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The Fabrication of Pressure Sensor Based on ZnO/PDMS Nanocomposite Film for Sensing Applications

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Abstract - The synthesize of ZnO nanoparticles and fabrication of pressure sensor with different weight percentages of ZnO nanoparticle have maximum β-phase content obtained when composited with PDMS polymer matrix to form ZnO/PDMS nanocomposites while compared with other wt. % ratios. The β-phase of ZnO/PDMS has been increased from 38.2% to 66.1% without requirement of any further processes. The Nano generator fabricated from ZnO/PDMS-ZnO (15wt. %) gives an output of 2.35v (open circuit voltage) and 0.38μA (short circuit current) with an instantaneous output power density of 0.21 μW/cm2. This enhanced piezo-response of the ZnO/PDMS nanocomposite films based pressure sensor is attributed to the enhancement of electroactive β-phase and enhanced d33 value in ZnO/PDMS with the addition of ZnO nanoparticles.

INTRODUCTION

The present parameters do not provide adequate input for the effective realization of a product utilizing micro/nano piezoelectric sensing and energy harvesting. A practical approach is imperative to assess these materials and reconstruct them to ensure their sensitivity, rise time, natural frequency, linearity, bandwidth, temperature drift, and other relevant parameters in packaged form. Among the various piezoelectric materials, Zinc Oxide (ZnO) stands out due to its uncomplicated fabrication processes, low-temperature processing, and compatibility with a diverse range of substrates [1-5]. Additionally, ZnO has attracted researchers due to its properties, such as suitability for harsh environments like high thermal radiation, non-toxicity, biocompatibility, chemical stability, affordability, and natural abundance. This makes it a promising and significant material for environmentally friendly green electronics and a sustainable future despite extensive material-level research, there is a lack of commercial products. The chosen ZnO composites will be used as the piezoelectric material in the ongoing research project, to stay updated with technological progress and support environmental sustainability [6-9].

The piezoelectric properties of ZnO/PDMS active material have to increase for the piezoelectric pressure sensors and the different approaches to increase in β-phase content in PDMS been discussed. Also β-phase has the high polar crystalline-electroactive nature which compared to other phases present in ZnO/PDMS, the nucleation of β-phase is essential for using ZnO/PDMS for pressure sensing devices [10– 13]. The piezoelectric properties of PDMS can be enhanced by adding functional nanomaterials such as TiO_2 [4], Fe-RGO [5], $BiVO_4$ [14] to disrupt the structural properties of PDMS which results to the nucleation of β-phase. Also, the fundamental nanomaterial with high piezoelectric properties like PZT has been incorporated into the PDMS to increase the overall piezo-response (i.e., from β-phase as well as from the piezoelectric response of the material) of the composite material [15]. However, mainly due to the toxicity and complex preparation method, it is hardly use as a nanofiller in PDMS

The synthesis of ZnO/PDMS based nanocomposite films and the results which investigates the effects on introducing the ZnO nanostructures on the PDMS and its enhanced piezoelectric property [16]. The different Wt. % of ZnO nanoparticles are introduced into the PDMS matrix and it is found that the β-phase content of ZnO/PDMS nanocomposite improved from 48.2% to 76.1% by incorporating ZnO nanoparticles into ZnO/PDMS without any requirement of further processes. The XRD, FTIR, and P-E loop measurements confirmed the increase in β -phase content. It is important to study the role of ZnO having piezoelectric

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property, since adding it to PDMS has been linked to improving the β-phase and its contribution to the overall performance of the piezoelectric pressure sensor fabricated from ZnO/PDMS based nanocomposite film [17-20].

MATERIALS AND METHODS

Synthesis of ZnO nanoparticles

For the synthesis of ZnO nanoparticles, 1.4g of Zinc Acetate is dissolved in 25ml of deionized water, and 4g of sodium hydroxide is dissolved in deionized water (25ml). Drop by drop; add the sodium hydroxide solution to the zinc precursor solution, stirring the mixture constantly. The mixed solution is poured into the Teflon beaker and sealed in an autoclave. The system is heated at 80°C for 10Hrs by using an oven. After cooling down to room temperature, the formed ZnO nanostructures are filtered and kept it to dry in an oven maintained at 60°C [22].

