Flexible Phynox Alloy with Integrated Piezoelectric Thin Film for Micro Actuation Application

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Abstract— **In this paper, we report on the application aspect of piezoelectric ZnO thin film deposited on flexible phynox alloy substrate. Highly crystalline piezoelectric ZnO thin films were deposited by RF reactive magnetron sputtering and were characterized by XRD, SEM, AFM analysis. Also, the effective d_{33} coefficient value measurement was performed. The actuator element is a circular diaphragm of phynox alloy on to which piezoelectric ZnO thin film was deposited. ZnO film deposited actuator element was firmly fixed inside a suitable concave perspex mounting designed specifically for micro actuation purpose. The actuator element was excited at different frequencies for the supply voltages of 2V, 5V and 8V. Maximum deflection of the ZnO film deposited diaphragm was measured to be 1.25 µm at 100 Hz for the supply voltage of 8V. The developed micro actuator has the potential to be used as a micro pump for pumping nano liters to micro liters of fluids per minute for numerous biomedical and aerospace applications.**

***Keywords*: Micro actuator; ZnO thin film; Piezoelectricity**

I. INTRODUCTION

There is a continuing interest in the field of sensors and actuators based on piezoelectric thin films. A wide variety of materials such as ZnO, PZT, AlN, and $BaTiO_3$ exhibits piezoelectric property in thin film form. The selection of ZnO thin film for present experimental study is motivated due to its ease of deposition on wide variety of substrates and it is a compositionally simple piezoelectric material [1]. ZnO thin films deposited on flexible substrates opens a new area of research for wide range of applications. Few investigators have employed polymer type flexible substrates such as polycarbonate [2], polyethersulfone [3] and polytetrafluoroethylene [4] for ZnO thin film deposition. These polymer type flexible substrates suffer from disadvantages such as, a bottom metallic electrode layer has to be deposited to form an M-I-M (metal insulator metal) type structure for sensor and actuator fabrication process and they cannot withstand higher temperatures. Hence a flexible substrate that is conductive and can easily withstand higher temperatures will be a good alternative for the simplification of the thin film based sensor development process. The new aspect of our present research work is the use of phynox alloy substrate for ZnO thin film deposition. Phynox alloy is a flexible and conductive substrate, which can withstand temperatures up to 500 ˚C.

Presently, existing literature mainly reports on the micro actuator fabrication using the silicon based structures. Silicon based micro structures are mechanically fragile and could fail due to fracture by mechanical over-loading [5]. Moreover the customary fabrication processes available for micro actuators, which involve standard MEMS based techniques are cumbersome and complex. In this present work, we propose a simple straight forward technique for micro actuator fabrication, which involves the use of a novel flexible phynox alloy substrate integrated with piezoelectric ZnO thin film.

II. EXPERIMENTAL

A. *Substrate employed for ZnO thin film deposition*

ZnO thin films were deposited on phynox (Elgiloy, an austenitic cobalt based alloy) (Lamineries, MATTHEY SA) for the micro actuation application. Phynox is a flexible metal alloy that has many ideal properties for its use as a sensing and actuating element. Properties of the phynox alloy are listed in Table I. Moreover, it also possesses good fatigue strength, extremely resistant to corrosion, exhibits low hysteresis and exceptional spring properties. Phynox is a biocompatible alloy and hence it is widely used as electrodes in pacemakers and often used for implant components. It is used as membranes for pressure sensors, in relays and switches which are needed in broad spectrum of applications in the automotive and robot industries. Phynox is also used widely in products related to telecommunication and aerospace industries [6].

In the present experimental work, thickness of phynox alloy substrate employed for ZnO thin film deposition is 40 µm. The integration of ZnO thin film on to the phynox alloy substrate reduces the overall complexity of the actuator fabrication process by incorporating the substrate as one of the two electrodes. Therefore, it eliminates the necessity of additional bottom metal layer deposition for contact purpose.

