A $ZnO/SiO_2/Si$ (100) love mode transducer

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Abstract- $ZnO/SiO_2/Si(100)$ Love mode transducers were fabricated. SiO_2 films were deposited using electron beam evaporation. ZnO films were deposited using r.f. magnetron sputtering. ZnO and SiO_2 films were examined by SEM and the performance of the transducers was examined by their acoustic response. The observation of the SAW Love mode delay line was performed under untuned conditions. Operating frequencies of the transducers were around 85 MHz.

A. Introduction

Zinc oxide films have been widely used for the fabrication of acoustic wave transducers. The thin film SAW device, which was proposed for the first time by Solie and Kino [1,2], is a layered structure comprising a piezoelectric film overlaid on a non-piezoelectric substrate. Thin-film SAW transducers comprising ZnO thin films as the piezoelectric layer are among the most successful transducers fabricated for practical applications [3]. ZnO is a well-known piezoelectric material of a hexagonal crystalline structure (Fig. 1). ZnO is a wurtzite-type crystal, having a 6-mm symmetry [4]. Layers occupied by zinc atoms alternate with layers occupied by oxygen atoms. The effective ionic charges are about 1 to 1.2, which results in polar c axis.

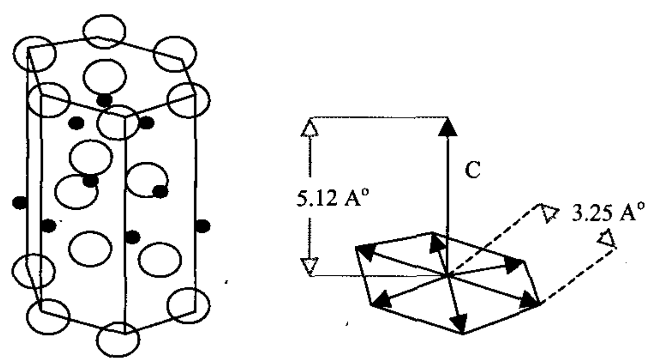


Fig. 1 ZnO crystal wurtzite structure with 6-mm symmetry.

After the deposition of a ZnO layer on a SiO_2/Si (100) structure, Rayleigh and Love modes are the major propagation waves. In this paper, propagation of Love modes in ZnO/SiO2/Si (100) structures will be investigated. Electron beam evaporation was used for the deposition of the SiO_2 layer, which produced a smooth and homogeneous SiO_2 surface. ZnO was deposited by r.f. magnetron sputtering and inter-digital metal fingers were deposited by electron beam evaporation. The SAW fingers pattern was located between the SiO_2 and ZnO layers.

B. Film Deposition

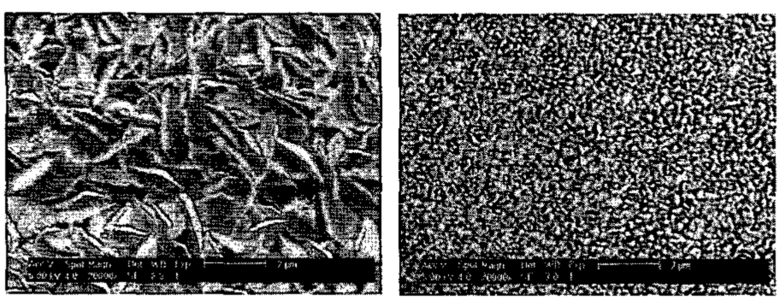
A wide variety of deposition techniques for ZnO films have been reported [4], which include, chemical vapour deposition, vacuum sublimation of ZnO, evaporation of Zn with an oxygen beam and r.f. magnetron sputtering. It is generally accepted that r.f. magnetron sputtering yields the best piezoelectric layer due to the highly oriented and dense layer obtained, as well as surface flatness. Sputtered films are polycrystalline with the individual crystals growing with their crystallographic c-axis normal to the substrate surface. The oriented columnar grains grow on an initial layer of randomly oriented crystallites.

A Si (100) *p*-type wafer was used as the substrate. A SiO_2 film (0.35 μm) was deposited using electron beam evaporation. This was followed by the deposition of Ti (100 Å), Ni (100 Å) and Au (200 Å). Ti has good adhesion to SiO_2 and Ni introduces a good adhesion between Au and Ti. The Au layer was employed as the top metal for the electrodes because c-axis oriented ZnO can be deposited with similar sputtering conditions as for SiO_2 surface.