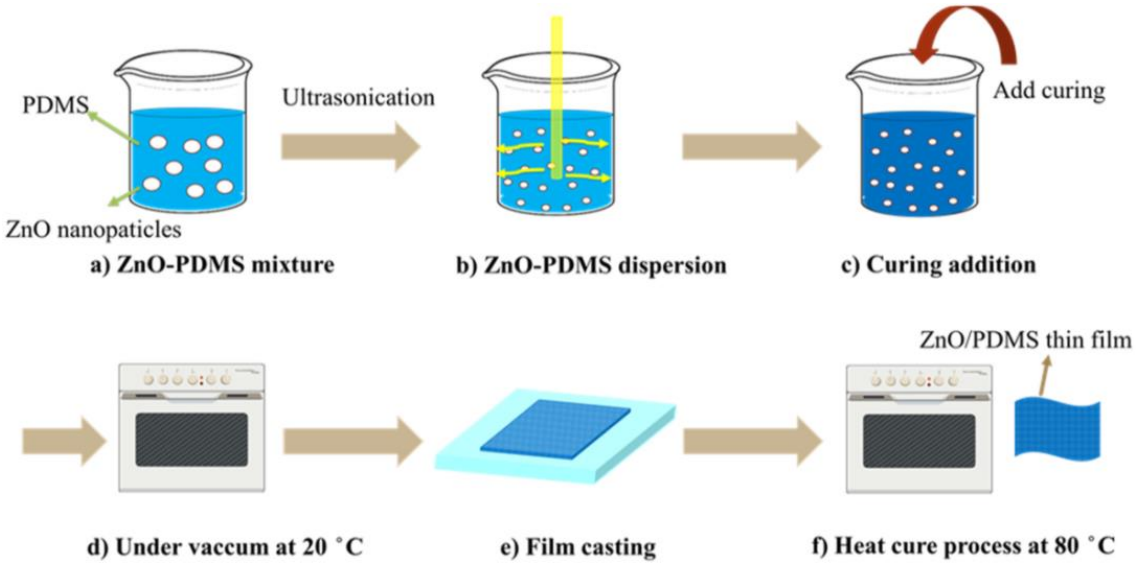

Figure 3.1 The preparation of PDMS and ZnO/PDMS nanocomposite films.

Preparation of ZnO/PDMS polymer flexible nanocomposite film

Figure 3.1 depicts the schematic diagram of the various steps involved in the synthesis of ZnO/PDMS nanocomposite films. Adding the prepared ZnO with PDMS compound A and mix with curing agent compound B in the ratio of 10:1 by using doctor blade method and outgassed for 1Hrs at room temperature under vacuum [23-27]. The composite was curing at 70°C for 24Hrs. Afterward, the ZnO nanoparticles are added into the ZnO in different weight percentages (0wt. %, 5wt. %, 10wt. % and 15wt. %), of size 1.5cm × 1.5cm as mentioned above. After this, we let the film cool down for a few Hrs. We dip the substrate with film into deionized water at room temperature. The film peels off from the substrate easily. No water gets stick on them because of the hydrophobic nature of the films. We have used these free-standing films (1.5cm × 1.5cm × 60μm) shown in **Figure** 3.1 for fabricating the Nano generator.

Fabrication of the piezoelectric pressure sensor

To explore the potential of the ZnO/PDMS flexible polymer nanocomposite films for use in pressure sensing, we fabricated the piezoelectric sensors from the films, as shown in **Figure** 3.2. For the fabrication of device from the free-standing nanocomposite films, first, a chromium layer of thickness 10nm, then a copper layer of thickness 50nm is deposited on both sides of the film by Thermal Evaporation Deposition. From the metal electrode, electrical wires are connected using silver paste for measurement. The system is encapsulated with an insulating tap so that when we impart pressure, the metal electrodes remain untouched. On both sides of the film, the total active electrode area is 1.5cm × 1.5cm.

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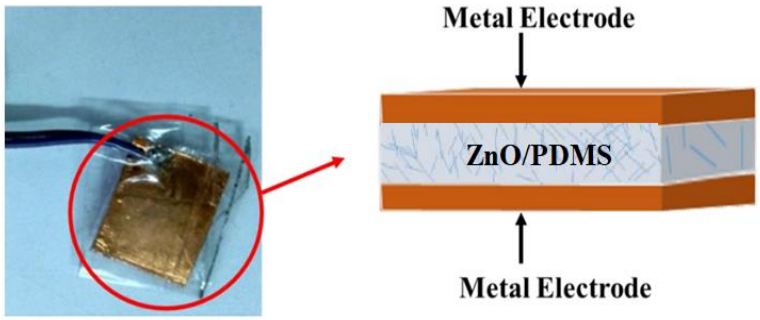

