Miniature SAW Device for RF-Wireless Applications Using MEMS Technology

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Abstract—A miniature SAW device is designed and fabricated at 1 GHz for wireless communication system. A 5 µm thin film of ZnO is successfully deposited using RF sputtering technique on PECVD SiO2 layer of 1µm on top of Si wafer under various operating conditions. The c-axis oriented ZnO film exhibit a sharp diffraction peak corresponding to the (002) reflection at 2θ=34.42. The fabrication process utilizing the MEMS technology of the SAW device is described. Simulation of the RF SAW filter is performed. Measurements and experimental work are presented for the RF SAW device.

I. INTRODUCTION

The realization of miniature RF-SAW device on CMOS substrate for mobile and wireless communication system has become very important in recent years. Acoustic wave propagation along the surface of a piezoelectric material provides a means of implementing a variety of signal-processing devices at frequencies ranging from several MHz to a few GHz [1]. The IDT provides the cornerstone of SAW technology. Its function is to convert electrical energy into mechanical energy and vice versa, for generating and detecting the SAW. The central frequency of a conventional SAW filter is determined by the width of its individual electrodes (d), spacing between the electrodes (g) and the SAW velocity (v) of the piezoelectric substrate. For our RF application we design the finger width d and the phase velocity which excite the SAW on the piezoelectric materials. Reducing the width of the IDT finger or choosing the piezoelectric material with a higher SAW phase velocity can increase frequency of operation into the GHz range [2-4]. The SAW wavelength \( \lambda \) (\( \lambda = 4d \)) is given by the ratio \( v/f_s \). Where \( v \) is the velocity of a wave on a piezoelectric substrate depends on the material and \( f_s \) is the central frequency. The sensing action of such transducers involves any influences that will alter the acoustic wave velocity \( v \) and, consequently, the associated properties of the wave, such as frequency and time to travel between the sensor and the detector.

In order to achieve good SAW performance, the piezoelectric films should have a smooth surface morphology, sharp interface, and perfect c-axis texture. It is also important that the SAW filter reveals high phase velocity and large electromechanical coupling coefficient as the thickness of piezoelectric film increases. ZnO has a high piezoelectric coupling coefficient, which can be used in surface and bulk acoustic wave devices [5]. ZnO films have been deposited on Si and SiO2/Si, GaAs, and sapphire (Al2O3) substrates. Si and GaAs substrates are of interest for the integration of SAW devices with the main stream microelectronics technology [6-7]. So these types of devices can be implemented with micro-electro-mechanical systems (MEMS) compatible with CMOS technology [8-9]. In this work a miniature SAW filter of 1 µm input/output IDTs of 30 pairs is designed and fabricated on 5 µm thin film of ZnO substrate with a center frequency of 1GHz. ZnO film is grown on SiO2/Si substrates by RF sputtering technique. The growth process is optimized to obtain highly oriented ZnO film with a smooth surface morphology. The structural properties of the films are investigated using X-ray diffraction. High quality ZnO thin film has been achieved, which are needed for fabrication of low-loss SAW filter. Characterization of the RF SAW device as a transmitter and receiver filter is performed. Measurements and experimental results are presented for the RF SAW filter.

II. DESIGN AND MODEL OF THE SAW DEVICE

The SAW is consists of two main parts, the IDT and piezoelectric substrate. The SAW has input/output IDTs of 30 pairs of electrodes each. We design the IDT finger dimension based on our permissible custom technology. In this design the finger width d and spacing between the Aluminum electrodes g is 1 µm each. The fundamental frequency of operation of the SAW device is determined by the width of its individual electrodes (d), spacing between the electrodes (g) and the SAW velocity (v) of the piezoelectric substrate. For our RF application we design the
SAW at operating frequency $f_0$ of 1 GHz. The SAW wavelength $\lambda$ is given by ($\lambda = 2d + 2g = 4\mu m$).

Among recently developed piezoelectric thin film materials, ZnO has been considered to be a very promising film for fabricating miniature high-frequency SAW devices. ZnO films with single crystal quality have also been reported to provide very high piezoelectric coupling coefficients. In this design a 5 $\mu m$ ZnO film is deposited on 1 $\mu m$ SiO$_2$ buffer layer as well as on the Si substrate. Figure 1 shows the 3-D view of the SAW sensor.

The impedance of the transducer as seen at the electrical port $Z(f)$ can be represented by either of the series or parallel circuits. The transducer total capacitance is $C_T = C_s wN$, where $C_s$ is capacitance per electrode pair per unit length ($pF/m$), which can be calculated as given in [10-12].

![Fig. 1 3-D view of the SAW device](image)

The capacitance $C_T$ is included explicitly since it contributes the major part of the reactance, while $R_a(f)$ and $X_a(f)$ are the resistance and reactance. The input /output IDTs are represented by the electrical circuit shown in figure 2. The signal which passed from the first IDT to reach the second IDT is attenuated by a $e^{-j\beta x(f)}$ factor [11], where $\beta = \frac{2\pi}{\lambda}$ is the wave propagation constant on the substrate.

