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Fabrication of ultrasonic focusing ejector by using C-axis textured ZnO films

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Abstract

Four-level Fresnel lens and piezoelectric transducer were fabricated as an ejector using focused ultrasonic energy. Highly c-axis textured ZnO films were successfully deposited on Pt (annealed)/Ti/SiO_2/Si substrate under feasible conditions. These conditions were to be applied and confirmed through investigating the influences of RF sputtering parameters on the properties of ZnO films.

1. Introduction

Ultrasonic focusing ejector is capable of ejecting small droplets of controlled diameter from a free liquid surface by focusing high-frequency acoustic wave without nozzles. The key elements of an ejector include a piezoelectric transducer and an ultrasonic focusing lens. Different types of ultrasonic focusing lens were investigated and fabricated such as spherical lens, reflection wall [1)] and Fresnel lens.[2,3)] Fresnel lenses are able to offer an advantage of planar geometry and relative ease of fabrication over other forms of the lens but the geometry is critical for efficient focusing, and thus tight thickness control of the lens elements is usually needed. The design and fabrication of "binary" acoustic Fresnel lenses which use multiple-phase levels to approximate the curvature of spherically focusing field offer high efficiencies was performed.[3)]

Piezoelectric transducer has been used to generate ultrasound being subsequently focused by acoustic lens for the purpose of droplet ejection. ZnO film is a promising material that is most studied and widely applied in piezoelectric transducers and sensors due to good piezoelectric properties and high electro-mechanical coupling coefficient. Several techniques have been developed for forming ZnO films. These techniques include radio frequency (RF) sputtering,[4)] pulsed laser deposition,[5)] and metal organic chemical vapor deposition.[6)] The most commonly used technique is sputtering because it is possible to obtain good orientation and uniform films close to single-crystal morphology even on amorphous substrate or at low substrate temperature.

In this paper the RF magnetron sputtering method, which offers a simple process and low equipment cost, was employed to develop a feasible fabrication of thick ZnO films. The effects of deposition conditions, especially the bottom-electrode material, on the growth of ZnO films were investigated. The ZnO films were sputtered on various substrates such as Pt/Ti/SiO_2/Si and Pt (annealed)/Ti/ SiO_2/Si. Besides, four-level Fresnel lenses with operating frequency of 100 MHz and 200 MHz were designed and fabricated.

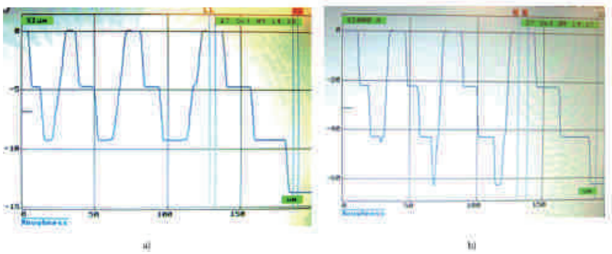
2. Experimental details

In the study, four-level Fresnel lens with their dimension as small as 250 μm was successfully fabricated by employing lithography and etching processes. As the step height of lens is too deep to coat photo resist (PR), silicon dioxide (SiO_2) was used as a hard mask in the deep etching process. A 350 nm thick SiO_2 was thermally grown. Through PR coating, exposure, development and silicon etching, the focusing lenses with a step height of 4.55 μm (100 MHz) and 2.27 μm (200 MHz) respectively were shaped. The process using other masks in lithography was repeated until a four-level Fresnel lens completed.

This study investigated the influences of bottom electrodes on the growth of ZnO film. Hence, a thin layer of SiO_2 was coated on a cleaned silicon wafer, and a 20 nm thickness of Ti film was subsequently deposited as a buffer layer to improve the adhesion between the substrate and bottom electrode. Pt was used as the bottom electrode with a thickness of 150 nm in the fabrication. To consider ZnO film growth on Pt and annealed-Pt bottom electrodes, two sets of samples were separately examined. The XRD patterns of Pt layers exhibiting a better (111) oriented Pt electrode was obtained after being annealed at 600°C for one hour. Finally, ZnO films were deposited on Pt/Ti/SiO_2/Si and Pt(annealed)/Ti/SiO_2/Si substrates through RF magnetron sputtering. The deposition conditions of the ZnO thin films are RF power of 178 W, substrate temperature of 380 ^{o}C, sputtering gas ratio (Ar/O_2) of 1 under the fixed setting of total sputter gas pressure of 1.3 Pa, and distance between the 4 inch target and substrate of 45 mm. After the confirmation of XRD patterns of ZnO films, Al evaporation and patterning was performed to shape the top electrode of the transducer. The thickness of the ZnO film was measured by Dektak^{3}ST α-step surface profiler. The X-ray diffraction (XRD) pattern of ZnO films was measured by Siemens D5000 diffractometer.

