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CONTROLLED FABRICATION OF FLEXIBLE ZNO THIN FILM PIEZO-ELECTRIC BASED PRESSURE SENSOR USING DC MAGNETRON SPUTTERING

Paramaguru PV[1], Maheswaran R[2] and Muruganand S[3]
[1]PhD research Scholar, Department of Electronics and instrumentation, Bharathiar University,
[2]Department of Electronics and Instrumentation, Bharathiar University,
[3]Associate Professor (Rted), Department of Electronics and Instrumentation, Bharathiar University
[1]paramaguru.ei@buc.edu.in, [2]mahes94@gmail.com and [3]drsmbu2010@gmail.com

ABSTRACT
Reveals the controlled fabrication of flexible piezo-electric based pressure sensor with application in tactile sensors. First the ZnO thin film were prepared by the DC magnetron sputtering (with zinc as a target and farming ZnO) by using reactive gas O_2 in the Argon environment on the PDMS substrate. Then these samples were optimized, the ZnO film shows the piezo electric characteristics has been selected for the further masking process. Here, flexible substrates were prepared using PDMS by spray pyrolysis technique with the thickness of 150µm sputtered with ZnO. Then with the prepared PDMS thin film substrate leads to DC magnetron sputtering to form Cu thin film layer about (10-20 nm) with the above optimized conditions as formed electrode with conducting leads which acts as electrode terminals. The formed Cu/ZnO /PDMS layer thin film substrate enables the significance in the output piezo electricity of about 250µv-3µv while the proportionality of the applied static pressure on the flexible thin film appropriately (1psi-25psi) shows the application of piezo electric Nano generators for low voltage applications. This piezo electric pressure sensor demonstrates a power density of 0.94µw/cm at 1kpa pressure with the load resistance of 0.010 - 0.0175 ohm was calculated from the resistant, current and voltage signals. The proposed piezo electric pressure sensor determines the constant voltage response on the static and dynamic pressure because the advancement of the flexible Cu/ ZnO /PDMS layers thin film on the PDMS substrate. This exhibits the advantages in linear response, high sensitivity (10µv/psi) a faster response time (50ms), long term durability and cost effective.

Keywords: MEMS – micro-electro mechanical systems, piezo- electric, PDMS , zinc oxide ZnO.

1. INTRODUCTION
As the research progresses in now days, the advancement in the smart sensor with introducing mems based technology especially in tactile care sensor for the comfort which provides. Here, piezo electric pressure sensors (PEPS) plays a major role in human action related with tactile sensing and also in health care applications from with the implementation of the thin film based sensors gives the high stability and sustainability. In this flexible type thin film PEPS's has emerging a change impact in the accuracy which it produces. Here, the flexible PEPS's pays major roles because compared with the solid type sensors only get the signal from the interrupted cross-section area which the sensor has to be mounded. Here in this type of flexible PEPS sensors has attention on the movement of the human action due to the flexibility. Also these sensors have well in the response of about (1 kpa-10 kpa) on the static and dynamic pressure ranges[2][3][4].

The incorporation of robots in complex human environments is becoming a focal point in the robotics industry, and specialized in-hand manipulation tasks will be needed for future generation of robots. A network of PEPS's based tactile sensors should be used to ensure constant measurement of the pressure exerted at all touch points in order to meet the specifications for the tactile movement. The piezoelectric composites have the advantages of versatility, mechanical robustness, insensitivity to overload, and easy and low-cost fabrication techniques among the various working concepts for robotic tactile sensing[1]. The fabrication of a lightweight and conformable piezoelectric tactile sensor is presented in this paper. The tunneling conduction mechanism in ZnO and poly dimethyl siloxane (PDMS) (ZnO/PDMS) composites was the basis for the newly produced revolutionary practical content. A giant piezoelectric activity can be obtained.

The conductive mechanism is caused by compressive deformation of the polymeric matrix, which reduces the distance between the conductive particles, resulting in the formation of electric conductivity paths and an increase in the overall composite's electrical conduction. The uniqueness of this solution lies in the proper tuning of the conductive system based on the particle density, which is believed to be normally distributed in the polymeric matrix of ZnO/PDMS composite. The conductive particles come into physical contact with each other in the majority of the studied cases as early as the mechanical load is applied. The porous paths can be represented by different theoretical models and the change in piezoelectricity is obviously a function of the filler concentration in the polymeric matrix[6]. The majority of these models, however, fail to predict activity below the threshold voltage. The conductive particles in a second form of piezoelectric composite are scattered very close together but remain fully covered by a polymeric film. As a consequence, in the absence of deformation, the value is infinitely high, resulting in the composite's insulating behavior. The polymeric layer between the particles thins out when a compressive load is applied[7].