TABLE I. PROPERTIES OF PHYNOX ALLOY

SR. No.	*Properties*	*Values*
1	Ultimate tensile strength	2600 N mm^{-2}
2	Young's modulus	220 kN mm^{-2}
3	Yield strength	2200 N mm^{-2}
4	Temperature range	-268.8 ˚C to 500 ˚C

B. *Deposition of ZnO thin film*

The target employed for ZnO thin film deposition was metallic Zinc circular target of 99.9% purity having a diameter of 75 mm and a thickness of 3 mm (VIN karola instruments, Norcross, USA). Prior to loading the phynox substrates for deposition, these were thoroughly cleaned with soap solution to remove any stains of oil and grease. Further, the substrates were ultrasonically cleaned to remove any dust particles and properly rinsed with organic solvent (Isopropyl alcohol) and subsequently dried in flowing nitrogen gas. The chamber was evacuated to an ultimate vacuum of $1x10^{-6}$ mbar. Initially, inert argon gas (99.9% pure) was admitted and subsequently reactive oxygen gas (99.9% pure) was introduced in to the chamber and flow rates of both the gases were controlled by mass flow controllers (MKS PR – 4000, USA). Pre-sputtering was carried out for 20 minutes in order to remove impurities from the target surface and to make plasma stable. The sputtering process parameters were optimized for the deposition of high quality piezoelectric ZnO thin films. The optimized parameters are shown in Table. II.

TABLE. II. OPTIMIZED SPUTTERING PROCESS PARAMETERS

SR. No.	*Sputtering process parameters*	*Optimized values*
1	Ultimate pressure	$1x10^{-6}$ mbar
2	Working pressure	0.035 mbar
3	Target to substrate distance	55 mm
4	Ar-O_2 ratio	90% - 10 %
5	Substrate temperature	250 ˚C
6	Applied RF power	100 W

C. *Microactuator fabrication*

The actuator element is a circular diaphragm of phynox alloy (diameter: 12 mm and thickness: 40 µm). Optimized high quality ZnO thin film (thickness: 480 nm) is deposited on to the phynox alloy diaphragm. Top electrode of silver thin film (thickness: 100 nm) is deposited on the ZnO film resulting in the formation of metal insulator metal (M-I-M) type structure. Double enameled thin copper wires (diameter: 0.07 mm) are attached to the top and bottom electrodes for electrical contact purpose.

Fig. 1a shows the 3-dimensional view of the fabricated micro actuator. ZnO film deposited circular diaphragm based actuator element was firmly fixed inside the specifically designed concave perspex housing. Use of perspex material for housing purpose was motivated from the facts that it can easily withstand temperatures up to 160 ˚C, easy handling and processing as well as it is cost-effective. Fig. 1b shows the final photograph of the fabricated micro actuator. The overall dimension of the finally packaged micro actuator is about (20 mm x 20 mm x 4.5 mm) which makes it compact and portable.

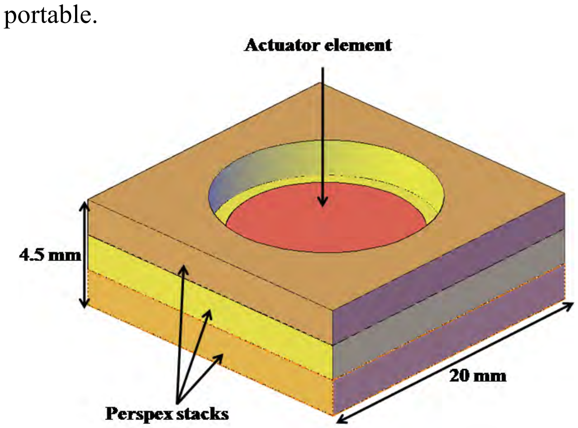

Figure 1a. A 3-dimensional model of the fabricated micro actuator.

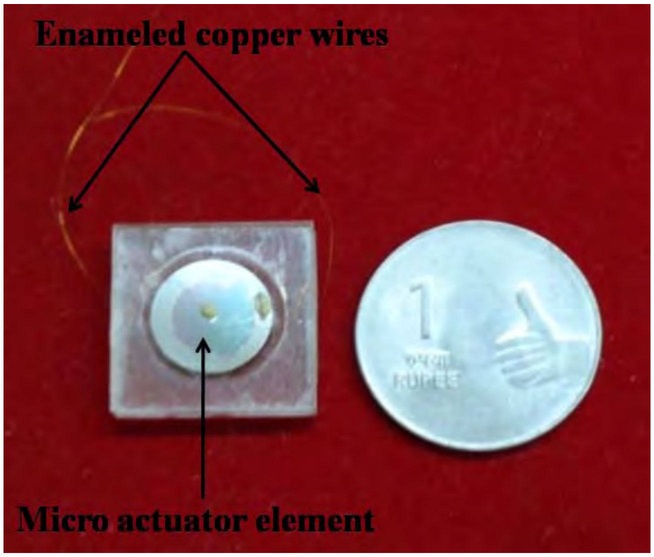

Figure 1b. Photograph of the fabricated micro actuator inside the concave perspex housing.

