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DROPLET MANIPULATION USING ZnO/SAPPHIRE BASED SAW DEVICES

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ABSTRACT

The hybrid ZnO/Sapphire material is selected to exploit the collective benefits of Zinc Oxide (ZnO) and sapphire for the development of a high performance Surface Acoustic Wave (SAW) device. The microfluidic applications of ZnO/Sapphire layered surface acoustic wave devices are discussed. In addition, acoustic streaming in droplets is investigated using a custom-made ZnO/Sapphire layered device. Experimental results show that a maximum acoustic streaming of ~600 μm/s is achieved when the device is operated at 158 MHz.

INTRODUCTION

There has recently been an increasing interest in developing high frequency surface acoustic wave (SAW) by depositing a piezoelectric thin film on a high acoustic velocity substrate.[1,2] SAW technology offers simpler and more compact devices without involving moving parts. The interaction of fluid with acoustic energy arising from SAW can be exploited for fluid manipulation at micro to nano scale.

ZnO is a multifunctional material for several applications because of its structural, optical and electrical properties.[3,4] Piezoelectric ZnO materials possess high electromechanical

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coupling coefficients, which make them attractive for realizing thin films SAW devices. In contrast, sapphire (Al_2O_3) substrates are widely used for their high acoustic velocity ((~10,000 m/s) and relatively low loss.[5] The high acoustic velocity of sapphire eliminates the need for sub-micron IDT patterning. The potential approach of developing a hybrid ZnO/Sapphire [6–8] SAW device is desirable as it enables the fabrication of microfluidic devices for various applications, such as biomedical and environmental sensing.

Various conventional deposition techniques, such as sol-gel, pulsed laser deposition (PLD), molecular beam epitaxy (MBE), metal organic chemical vapour deposition (MOCVD) and sputtering have been used to prepare ZnO thin films. Each deposition method has advantages, depending on the specific application that it is used for. Sputtering, however, is currently the most commonly used deposition technique for the preparation of polycrystalline ZnO, which is the most favored material for acoustic applications. Sputtering offers several advantages, such as deposition at low substrate temperatures and high sputtering rates, the fabrication of thin films with a uniform surface and excellent crystallinity. In this paper, we investigate acoustic streaming in droplets placed on a ZnO/Sapphire layered device. Experimental results show that a maximum acoustic streaming of ~600 μm/s can be attained when the device is driven by a 158 MHz sine wave.

EXPERIMENTAL

In this study, a ZnO thin film was deposited on a sapphire substrate using a radio-frequency magnetron sputtering system. A 99.99% pure, 3-inch diameter ZnO target was used to sputter ZnO onto a sapphire substrate. The sputtering power was 150W and the deposition process parameters are listed in Table 1. Post-annealing treatments were sequentially carried out at 500°C for 5 hrs in ambient air to eliminate the intrinsic stress induced by sputtering and also to provide sufficient energy to ensure that ZnO molecules are crystallized. The ZnO film thickness was measured using a surface profilometer, and X-ray diffraction was used to analyze the crystallographic structure of the ZnO film.

After the required film quality has been evaluated, SAW devices were fabricated on the ZnO thin films. Inter Digital Transducer (IDT) patterns were transferred on to the ZnO surface by conventional lift-off process. The IDT consists of an adhesion layer of 10 nm Cr and 200 nm of Au, which were thermally evaporated. The IDT was designed to have 60 numbers of finger-pair with 8 μm dimension for both the width and the spacing, which corresponds to a wavelength of 32 μm.

Table 1: ZnO Deposition Parameters

Target	ZnO
Process gas	60% Ar + 40% O_2
Substrate temperature	150°C
RF power	150 W
Process pressure	10 mTorr

RESULTS AND DISCUSSION

The XRD data plotted in Figure 1 show the high 2θ intensity at 34.4°, which represents a (002) diffraction peak, indicating that the ZnO deposited on sapphire is c-axis oriented. The deposited ZnO film was required to be c-axis oriented, due to its high electromechanical coupling coefficient. Several SAW devices were made with Cr/Au fingers for $\lambda = 32$ μm. All ZnO films had a thickness (h) of 1 μm ($h/\lambda = 0.03$).

The measured centre frequency and the calculated phase velocity were 161 MHz and 5152 m/s, respectively. The fabricated SAW devices were utilized to induce acoustic streaming in a sessile droplet. Figure 2 shows the successive images of the SAW streaming inside a 1μL 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 activations. The streaming speed with respect to increasing input power is shown in Figure 3.

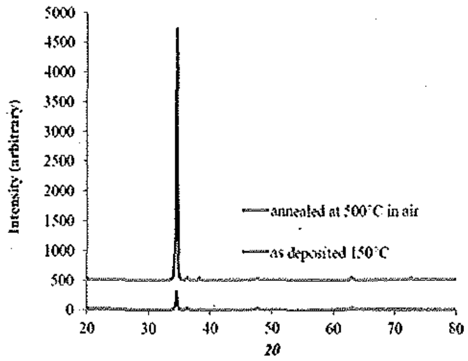

Fig. 1: XRD Spectra of Sputtered ZnO Film on Sapphire Substrate

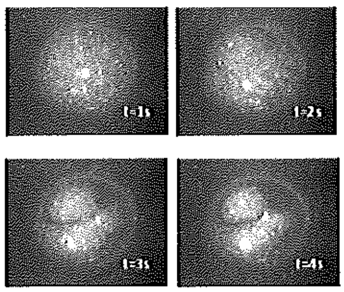

Fig. 2: Successive Images of the SAW streaming inside a 1 μL water droplet seeded with 4.8 μm fluorescent particles. The IDT is located to the right of the droplet. The particles are concentrated in the two vortices within 4 seconds of IDT activations.

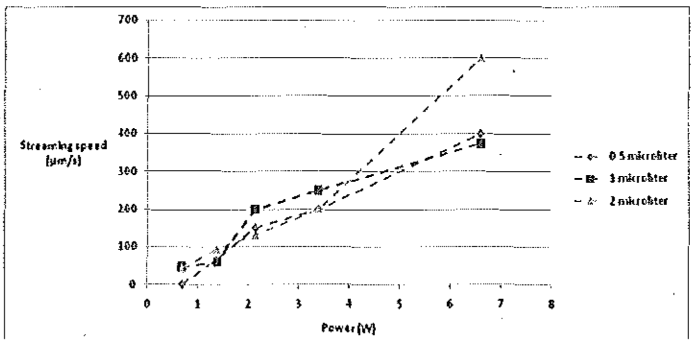

Fig. 3: Acoustic Streaming Speed of the Water Droplet Versus Input Power (RF frequency of 158 MHz)

Three different volumes of water droplets were used in the experiments, and a maximum streaming speed of 600 μm/s was observed.

Acoustic streaming was a steady fluid motion that resulted from the propagation of acoustic waves through a dissipative fluid medium. As the acoustic waves attenuated in the fluid medium, it generated a gradient in the momentum flux. This induced a Reynolds stress, causing the steady fluid velocity.

CONCLUSION

Acoustic streaming in micro droplets has been investigated using a ZnO/Sapphire based layered device. Acoustic streaming has been observed in the form of two vortices. Results have shown that micro particles can concentrate in the form of vortices within 4 seconds of IDTs activations. A maximum acoustic streaming of ~600 μm/s has been measured when the device was operated at 158 MHz. These results have application in biomedical and environmental sensing.

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