3. Results and discussions

Based on the previous fabricated focusing lens, we improved its performance using a three-mask process. The α-step measurement showed a better surface profile of Fresnel lens as illustrated in **Fig. 1**. An oblique view of Fresnel lens is shown in **Fig. 2**. It is noted that for the 100-MHz lens the 4th phase level of the lens (Fig. 1a, Fig. 2a) disappeared. The reason shows as following. One is the coated PR layer was not thick enough, and the other is a uniform coverage was not available due to a high aspect ratio to protect Si wafer surface in the etching process. Besides, due to the loading effect the last two rings of the 200-MHz lens had only three phase level and the lowest level was not etched; that is, a wafer in a smaller open area etches slowly compared with a larger one.



(a) (b)

Fig. 1. Surface profile of Fresnel lens with a three-mask process: (a) 100 MHz, (b) 200 MHz.

After a two-and-a-half-hours deposition, a ZnO film with a thickness of about 3.7 μm was obtained. **Figure 3** shows the XRD patterns of two ZnO films deposited using various conditions of Pt substrates. The ZnO film deposited on the annealed Pt electrode characterizes an apparently higher (002) orientation than the Pt substrate without being annealed does. This result is appropriate for the high frequency piezoelectric transducer application.

4. Conclusions

In this paper, two main components of an ultrasonic ejector were designed and fabricated. To obtain a precise profile of the Fresnel lens depends on the uniform thickness of PR layer in the lithography. A feasible fabrication process of the piezoelectric transducer was proposed and justified

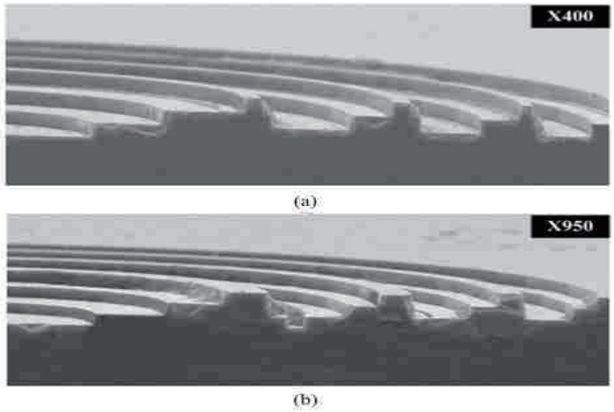


Fig. 2. Oblique view of Fresnel lens with a three-mask process: (a) 100 MHz (b) 200 MHz.

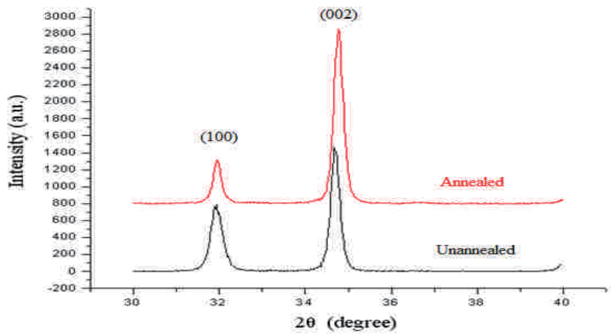


Fig. 3. XRD patterns of ZnO films deposited on Pt electrodes.

through analyzing the influences of the deposition conditions on the properties of ZnO films. ZnO films were successfully deposited on Pt (annealed)/Ti/SiO_2/Si substrate. These films show a highly c-axis orientation and satisfy the requirements of piezoelectricity for a high frequency piezoelectric transducer application.

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