III. RESULTS AND DISCUSSIONS

A. Characterization of ZnO thin film

Fig. 2a shows the X-ray diffraction characteristics of the ZnO thin film deposited on phynox alloy substrate. As can be seen, the deposited film possesses (002) preferred polycrystalline structure. The presence of (002) peak indicates that, the film have a strong c-axis orientation which is perpendicular to the substrate. This high degree of (002) preferred polycrystalline structure and strong c-axis orientation enhances the piezoelectric properties of ZnO thin film [7]. In Fig. 2a, the peaks corresponding to constituents of phynox alloy substrate at 43.5˚ and 74.6˚ are also present. These peaks correspond to (111) and (110) planes of chromium and cobalt respectively (ICDD – PDF No. 882323 and 011278 respectively), which are the major constituents of the phynox alloy.

Fig. 2b shows the SEM image of the as-deposited ZnO film, its analysis reveals that the surface of film is smooth, dense and free from defects. The film was having well oriented grains with uniform and large grain size in the range from 70 – 75 nm. Fig. 2c shows the AFM image of the ZnO film, the film was having very low value of rms surface roughness of about 1.87 nm.

The effective d_{33} coefficient value of as-deposited ZnO film was measured using Piezometer system (PM-200, Piezotest, London, UK) and found to be 12.8 pC N^{-1}. This high value of effective d_{33} coefficient was attributed to the larger grain size and lower rms surface roughness, which in turn indicates better piezoelectric property of the as-deposited ZnO thin film.

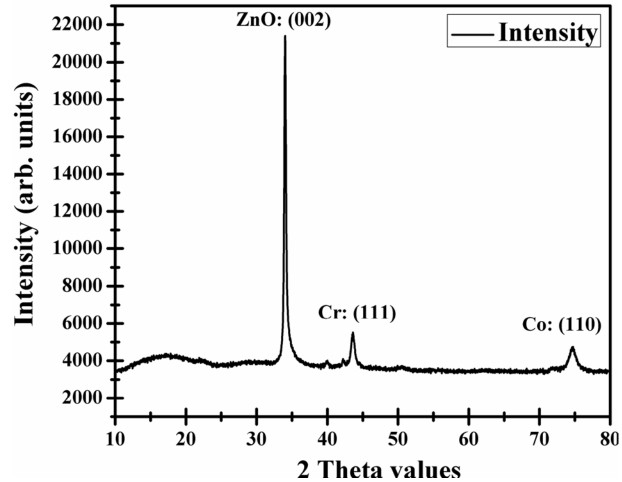

Figure 2a. X-ray diffraction charcateristics of ZnO thin film deposited of phynox alloy substrate.

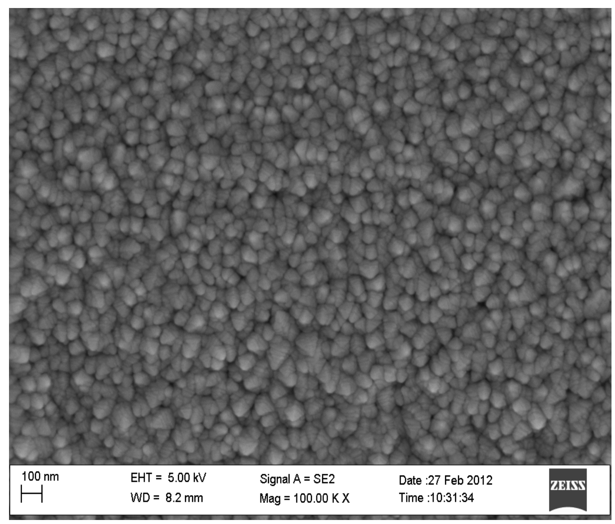

Figure 2b. Scanning electron microscope image of the optimized ZnO thin film deposited of phynox alloy substrate.