ZnO films were sputtered, using different conditions, on the evaporated SiO_2 surface and Au surface to determine the optimum sputtering conditions. Substrate temperature, target to substrate distance and deposition rate were the parameters that were investigated during the experiments. SEM (Scanning Electron Microscopy) and acoustic measurements were used for determining the quality of the deposited ZnO. Substrate temperatures from 180°C to 240°C, deposition rates from 200 nm/minute to 100 nm/minute and target to substrate distances from 3.5cm to 6cm were examined. The best quality ZnO was obtained for a substrate temperature of 265°C, 105 nm/minute deposition rate and 5 cm target to substrate distance. The sputtering pressure was 10 mTorr and the sputtering gas combination was 40% oxygen and 60% argon.

C. SEM Analysis

Poor quality ZnO is shown in SEM images in figures 2 (a) and 2 (b).



(a) (b)

Fig. 2. SEM images of poor quality ZnO films sputtered using non-optimum conditions.

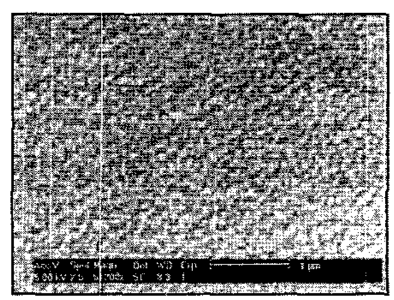


Fig. 3 SEM image of a good quality ZnO film.

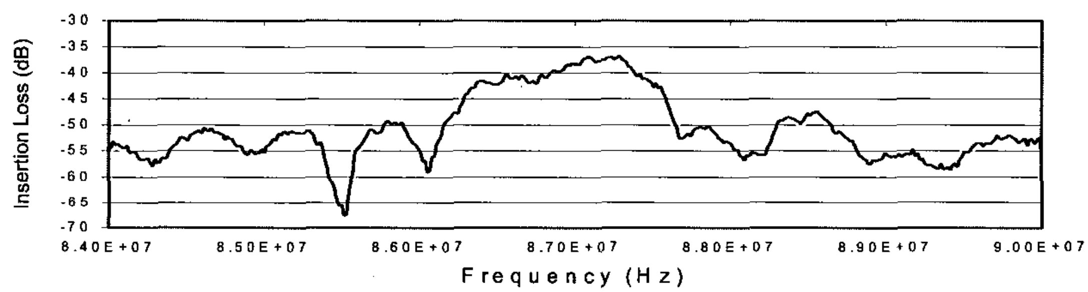
Figure 2 (a) is an image of ZnO deposited on a SiO_2 film when the SiO_2 has not been annealed. Columns have triangular and quadrangular base shapes. Grains are large (0.5-2 μm in length) and the ZnO shows no piezoelectricity. Annealing the SiO_2 before depositing ZnO proved to be an important step. Heat treatment improves the crystallinity of SiO_2. Fig. 2 (b) shows ZnO deposited on the heat treated SiO_2 but not with the optimum sputtering conditions. In this case, grains are smaller and circular shape grains are more dominant. Piezoelectricity of the material is still poor. The best quality ZnO is shown in Fig. 3. It was deposited using the optimum parameters mentioned in section C.

The grains' bases look circular. They are small (50-200 nm in radius) and the surface looks very smooth. Piezoelectricity is the highest obtained in this study. Good quality c-axis oriented ZnO is transparent but poor quality films look hazy [5].

D. Acoustic response

Propagation characteristics of the $ZnO/SiO_2/Si(100)$ structure were investigated by measuring the S parameters of a SAW structure with fingers and spacing (IDTs Inter-Digital Transducers) of 7.5 μm width. It has 16 IDTs (Inter-Digital Transducers) in one port and 64 IDTs in the other port. The measurements were carried out for transducers of two different thicknesses of ZnO film: 5 μm and 6 μm.

The frequency response (Fig. 4) and input admittance (Fig. 5) of transducers were measured. Measurements were performed with 50 Ω connection lines. Fig. 5 shows the input admittance of the Love mode SAW of the same transducer in the 16 IDTs port. Electromagnetic coupling coefficients were 0.8×10^{-2} and 0.91×10^{-2} for thicknesses of 5 μm and 6 μm respectively. These values are 30% less than the theoretical values calculated by the transfer matrix method [6].