Figure 3.2 Photographic and cross-section diagram of the fabricated piezoelectric pressure sensor

RESULTS AND DISCUSSION

Structural and morphological analysis of ZnO nanoparticles

The XRD pattern of ZnO nanoparticles (**Figure** 3.3a) exhibit peaks at 2θ = 31.8°, 34.33°, 36.16°, 47.58° and 56.62° corresponding to the different planes of the hexagonal phase of ZnO (100), (002), (101), (102) and (110) planes, respectively (JCPDS card no. 36-1451). **Figure** 3.3a displays the transmission electron microscope (TEM) images of the ZnO nanoparticles. The average thickness of the ZnO nanoparticles is ~89nm.

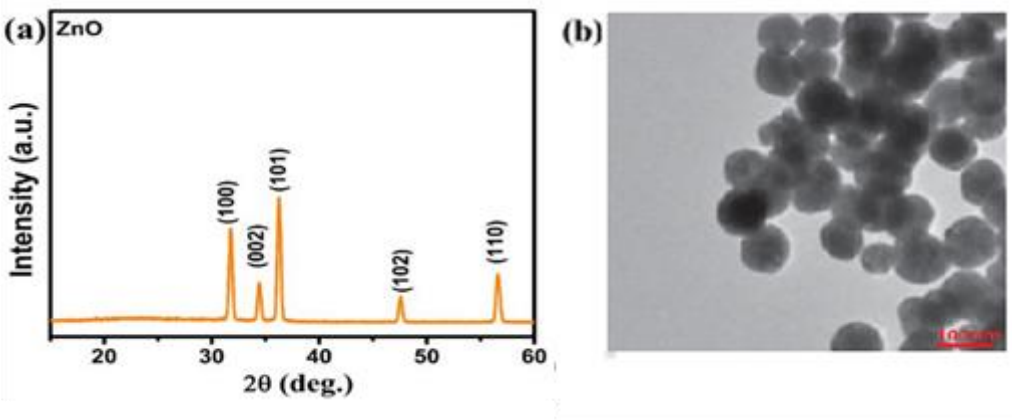

Figure 3.3 (a) XRD patterns of ZnO nanoparticles and (b) TEM images of ZnO nanoparticles.

XRD analysis of the nanocomposite films

In **Figure** 3.4 displays the XRD patterns of PDMS, and ZnO/PDMS nanocomposite films. In the XRD pattern, the peaks at 18.42^0 and 20.24^0 are for a-phase and polar crystalline β-phase respectively [28, 29]. Although the β-phase corresponding peak is present in the XRD peak, it cannot compare the relative content of β-phase in ZnO/PDMS for the nanocomposite films.

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The XRD patterns confirm the successful formation of ZnO/PDMS nanocomposite films.

