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Effect of fabrication parameters on the characteristics of Fresnel lens and piezoelectric transducer

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Abstract

A two-mask fabrication process of a four-level Fresnel lens was used to evaluate its characteristics through investigating the effect of SU-8 photoresist (PR) on the profile of the focusing lens. A two-step deposition of ZnO films was applied to fabricate a piezoelectric transducer with the structure Al/ZnO/Pt/Ti/SiO_2/Si under reasonable conditions.

1. Introduction

An ultrasonic focusing lens and a piezoelectric transducer are the key components constructing an ultrasonic focusing ejector,[1)] which is capable of ejecting small droplets of controlled diameter from a free liquid surface by focusing high-frequency acoustic waves without using a nozzle. Among the ultrasonic focusing lenses, which were investigated and fabricated, such as a spherical lens, a reflection wall, a Fresnel lens,[2)] a self-focusing acoustic-wave liquid ejector,[3)]and a new type of lens using an air chamber as an acoustic reflector,[4)] Fresnel lenses offer advantages of planar geometry and relative ease of fabrication over other forms of lenses, but the geometry is critical for efficient focusing, and thus tight control of the thickness of lens elements is usually required. Therefore, the design and fabrication of "binary" acoustic Fresnel lenses, which use multiple-phase levels to approximate the curvature of a spherical focusing field and offer high efficiencies, were carried out.

Among the materials used to produce piezoelectric transducers and sensors, ZnO is a promising material that has been well studied and widely applied owing to its good piezoelectric properties and high electro-mechanical coupling coefficient. Various deposition techniques, which have been employed and developed such as sputtering,[5)] metal-organic chemical vapor deposition, and pulsed laser deposition to enhance high-quality ZnO films.

In this study, a two-step deposition with a reasonable condition was employed using the RF magnetron sputtering method to investigate the effects of fabrication parameters on the properties of ZnO films. The high c-axis orientation of ZnO films, which have been deposited on a substrate Pt/Ti/SiO_2/Si, was confirmed. In addition, a two-mask process fabrication employing SU-8 photoresist (PR) to fabricate the four-level Fresnel lenses was carried out. The influences of SU-8 PR on the profile of Fresnel lens were also indicated.

2. Experimental details

The four-level Fresnel lens was designed and fabricated for the ultrasonic ejector working at a resonant frequency of 100 MHz. The maximum redial distance and the step height of the Fresnel lens were designed as 244 μm and 4.55 μm, respectively. In this study, the inductively coupled plasma (ICP) technology was used for silicon etching (Machine type: STS Multiplex ICP). The fabrication processes of acoustic focusing lens are carried out by two cycles corresponding to two different masks. In the first cycle fabrication processes, the Si substrate is etched with the depth of $2h$, where h is the step height of Fresnel lens. And then, the wafer is aligned and exposed with 2[nd] mask and repeated the same processes only the Si etch with the depth of h in the second cycle.

To fabricate the piezoelectric transducer, a ZnO film was deposited on a Pt(150 nm)/Ti(20 nm)/SiO_2(150 nm)/Si substrate. The deposition was divided into two stages, which included an approximate 100 nm-thick ZnO film deposited in a low pressure as 0.7 Pa, RF power of 100 W and sputtering gas ratio Ar:O_2 = 1:3, followed by the second layer of ZnO film deposited until a thick enough film fulfilled under fabrication conditions such as 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. Pt was considered as one of the best materials used to make a bottom electrode for ZnO piezoelectric transducer due to its small lattice difference with ZnO film. However, to consider the ZnO film growth, a set of ZnO samples were deposited under the conditions including the substrate temperature of 380 ^{o}C and the total sputter gas pressure of 1.3 Pa since the beginning of the deposition to make a comparison with ZnO films deposited by a two-step process. The thickness and the XRD pattern of the ZnO films were measured by a Dektak^{3}ST α-step surface profiler and a Siemens D5000diffractometer, respectively. Finally, Al evaporation and patterning was carried out to produce the top electrode to complete the fabrication of the transducer.

