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ZnO/sapphire based layered surface acoustic wave devices for microfluidic applications

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Abstract- The microfluidic applications of a ZnO/Sapphire based layered surface acoustic wave structure are being investigated. Properties of the ZnO/Sapphire layered SAW device including surface wave velocity and propagation loss were measured and correlated to the fluidic behavior of micro droplets. Acoustic streaming was observed in the form of two vortices. Micro particles were also observed to concentrate in the vortices within 4 seconds of device activations.

I. INTRODUCTION

Surface acoustic wave (SAW) microfluidics has generated considerable interest. SAW technology offers simpler and more compact devices and do not involve moving parts. The fluid-acoustic energy interaction arising from SAW can be harnessed to generate various types of micro to nano liter scale fluid manipulation. Depending on the actuation power, the manipulation could be in form of mixing, transport or even atomization [1-10].

There is also considerable interest in using thin film piezoelectric materials for SAW microfluidics due to several advantages. The foremost would be the possibility of incorporation with controller circuits to achieve an integrated Lab-On-a-Chip (LOC) device.

ZnO is a versatile material for many applications due to its structural, electrical and optical properties [11-12]. Piezoelectric ZnO possesses a high coupling coefficient, which make it attractive for thin films SAW devices. ZnO thin films have been deposited by several techniques, including sol-gel, MOCVD, MBE, PLD and sputtering. Among these techniques, sputtering is the most commonly used deposition method for polycrystalline ZnO, typical for acoustic applications.

SAW microfluidics devices based on thin film ZnO has been recently reported and showed promising results. Du et al [13-15] has developed a SAW device using deposited thin film ZnO on a silicon substrate; and showed the feasibility of utilizing it for microfluidics manipulation.

There is furthermore, an increasing interest in developing surface acoustic wave (SAW) devices operating at high frequencies without fabricating submicron electrode. By depositing a piezoelectric thin film on a high acoustic velocity substrate, the surface velocity can be significantly increased.

Sapphire (Al_2O_3) substrate is widely used for its high acoustic velocity and relatively low loss. ZnO on sapphire devices have been reported [16-20], yet it usage for microfluidics is limited to date. For this reason, in this work, we correlate the ZnO/Sapphire device characteristics with the fluidic manipulation. The fabrication of ZnO/sapphire layered structures is detailed, the SAW frequency response characteristics are measured, and the interaction of the acoustic wave and the coupled fluid is discussed.

II. EXPERIMENTAL

ZnO thin films were deposited on sapphire (0001) substrate by RF magnetron sputtering (Hummer BC-20 DC/RF Sputter system, Anatech USA). The substrate temperature during the deposition process was 150ºC and a sequential post-annealing treatment was carried out at 500ºC for 5 hrs in ambient air. This was done to provide sufficient energy to rearrange the atoms in the crystal sites and also to eliminate the intrinsic stress induced by sputtering. The sputtering rate was approximately 0.25 µm/hour.

TABLE I: ZnO deposition process parameters

Target	ZnO (purity 99.99%)
Target-substrate distance	~12cm
Sputtering gas	60% Ar + 40% O2
Substrate temperature	150ºC
RF power	150W
Sputtering pressure	10mTorr

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The crystalline structure of ZnO on sapphire was examined by X-ray diffraction with Cu Kα, λ of 0.1542 nm (Phillips X-ray Diffractometer); and the surface morphologies were observed with atomic force microscopy. The XRD result in Fig. 1 shows the high *2θ* intensity at *34.4º*. This angle, representing (002) diffraction peak, indicates that the ZnO deposited on sapphire is c-axis oriented. The SEM cross-section showed the ZnO grew in a column structure. The AFM scan reveals a surface roughness of ~6nm over a 5x5 µm scan area. The c-axis orientation and smooth surface are critical parameters of a SAW device.

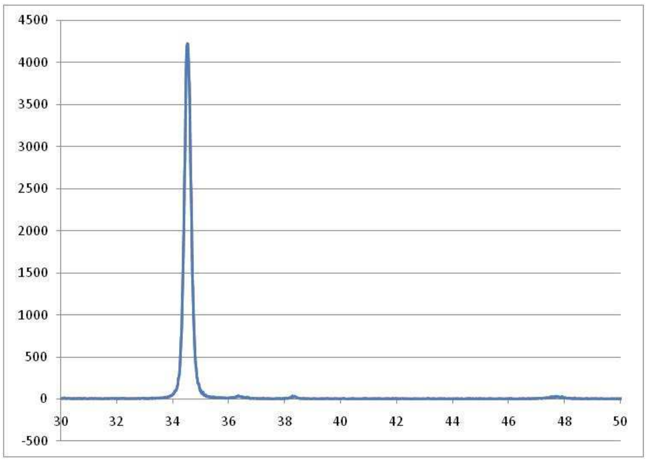

Fig. 1. XRD result of the sputtered ZnO on sapphire substrate. Diffraction peak is observed at *2θ* of *34.4º*, which indicates the (002) crystallographic orientation.