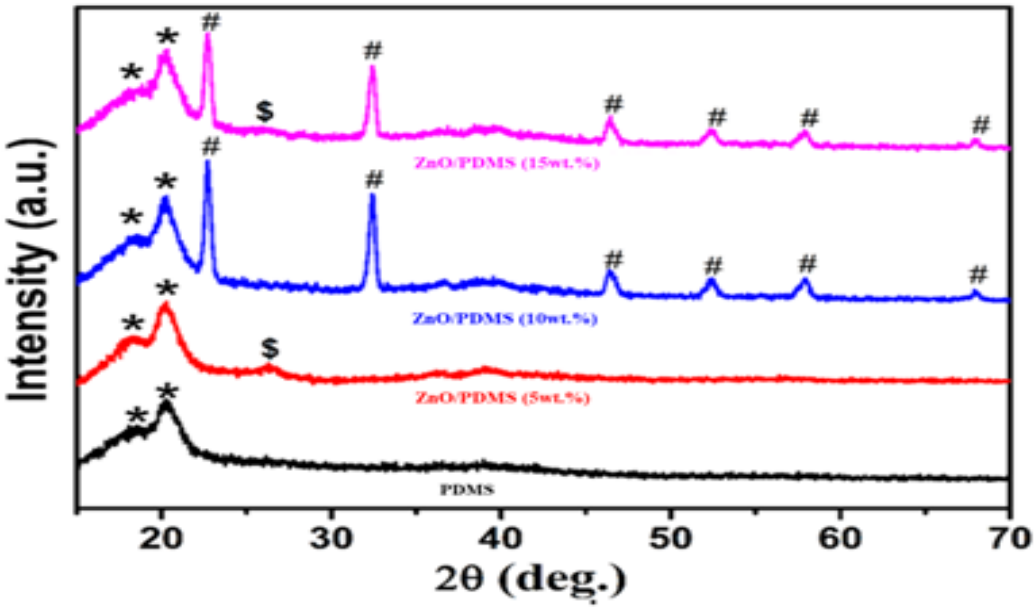

Figure 3.4 XRD patterns of PDMS and ZnO/PDMS nanocomposite films. The peaks corresponding to ZnO phases are marked with '#' respectively.

Surface morphology analysis of the nanocomposite films

The surface morphology of ZnO/PDMS for different ratios of ZnO films are studied. **Figure** 3.5 displays the Scanning Electron Microscope (SEM) images, revealing a uniform distribution of ZnO within PDMS matrix.

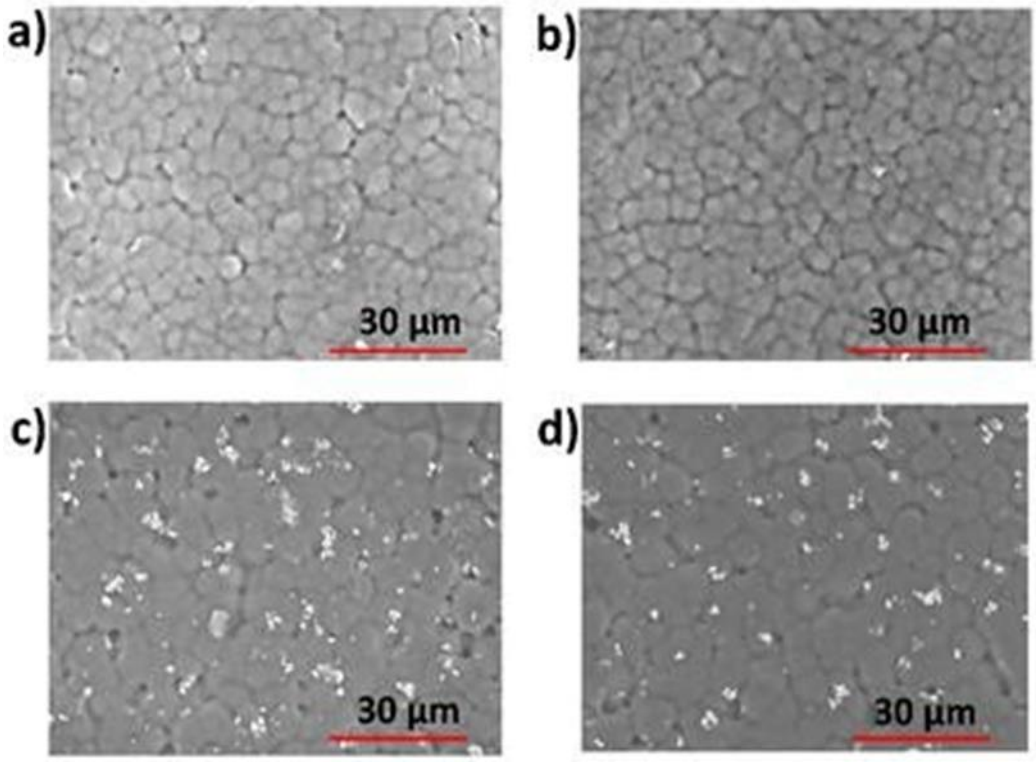

Figure 3.5 SEM images of (a) PDMS (b) Zno/PDMS (5wt. %) (c) ZnO/PDMS (10wt. %) and (d) Zno/PDMS (15wt. %) films.

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FTIR analysis of the nanocomposite films

Figure 3.6 shows the Fourier Transform Infra-Red (FTIR) spectra of PDMS and ZnO/PDMS, of different (5wt. %), (10wt. %), (15wt %) films. The different peaks corresponding to different α and β -phases of ZnO/PDMS [30] are marked. The ratio of β-phase content in ZnO/PDMS and its composite films is calculated.

