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Development of a Novel Acoustic Sensor using Sputtered ZnO Thin Film

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ABSTRACT

In this paper we report fabrication and characterization of ZnO thin film for acoustic sensor application. ZnO thin film of thickness about 680 nm was deposited using RF reactive magnetron sputtering. This film was characterized using X-ray diffraction (XRD) and Scanning Electron Microscope (SEM) for its microstructure and morphology. The sensing property of the ZnO thin film was investigated using a standard electro-acoustic calibrator. The as-synthesized ZnO thin film produced noticeable piezoelectric voltage output for different Sound Pressure Levels. This study indicated the suitability of sputtered ZnO thin film for acoustic sensor application.

Keywords: ZnO, Thin film, Sputtering, Piezoelectric, Acoustic.

1. INTRODUCTION

Acoustic sensors are used for detecting the mechanical pressure variations generated by acoustic signals. These sensors convert sound energy in to electrical signal. Various sensing mechanisms such as electrostatic, electromagnetic and piezoelectric methods are widely employed for developing acoustic sensors. Acoustic sensors find applications as microphone, hydrophone, ultrasonography devices etc. Apart from these, Acoustic sensors are widely used for aerospace applications also. A jet plane generates acoustics of about 150 dB while the safe limit of acoustic level of human ear is 85 dB. A launch vehicle generates about 200 dB acoustic signals during lift-off[1]. The sinusoidal sound pressure wave generated due to the acoustic emission from aircraft, launch vehicles etc lead to mechanical loading of structures exposed to it. Hence study of acoustic signals is of great importance in the health monitoring of aerospace structures. The acoustic sensors used in aerospace applications are mainly based on piezoelectric principle.

ZnO, a semiconducting piezoelectric material which has been a topic of interest for researchers for the past few decades. ZnO is described as a promising material for future world's requirements by C. Jagadish *et al*.[2]. The possibility of easy synthesis of thin film and wide variety of nano structures with tailor made properties make ZnO a very attractive material. It is biocompatible, chemically inert and radiation hard. The high electron mobility, high thermal conductivity, piezoelectricity, wide and direct band gap and large excitation binding energy make ZnO suitable for wide range of devices[3].

Thin films of ZnO are extensively researched due to their advantages like better performance, improved properties, miniaturisation, large surface area to volume ratio, weight reduction, low cost and mass production etc compared to its bulk form. Studies in the recent past demonstrated the potential of ZnO thin film for various sensing applications[4-13].

In the present work, the piezoelectric property of ZnO is utilised for the development of a novel acoustic sensor. We have fabricated ZnO thin films using RF reactive magnetron sputtering method, which is widely used by researchers for preparing high quality piezoelectric films of ZnO[7,11,14-21]. Subsequently, this film was characterised using XRD & SEM and evaluated for its application as acoustic sensor.

2. EXPERIMENTAL

2.1 Deposition and characterisation of ZnO thin film

ZnO thin film was deposited on a flexible metallic alloy substrate (Elgiloy) of thickness 50 µm using RF reactive magnetron sputtering. Prior to deposition, substrate of size 25 mm x 7 mm was cleaned thoroughly using ultrasonic cleaning with soap solution, acetone and isopropyl alcohol as reagents. Initially the chamber was evacuated to an ultimate pressure of $5x10^{-6}$ mbar. Sputtering gas Argon and reactive gas Oxygen were admitted to the sputtering chamber. The Ar and O_2 ratio was maintained at 17.1: 3.1 Sccm. The optimised parameters used for the deposition are RF power 120 W, target to substrate distance 28 cm and working pressure of $1.4x10^{-2}$ mbar. The substrate temperature was maintained at 24 ± 2^oC. After pre sputtering, the shutter was removed and deposition was carried out for a duration of 60 minutes. The deposited film covered an area of 20 mm x 7 mm on the substrate.

Microstructure and crystallography of the deposited film was characterised using X-ray Diffractometer (Make:-Bruker D8 Advance Diffractometer) with Ni filtered Copper Kα radiation, λ=0.015404 A^0. The topography and cross-section of the film was characterised using Scanning Electron Microscope (FE-SEM, Make:- Carl Zeiss). FE-SEM was also used to measure the thickness of the film.

2.2 Acoustic sensor assembly and its performance study

After the material level characterisation of the as-synthesised ZnO thin film it was assembled as an acoustic sensor with suitable electrical and mechanical interface and tested using an electroacoustic calibrator (Make:- NAL, India). The sensing film deposited on Elgiloy substrate was bonded on a metallic (SS304) pressure connection port using M Bond 200 adhesive. This metallic pressure port has M14 x 1.5 male thread as mechanical interface to mount on the acoustic calibrator. The electrical inter-connecting leads were taken out using enamelled copper wire of 0.07 mm diameter. Silver epoxy paste was used for fixing the electrical lead wires on to the device. It is to be noted that no separate electrode deposition was carried out in the present work. The metallic substrate itself acts as the bottom electrode and a fine layer of silver epoxy paint over the ZnO film acts as the top electrode. Fig.1 shows the schematic of ZnO thin film based acoustic sensor.