3. Results and discussion

The four-level Fresnel lenses were successfully fabricated through a two-mask process employing SU-8 PR in the lithography. Fig. 1 illustrates a top view and its surface profile of a 100 MHz Fresnel lens after the first cycle of fabrication. The trench width and its side-wall were clearly shown. However, the side-wall of the outermost trench is not very uniform and it has a little disagreement with the designed value. This phenomenon probably causes by the loading effect because of its high aspect ratio. In addition, the exposed PR layer of the second cycle of fabrication is shown in Fig. 2. The image is quite clear even there still exists some PR in a small inter trenches. It may cause by a "T-topping" effect due to a thick film of such a high viscosity PR as SU-8. This problem was solved by applying a lower exposure dose to avoid the phenomenon of refraction index change between the top and lower PR layers.

ZnO films were deposited through RF sputtering method on the substrate $Pt/Ti/SiO_2/Si$. The XRD patterns of these films confirmed their high c-axis orientation (shown in Fig. 3). It exhibits the (002) orientation of the ZnO film deposited by a two-step method is higher than that in one-step method. The c-axis preferred orientation of ZnO film is one of the most important factors for the piezoelectric transducer of an ultrasonic ejector. Therefore, the two-step method of deposition was considered in this study because it satisfies the requirement of the device with reasonable characteristics.

(a) (b)

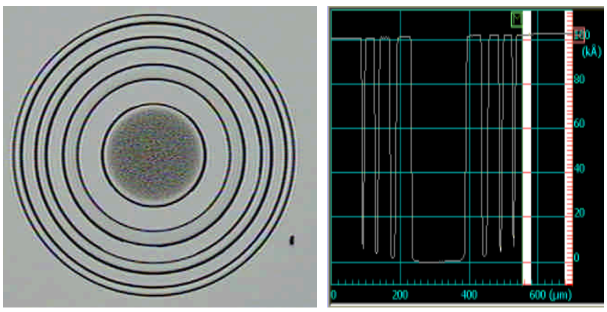

Fig. 1. First cycle of fabrication of Fresnel lens: a) top view; b) surface profile.

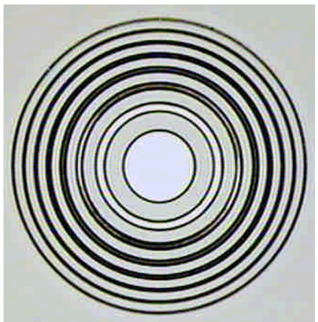

Fig. 2. SU-8 PR mask of the second cycle of fabrication.

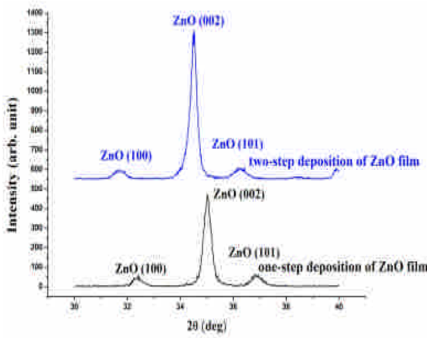

Fig. 3. XRD pattern of ZnO films deposited by one- and two-step methods.

4. Conclusions

A feasible fabrication process of Fresnel lens was proposed and examined by using SU-8 PR with a two-mask process. The precise profile of the focusing lens can be obtained and improved by adjusting the fabrication condition in the lithography process, such as soft-baking, exposure and post-exposure bake processes. In addition, a two-step deposition of ZnO film was employed to produce a preferred c-axis orientation of the piezoelectric film. This fabrication was proposed and confirmed that it can satisfy the requirements of piezoelectricity for a thick ZnO films through analyzing the influences of the deposition conditions one- and two-step method on the properties of ZnO films.

5. References

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