Tunneling of electrons happens next, resulting in conductivity paths and a significant decrease in total electrical resistance. Various models, including electric field mediated emission, Richardson–Schottky transmission modes, and Pole–Frenkel conduction; have been used to describe the conduction process over the last decade. The tunneling effect, on the other hand, is the most well-known and widely recognized model for predicting electrical conduction in piezo resistive polymer composites. In addition, we and other authors demonstrated that using nickel filler particles with nano structured and extremely sharp tips improves composite electrical conduction by many orders of magnitude in response to mechanical strain. In order that the silicone rubber filled with smooth zinc particles had a significantly lower piezoelectric action at the same applied strain, implying that the tips play a fundamental role in piezoelectric enhancement. The chance of electrons tunneling through neighboring particles through their sharp tips increases as the composite is stretched, resulting in an exponential decrease in the sample's electrical resistance[10][13]. By the investigated piezoelectric transduction in tactile robotic applications, revealing the electric resistivity of conductive inks as a result of the pressure applied on the thin film. The high mechanical versatility provided by the polymer, combined with the ability to switch from insulating to conductive electrical action, enables this composite a good option for use as a smart sensing skin for robotic applications. Our piezo resistive composite, in particular, could meet the key criteria for an effective tactile sensing skin.

2. MATERIALS AND METHODS

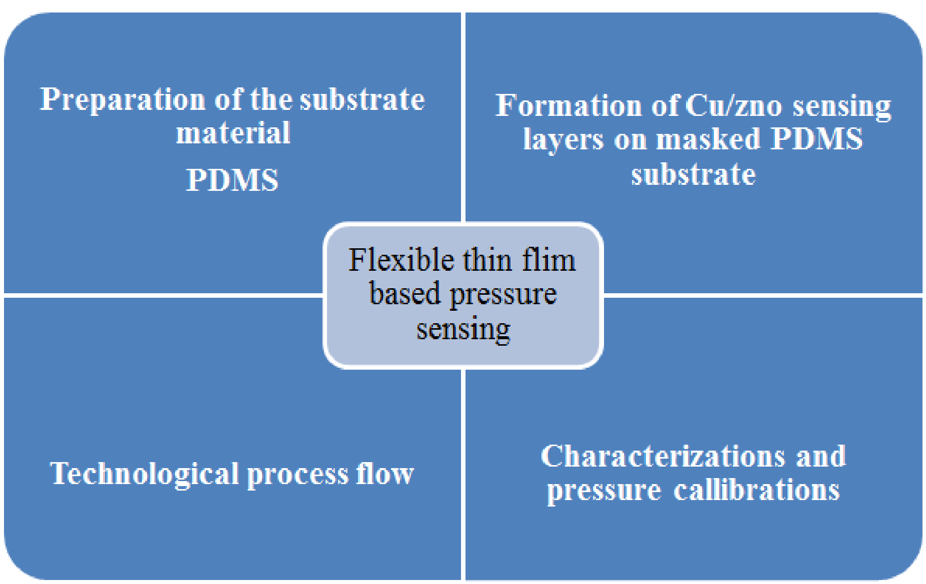


Fig 1: over view block diagram

2.1.PREPARATION OF THE SUBSTRATE MATERIAL

The curing agent was then applied at a weight ratio of 1:10 to the PDMS copolymer, and the resulting paste was dropped to smooth surface to form substrate by using doctor blade method and outgassed for 1 hour at room temperature under vacuum[11]. The composite was curing at 70°C for 24 hours. Then the designed structural mask has placed on the top of the PDMS layer. The designed structural mask by using CNC and laser technique as shown in fig2, the gap between the each fringe of above mask has 100µm width as a sensible electrode layer deposition. The structural mask has been printed on the 10 gradient stainless steel of 0.5mm thickness. The prepared substrate PDMS layer was placed and followed the optimized, parameter in DC magnetron sputtering process.

2.2.FORMATION OF ZN/ZNO SENSING LAYERS

The optimization of ZnO and Zn were carried out by changing the limitations of the following parameters. Such as, at constant temperature the distance between substrate and source (target) of above 45mm. Then the base pressure of above 10-6 mbar and working pressure of 0.6x10-3 to 0.8x10-3 mbar pressure varying with; the flux as Ar for Zn seed layer. Also in case of ZnO additionally the O2reactive gas was added with Ar. From the above process the suitable Zn seed layer was obtained were sputtered at 0.75x10-3 mbar working process have resultant XRD and SEM characteristics as shown in fig2. Then also in the case of ZnO layer sputtered at 0.6x10-3 m bar working pressure with O2 and Ar medium have resultant (XRD and SEM). Proves the material having properties of ZnO and also surface morphological. The piezo electric property of sputtered ZnO film layer on a flexible substrate carried out by four probe method to finding the IV-characteristics with respect to the applied pressure as shown in fig2. This above property shows the piezo electric property of ZnO to make step in a fabrication of piezo electric pressure sensor [23].