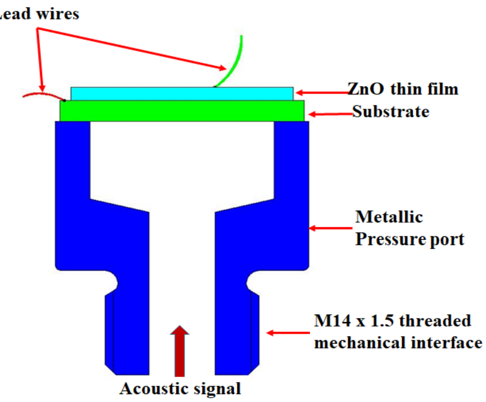

Fig.1 Schematic of ZnO thin film acoustic sensor with mechanical and electrical interface

The ZnO thin film based acoustic sensor was mounted on the acoustic calibrator using the mounting thread of the pressure port. Output from the sensing film was acquired using a storage oscilloscope. The test set up used for the characterisation of ZnO thin film acoustic sensor is shown in fig. 2.

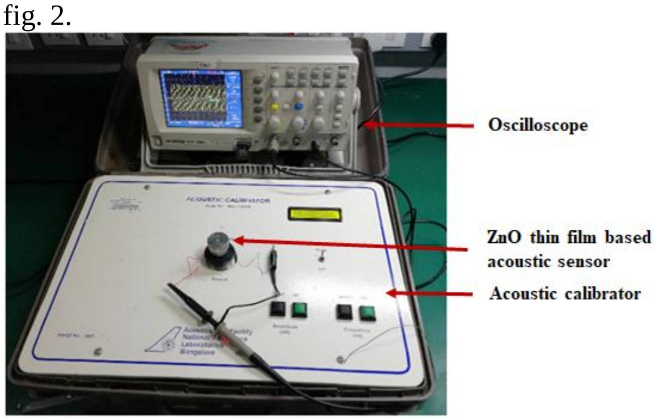

Fig.2 Image of acoustic test set-up

3. RESULTS & DISCUSSION

3.1 Material characterisation

X-ray diffraction studies conducted on the ZnO thin film indicate that the as-synthesised ZnO film is highly c-axis oriented. Fig.3 shows the XRD pattern of the sputtered ZnO film. Sharp peak at 34^o indicates high crystallinity with preferred grain growth along (002) plane. This favours the piezoelectric property of the film. Other two peaks in fig.3 corresponds to Chromium and Cobalt of alloy substrate.

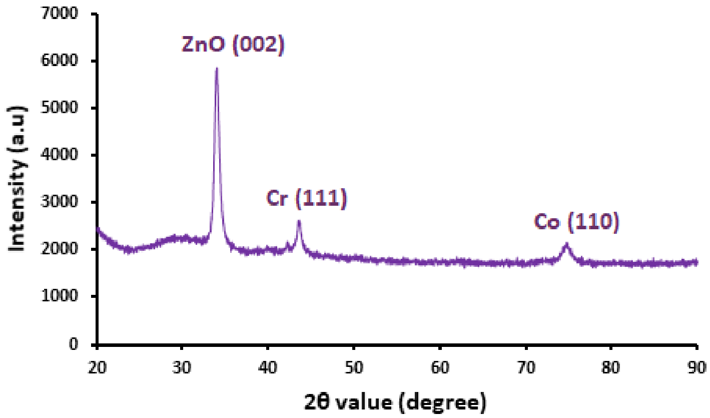

Fig.3 XRD pattern of ZnO thin film

Fig. 4 shows the FE-SEM image of the ZnO thin film deposited using RF reactive magnetron sputtering. The topography in fig. 4(a) shows formation of highly packed homogenous film. Average film thickness of about 680 nm is measured from the FE-SEM cross-section image. As seen in cross-section, growth of the film is perpendicular to the substrate surface.

