3$ were not studied experimentally, but the theoretical studies have indicated that in the optimized SAW devices on this hetrostructure can attain electromechanical coupling as high as 10 % and > 25 % for Rayleigh wave and LSAW, respectively. Our experimantally measured acoustic velocities were in a good agreement with simulated ones, reported in literature and the good acoustical performance of these heterostructures was demonstrated.

IV. Conclusions

Epitaxial Z-ZnO, Y-ZnO, and X-ZnO films with high crystalline quality were grown epitaxially on almost all basic cuts of $LiNbO_3$ substrates (Z-, X-, Y- 41°Y-, and 36°Y- cuts). Good acoustical performance of single port resonators on ZnO films on Y-$LiNbO_3$ and Y-41° $LiNbO_3$ substrates was demonstrated. This work opens new orientation combinations for ZnO/$LiNbO_3$ heterostructure. Thus, further optimation of the SAW device design of these new combinations has to be done in order to attain the highest SAW device performance possible.

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