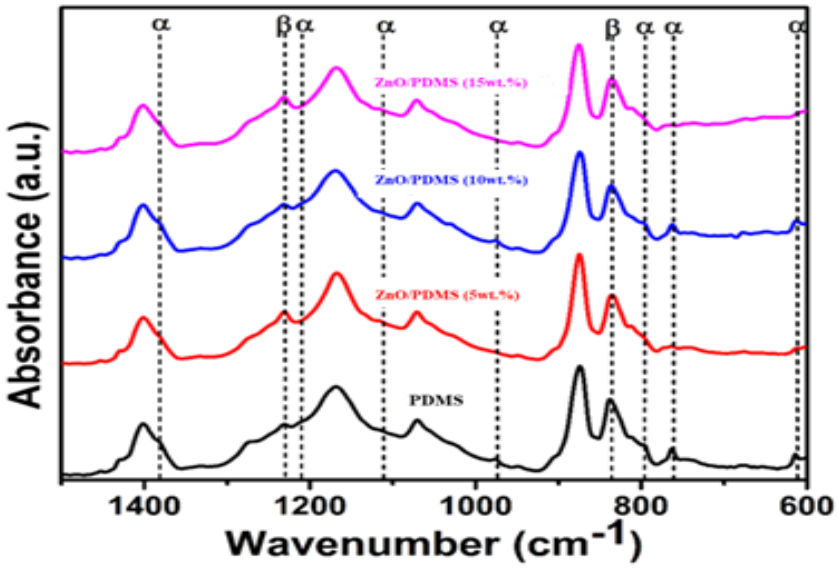

Figure 3.6 The FTIR spectra of PDMS and ZnO/PDMS of different (5wt. %), (10wt. %), (15wt. %) films.

The value of (β) for PDMS film is obtained as 49%, and for ZnO/PDMS of (15wt %) nanocomposite films the values of (β) are found to be nearly same as 78 %. These results indicate that the synthesized ZnO/PDMS based nanocomposite film has the same β -phase although higher from bare ZnO/PDMS film. Now if the performance of the piezoelectric Nano generator depends only on the β-phase content, then the entire three nanocomposite film based pressure sensors will give output.

Polarization-electric field measurement of the films

Polarization-electric field (P-E) loops measurement has been carried out to study the ferroelectric property of PDMS. The **Figure 3.7** reveals differences in the ferroelectric properties of these films. The values of remnant polarization (*DR*) have been obtained as 10.8, 16.0, 18.1, and 20.1 x10^{-3}mCcm^{-2} for the ZnO/PDMS, films respectively.

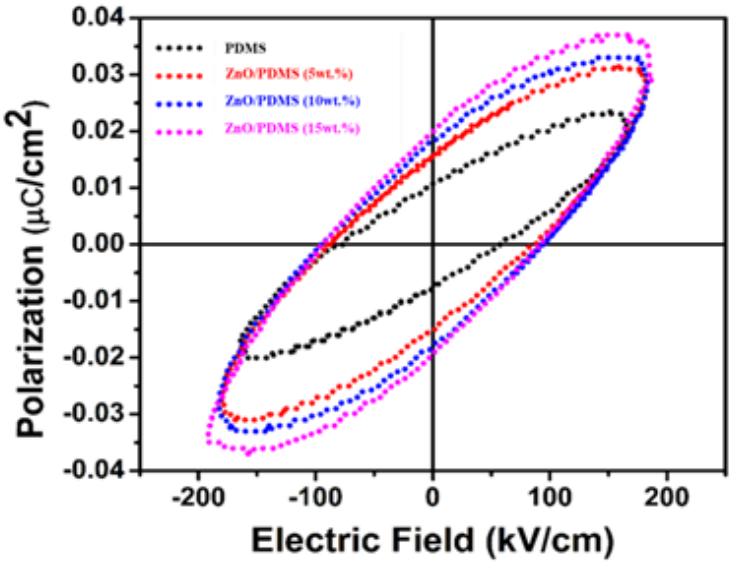

Figure 3.7 P-E loops for PDMS and ZnO/PDMS of different (5wt. %), (10wt. %), (15wt. %) films.

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The results are interesting as the □-phase content is nearly similar in all the nanocomposite films, but the remnants polarization is found to be different, and the value of remnants polarization for ZnO/PDMS film is determined to be the highest. Therefore, the addition of ZnO helps in aligning the dipoles of PDMS, which resulted in the higher values of remnants polarization. ZnO being a ferroelectric material, provides additional polarization. The films having higher remnants polarization are expected to produce higher piezo voltage when equal pressure is applied to the materials.