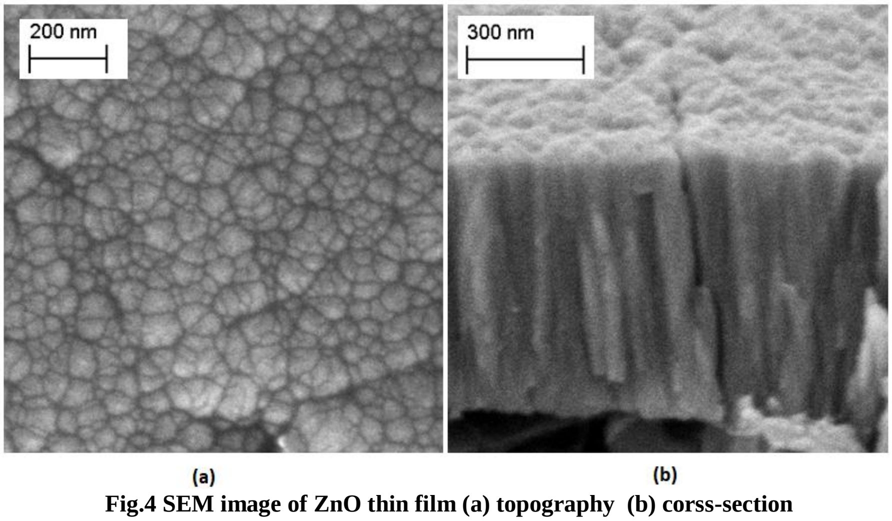

Fig.4 SEM image of ZnO thin film (a) topography (b) corss-section

3.2 Characterisation of acoustic sensor

ZnO thin film deposited on Elgiloy substrate was mounted on the acoustic calibrator using the adaptor as shown in fig.2. Acoustic signals of frequency 2 kHz and Sound Pressure Level (SPL) 120, 130, 140 & 150 dB were applied to the sensing film. Piezoelectric ZnO film produced noticeable output for all the acoustic pressure levels. Typical output waveform obtained from the sensing film is shown in fig.5. Response of ZnO film for different SPLs are indicated in fig. 6. Output of ZnO thin film is found to be increasing with increase in SPL, from about 7mV for 120 dB to 51.2 mV for 150 dB SPL.

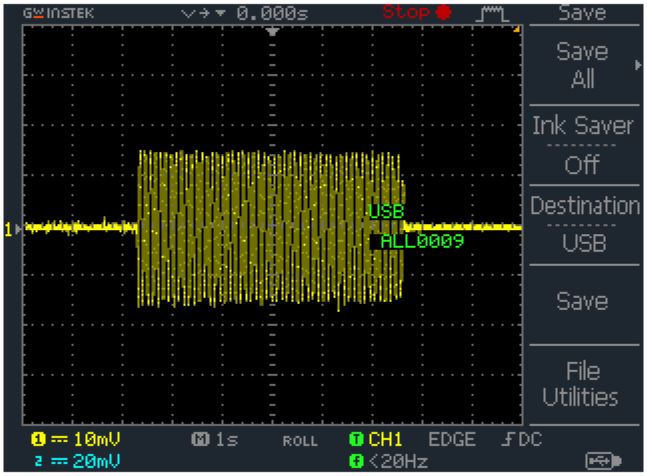

Fig.5 Typical output of ZnO thin film based acoustic sensor (Sound Pressure Level-130 dB, Frequency-2 kHz)

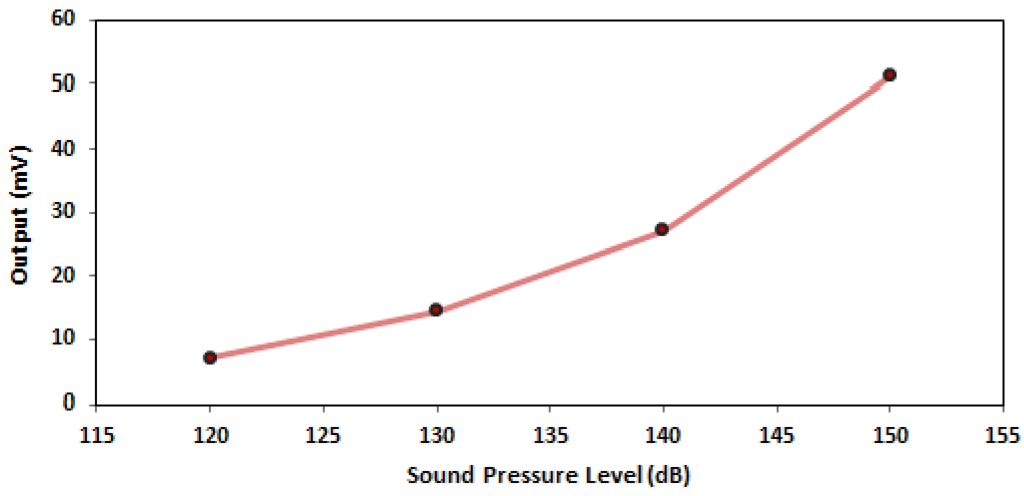

Fig.6 Response of ZnO thin film acoustic sensor for different Sound Pressure Levels

4. CONCLUSIONS

Homogenous thin film of ZnO with c-axis orientation was prepared by RF reactive magnetron sputtering. The film deposition was carried out for 60 minutes which yielded an average film thickness of 680 nm. This piezoelectric film was suitably packaged and evaluated for its acoustic sensing properties using an electro-acoustic calibrator. The ZnO film responded to acoustic pressure signals from 120 to 150 dB with noticeable output. This work demonstrates that ZnO thin film of thickness 680 nm, deposited on metallic alloy substrate using RF reactive magnetron sputtering is highly efficient for sensing acoustic signals.

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