![Fig. 2 The transducer equivalent electrical circuit](image)

### III. THE SIMULATION RESULTS

Frequency response simulation of the equivalent circuit is shown in figure 3, where the voltage gain is represented in dB, and its maximum value is shown at 1GHz, with band width 30 KHz.

![Fig. 3 Frequency response of the SAW electrical equivalent circuit at 1GHz](image)

### IV. FABRICATION OF SAW DEVICE

The fabrication steps of the SAW device is described as follows:

- A 100 mm diameter p-type, both side polished, (100) orientation, RCAI and RCAII Clean methods are used for initial wafer cleaning followed by 1 $\mu m$ thick thermal silicon oxidation at 1000°C, figure 5(a).

- Low stress Nitride thin layer (600 $A$) is deposited as a supporting layer using LPCVD, where the vacuum inside the tube is 166mbar, and the temperature is 812°C, the gases used are Ammonia (13, 23 sccm), and Dichlorosilane (71, 100 sccm), figure 5 (b).

- A 5$\mu m$ thick piezoelectric zinc oxide (ZnO) layer is deposited by RF sputtering at 600W, pressure 10mtorr and the sputtering time is 8 hr, figure 5(c).  

- A layer of aluminum film (1$\mu m$) is deposited by RF sputtering, for 40 min using 600 watt power. Lithography, followed by Al metal etching, formed the input and output IDT’s of the sensor using Aluminum etchant at 55$^0$C with etching rate 100 $A/min$, figure 5(d,e).
- This Al electrode was covered by 0.3 µm thick plasma enhanced chemical deposition (PECVD) silicon dioxide at 300°C and pressure 0.3 torr for 5 min, figure 5(f).

- The Second lithography, using thick resist coating followed by reactive ion etching (RIE) of PECVD oxide layers till the Al contact pads are opened.

Using of Multi-Layer ZnO/ Si₃N₄/ SiO₂ SAW sensor give the advantage of increasing the surface velocity, where the velocity is a function in the layer thickness [9].

-X-ray diffraction technique was used to determine the degree of crystallinity, lattice constants, crystal structure, density, and average grain size of the deposited films. Diffraction phenomenon is expressed in terms of the Bragg’s diffraction condition given by: 
\[ n \gamma = 2D \sin \theta \],
where \( \gamma \) is the wavelength of X-rays, \( \theta \) is the angle at which incident X-ray beam is diffracted in phase and \( D \) is the interplaner spacing distance of (hkl) plane, where h, k, and l are the miller indices. The XRD of 5µm thick zinc oxide film grown at C-axis

-Orientation over PECVD SiO₂ of 1µm used in Surface Acoustic Wave Sensor fabrication is shown in figure 6. The experimental results exhibited a sharp diffraction peak corresponding to the (002) preferred orientation and the reflection at \( 2\theta = 34.42^o \) as shown in figure 6 which is very close to the unstressed ZnO powder value of 34.43o.

-By measuring SAW characteristics of ZnO/SiO₂/Si bilayered structure, the phase velocity is calculated to be 4000 m/s and electromechanical coupling coefficient is 1.2%. The velocity and coefficient are strongly influenced as the thickness of ZnO increased and the substrate materials on which the ZnO film is deposited.

CONCLUSION

In this work we described the design and fabrication of a miniature SAW filter of a center frequency of 1GHz. 5 µm thin film ZnO is grown on a thin layer of 1µm SiO₂ over a Si substrate by RF sputtering technique. The properties of ZnO film is examined by XRD.

ZnO film has been continuously deposited on SiO₂/ Si wafer by RF reactive magnetron sputtering method. The preferred orientation of ZnO film has been examined and the SAW characteristics of these films have been measured. The experimental results can be summarized as follows:

![Figure 5 Fabrication Steps of SAW Device](image)

![Figure 6 XRD pattern of 5um ZnO film deposited over SiO2/Si wafer.](image)
The measured results show that the velocity and electromechanical coupling coefficient are strongly influenced as the thickness of ZnO is increased. There are many factors that the central frequency of a conventional SAW filter is determined. Those are the IDT geometry, and the velocity of piezoelectric substrate material. Recent advances in MEMS and NEMS make it possible to reduce the electrode width to submicron and fabricate a multilayer piezoelectric structure. Also increase the thickness of the piezoelectric layer in SAW devices.

ACKNOWLEDGEMENT

This work has received primary funding from the NSF Directorate for Engineering, Division of Electrical and Communications Systems. Additional funding and support has been provided by ERI. We would like to thank Prof. Dr. Ayman El-Dessouki, president of ERI for supporting this work in the Central Electrical and Electronics Research Inst., CEERI, India. We thank Eng. Sherief Saleh for his assistance in this work, and Dr. S. Ahmed from CEERI for providing the MEMS facilities.

VI. REFERENCES