Electrical measurements of piezoelectric pressure sensor

Figure 3.8 shows the performance of the piezoelectric pressure sensing with PDMS and ZnO/PDMS of different (5wt. %), (10wt. %), (15wt. %) nanocomposite films. The ZnO/PDMS 15wt. % film gives more output voltage (~0.83V) as compared to that using ZnO/PDMS 10wt. % film (~0.37V). Furthermore, the voltage signal generated from is significantly higher ~1.62V, which is higher than the voltage generated in ZnO/PDMS. **Figure** 3.9 shows the output voltage of applied pressure using different nanocomposite films, as well as their corresponding remnants polarization (DR). It is evident that for the films with larger values of *DR*, the output voltage of the sensor is also higher for films with higher DR values. It is because higher remnants polarization refers to the presence of a larger number of electric dipoles oriented in the same direction in the material, thereby increasing the overall piezoelectric property of the film [31]. As a result, the piezoelectric pressure sensor fabricated from films with higher remnants polarization has a higher output voltage than those made from films with lower remnants polarization.

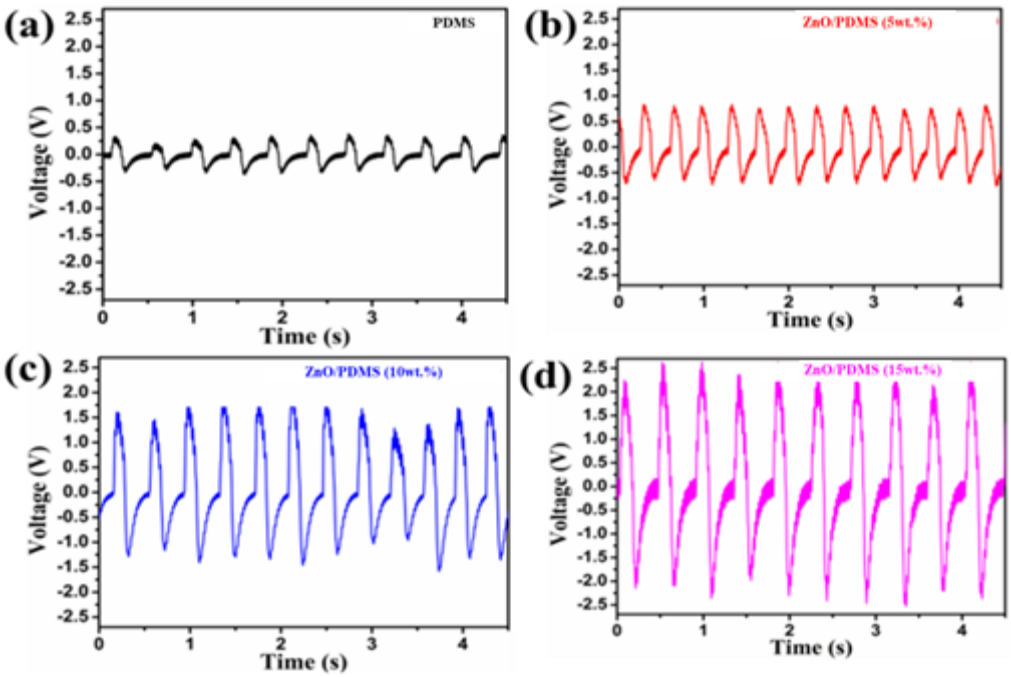

Figure 3.8 Output open circuit voltage of PDMS and ZnO/PDMS of different (5wt. %), (10wt.%), (15wt. %) nanocomposite films.

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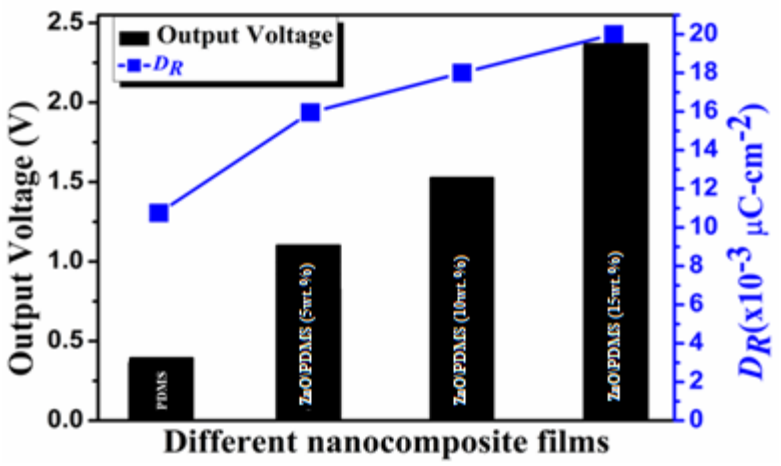

Figure 3.9 The output voltage and the corresponding remnants polarization (DR) of ZnO/PDMS of different nanocomposite films.