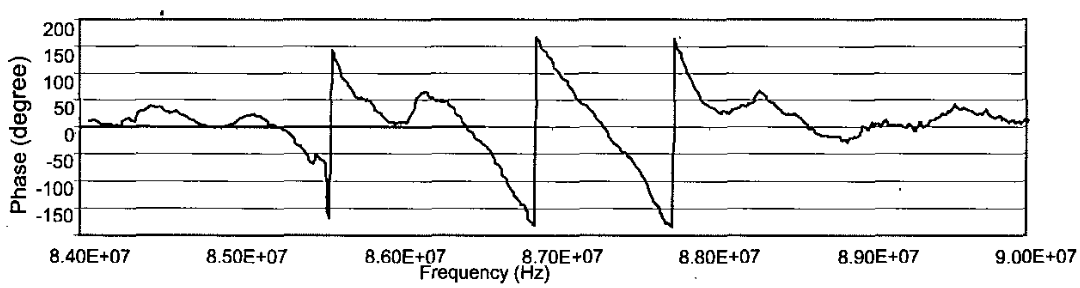


Fig. 4 Insertion loss of the ZnO (5 μm)/ SiO_2 /Si (100) structure: magnitude and phase.

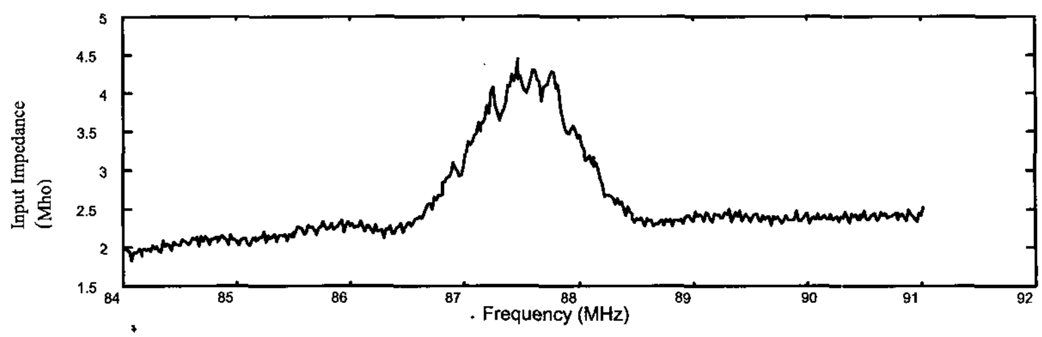


Fig. 5 Magnitude of admittance of the ZnO (5 μm)/ SiO_2 /Si (100) structure.

E. Conclusion

A ZnO/SiO2/Si(100) structure Love mode SAW was designed and fabricated using electron beam evaporated SiO_2 and sputtered ZnO films. Optimum parameters were obtained for the deposition of ZnO using r.f. magnetron sputtering on SiO_2 film. Heat treatment of the SiO_2 evaporated film is necessary before the deposition of ZnO layer. The effective coupling coefficient shows a good agreement with the theory.

Acknowledgment

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References:

[1] G. S. Kino and R. S. Wagers, "Theory of Interdigital Couplers on Non-piezoelectric Substrates," J. Appl. Phys., Vol. 44, 1973, pp. 1480-1488.

[2] L. P. Solie, "Piezoelectric Acoustic Surface Waves for a Film on Substrate," Appl. Phys. Lett., Vol. 8, 1996, pp. 220-221.

[3] O. Yamazaki, T. Mitsuyu and K. Wasa, "ZnO Thin Film SAW Devices," IEEE Trans. on Sonics and Ultrasonics, Vol. SU-27, Nov. 1980, pp. 369-379.

[4] F. C. M. Van De Pol, "Thin-Film ZnO – Properties and Applications", Ceramic Bulletin, Vol. 69, No. 12, 1990, pp. 1959-1965.

[5] F.S. Hickernell, " Zinc Oxide Films for Acoustoelectric Device Applications," IEEE Trans. on Sonics and Ultrasonics, Vol. SU 32, No. 5, 1985, pp. 621-629.

[6] E. L. Adler, J. K. Slaboszewicz, G. W. Farnell and C. K. Jen, "PC Software for SAW Propagation in Anisotropic Multilayers," IEEE Trans. on Ultrason. Ferroelec. And Freq. Control, vol. 37, No. 2, May 1990, pp. 215-223.