The interdigital transducer (IDT) patterns were transferred on to the ZnO surface using a conventional lift-off process. The IDT consists of an adhesion layer of 10nm Cr and 200nm of Au, which were thermally evaporated. Both the width and the spacing of the IDT patterns were 8µm, which corresponds to a wavelength of 32µm.

The frequency response of the ZnO/Sapphire SAW structure was measured using a network analyzer (Agilent E5062A). A set of experiments were conducted to examine the effects of acoustic streaming in a droplet using the fabricated ZnO/sapphire based layered device. Water droplet with a volume of 1 µL seeded with 4.8 µm size fluorescent polymer microspheres (Duke Scientific Corporation, USA) was placed onto the surface of ZnO, in the propagation pathway of the SAW for flow visualization. The images were captured using a high speed camera (Motion BLITZ, Mikroton GMBH). The input power was provided using a signal generator (Agilent N9310A) coupled with an amplifier (Model 10W 1000C, Amplifier Research). The power input to the IDT was monitored using a power sensor (U2004A, Agilent Technologies).

III. Results and Discussions

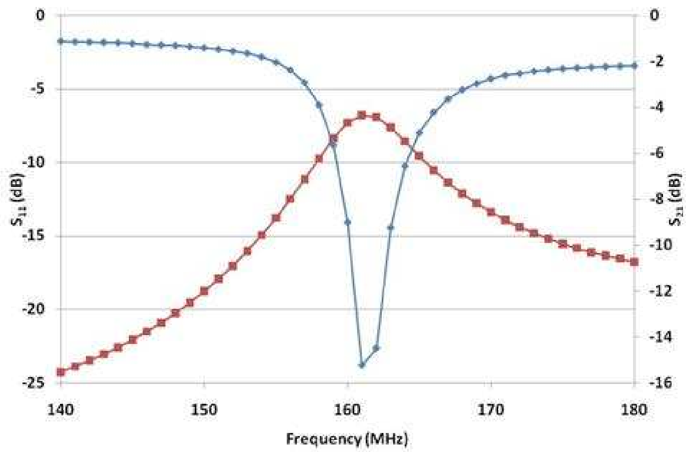

Fig. 2. Frequency Response S_{11} and S_{21} of the ZnO/Sapphire SAW devices

Fig. 2 shows the measured frequency response of the fabricated ZnO/Sapphire device. The SAW device is designed to have a value of λ = 32µm. The thickness (h) of ZnO film is 1 µm (h/λ = 0.03), while the centre frequency is 161MHz. The calculated phase velocity is 5152 m/s from the relation $V_p=F_o.\lambda$. In Fig. 3, the successive images of the SAW streaming inside a 1 µL water droplet seeded with 4.8 µm fluorescent particles is shown. The IDT is located to the right of the droplet. The particles are concentrated in the two vortices within 4 seconds of IDT activations.

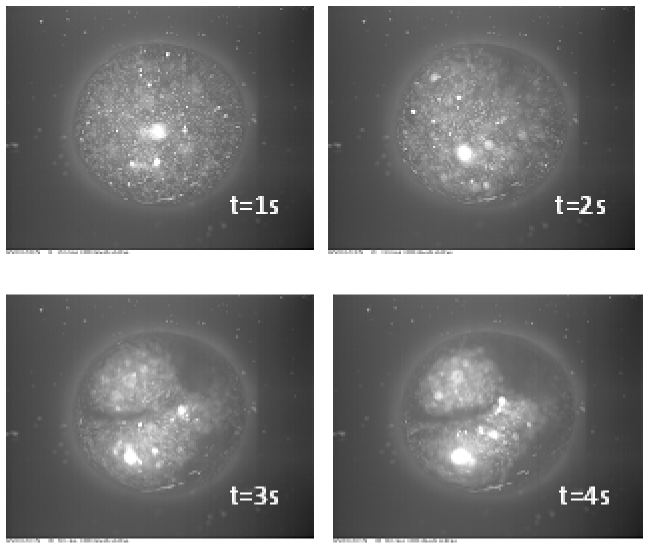

Fig. 3. Successive images of the SAW streaming inside a 1 µL water droplet seeded with 4.8 µm fluorescent particles. The IDT is located to the right of the droplet. The particles are concentrated in the two vortices within 4 seconds of IDT activation.