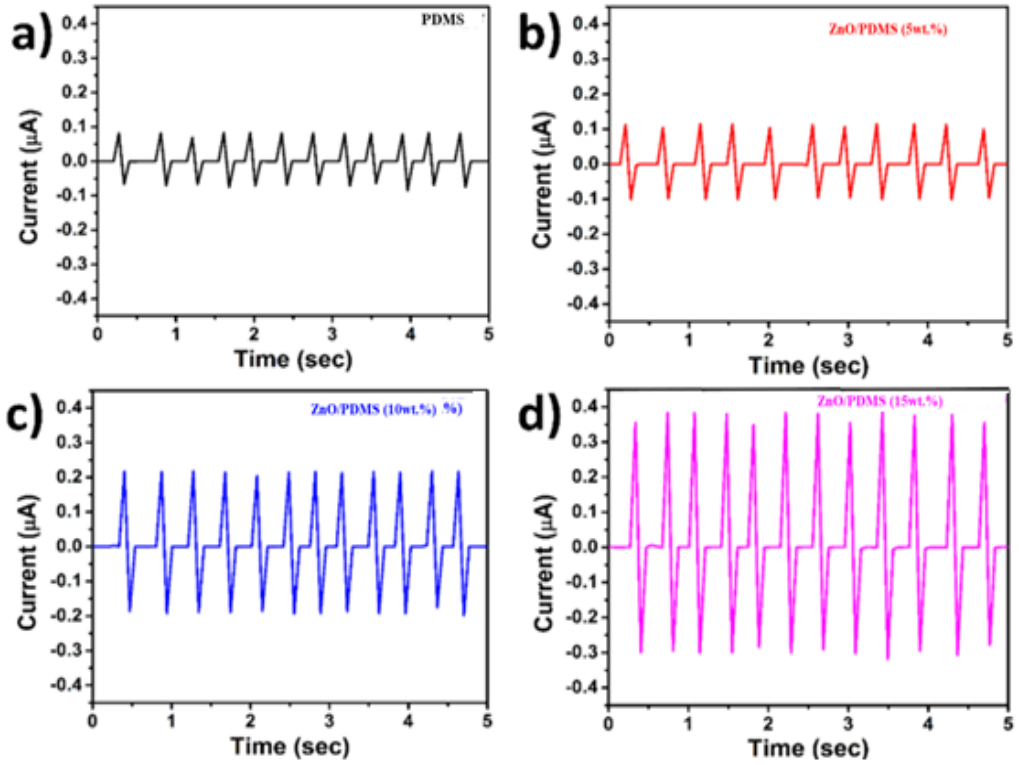

Figure 3.10 Short circuit output current obtained PDMS and ZnO/PDMS of different (5wt. %), (10wt. %), (15wt. %) nanocomposite films.

In order to further study the performance of the pressure sensor fabricated from PDMS and ZnO/PDMS based nanocomposite films, we carried out short circuit current measurements. **Figure** 3.10 shows the short circuit current measured from the sensor by applying a dynamic force of the same amplitude and frequency as in the voltage measurement. The short circuit current is obtained as 0.08μA, 0.11μA, 0.22μA, and 0.38μA for PDMS and ZnO/PDMS of different (5wt. %), (10wt. %), (15wt. %) nanocomposite films based pressure sensor.

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CONCLUSION

The ZnO/PDMS nanocomposite films with different loadings of ZnO have been fabricated successfully. The β-phase of ZnO/PDMS has been increased from 38.2% to 66.1% without requirement of any further processes. The Nano generator fabricated from ZnO/PDMS-ZnO (15wt. %) gives an output of 2.35v (open circuit voltage) and 0.38μA (short circuit current) with an instantaneous output power density of 0.21 $\mu W/cm^2$. This enhanced piezo-response of the ZnO/PDMS nanocomposite films based pressure sensor is attributed to the enhancement of electroactive β-phase and enhanced d33 value in ZnO/PDMS with the addition of ZnO nanoparticles.

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