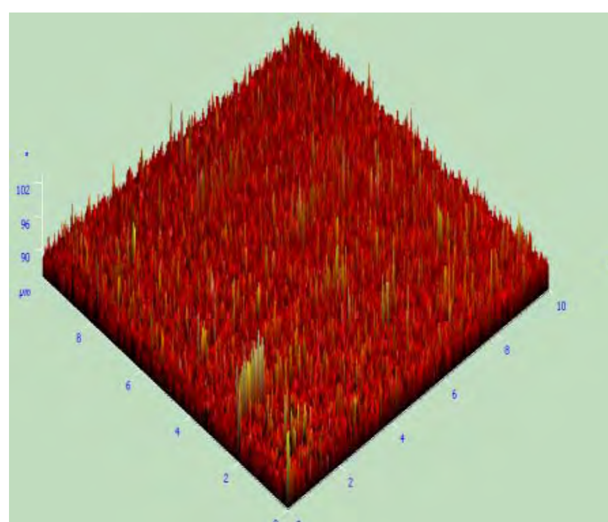

Figure 2c. Atomic force microscope image of the optimized ZnO thin film deposited of phynox alloy substrate.

B. *Response studies of fabricated micro actuator*

The response study of fabricated micro actuator was carried out using Laser Doppler Vibrometer (LDV) (Polytec, MSA-500). Input supply voltages of 2V, 5V and 8V were given at different frequencies to measure the maximum deflection. Fig. 3a shows the variation of displacement of ZnO film deposited circular diaphragm with respect to the change in frequency for different applied voltages. As can be seen, the maximum displacement is achieved at lower frequencies for all the supply voltages. There is a sharp decrease in the displacement for the frequencies higher than 500 Hz. Fig. 3b shows the maximum displacement measured for the portion of circular diaphragm (12x10 rectangular grid) from its mean position. Maximum measured displacement was 1.25 µm at the input supply of 8 V at 100 Hz.

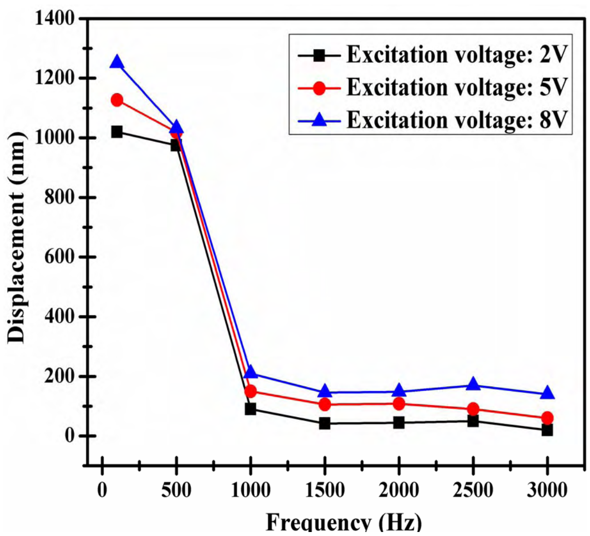

Figure 3a. Variation of displacement of circular diaphragm versus frequency at different supply voltages.

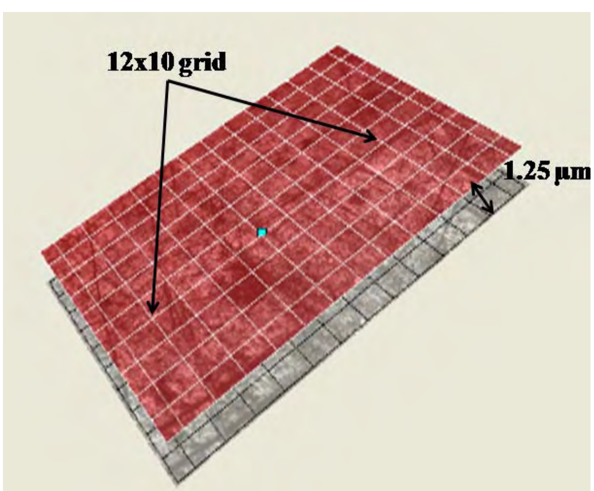

Figure 3b. Maximum displacement of the portion of circular diaphragm (12x10 rectangular grid) at the input supply voltage of 8 V at 100 Hz.

IV. CONCLUSION

ZnO thin film was deposited on flexible phynox alloy substrate for micro actuation application. Sputtering process parameters were optimized for obtaining high quality piezoelectric ZnO thin films. ZnO film deposited circular actuation element was firmly fixed inside a suitable concave perspex housing. The fabricated micro actuator is tested at different supply voltages at varied frequencies for the maximum deflection of the circular diaphragm. The micro actuator developed is compact and cost-effective.

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