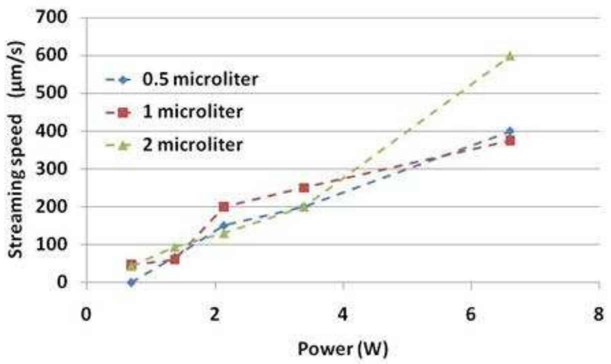

Fig. 4. Acoustic streaming speed of the water droplet resulted from increasing input powers (frequency of 158 MHz)

The streaming speed with respect to increasing input power is shown in Fig. 4. Three different volumes of water droplet were used. A maximum streaming speed of 600µm/s was observed for an input power of 6.61 W at frequency of 158 MHz.

In Fig. 5 the acoustic streaming speeds of droplets with the same volumes (1µL) but with different input frequencies are compared. The device operated at 158MHz showed higher streaming speed than at 161MHz, approximately up to 4 times. This frequency shift could be due to damping caused by the droplet, which is placed in the propagation pathway of the SAW.

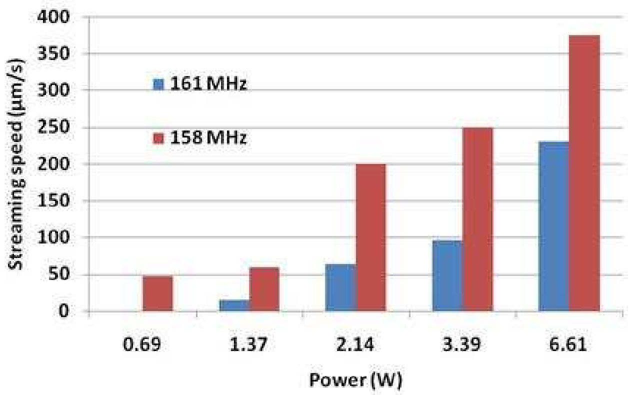

Fig. 5. Comparison of the streaming speed for different input frequencies.

One interesting phenomenon that occurs in a thin film SAW device is the occurrence of the higher order harmonic wave. This wave, called the Sezawa wave, appears in addition to more commonly observed Rayleigh wave. The Sezawa wave normally has a higher phase velocity than the Rayleigh wave; this is attributed to the higher resonance frequency of this mode [16-18]. It has been reported that the electromechanical coupling coefficient (K^2) of the Sezawa mode is up to 4 times higher compared to the Rayleigh mode for the same devices [21].

The Sezawa waves appearances nevertheless, are very limited. They only appear in multiple layers substrate; and only if to the acoustic velocity of the surface layer lower than or equal to the acoustic velocity in the lower substrate [16-19]. Not only that the material selection must be satisfied, another essential requirement for the Sezawa wave to appear is that the surface layer thickness and the acoustic wavelength must be over a certain ratio; $h/\lambda \geq 0.15$, in which h and λ are the film thickness and acoustic wavelength, respectively [16-18].

It is within the scope of this work to utilize the Sezawa wave for microfluidics. ZnO film with various thicknesses has been deposited onto sapphire substrates using the same parameters, as given in Table 1. Work on characterizing the Sezawa waves and fluidic coupling are being carried out. By employing the Sezawa waves, more efficient acoustic streaming is expected. Comparison of the acoustic streaming caused by the Rayleigh and Sezawa waves shall be presented.

IV. Conclusions

The acoustic streaming in droplets has been investigated using a ZnO/sapphire based layered device. Acoustic streaming was observed in the form of two vortices. Micro particles were also observed to concentrate in the vortices within 4 seconds of device activation. A maximum acoustic streaming of ~600µm/s was observed when the device was operated at 158MHz. Furthermore, work on utilizing a higher order harmonic wave, called the Sezawa wave is being conducted. The acoustic steaming result shall be presented.

Acknowledgment

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