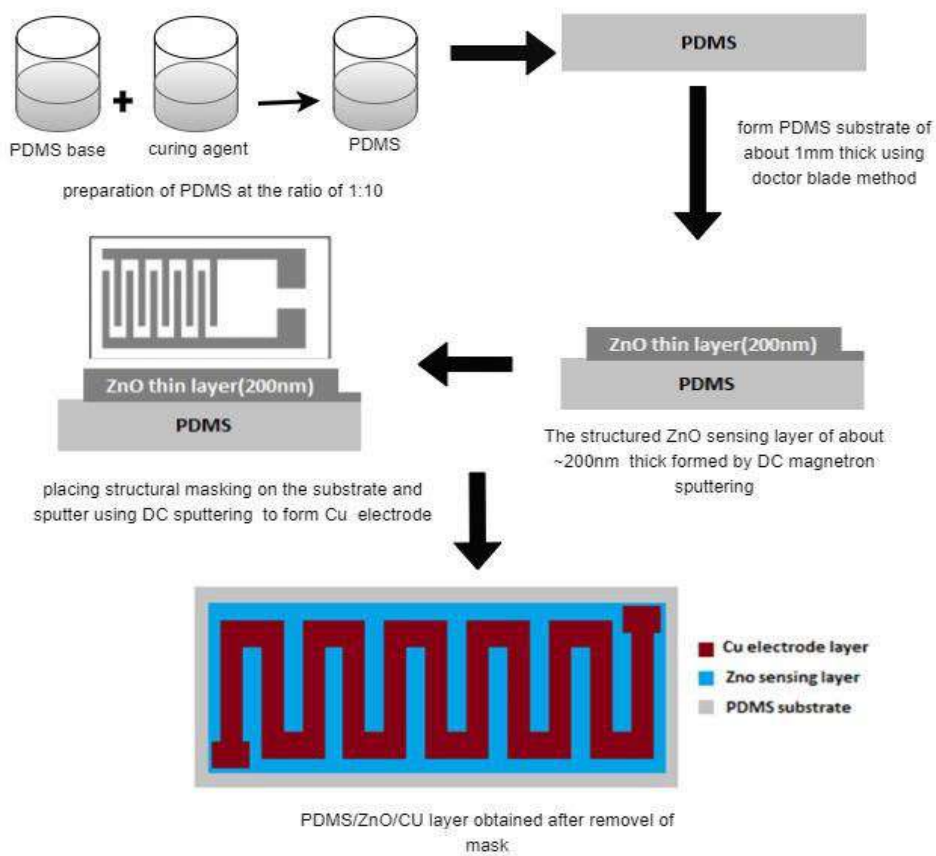
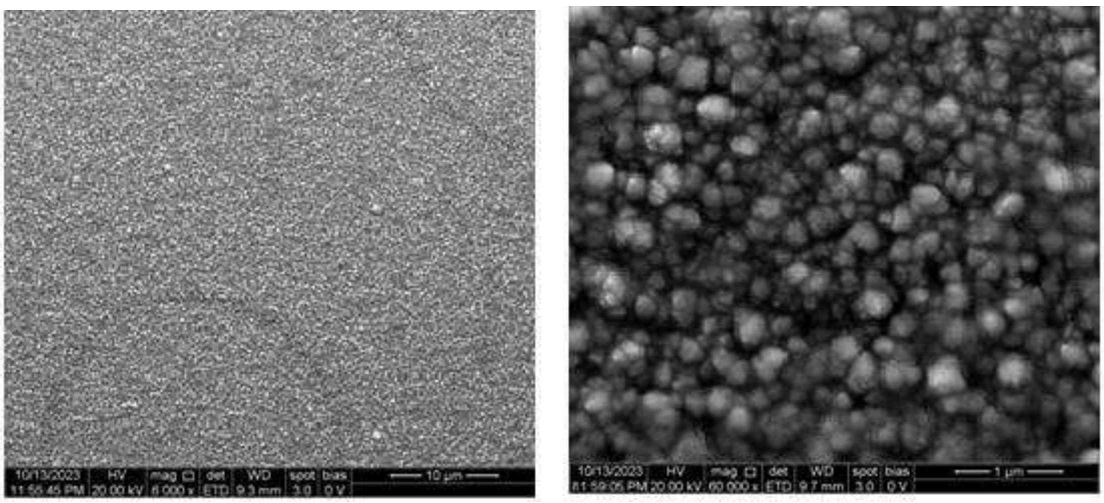


Fig2: Material preparation and its step by step methods involves

3. RESULTS AND DISCUSSION:

3.1. Material Characterizations

Prior to fabricating the PDMS/ZnO piezoelectric composite, a the prepared samples was collected for SEM and XRD analysis. The SEM images reveal that nanoparticles had 50–200 nm lateral dimensions. Most of the Zno particles in the surface of the thin film exhibit polyhedral form with only a few rectangular shapes (Fig. 3). XRD pattern (Fig. 4) exhibited expected peaks from the wurtzite crystal structure (compared to ICDD database) to the plane 002. Based on XRD pattern, sputtered ZnO thin flim was mostly free of impurities with only small residual peaks observable at 37.6°.



(a) (b)

Fig 3: Shows the surface morphological structure of fabricated PDMS/ZnO thin flim,

(a) surface view of 10 um, (b) surface view of 1 um

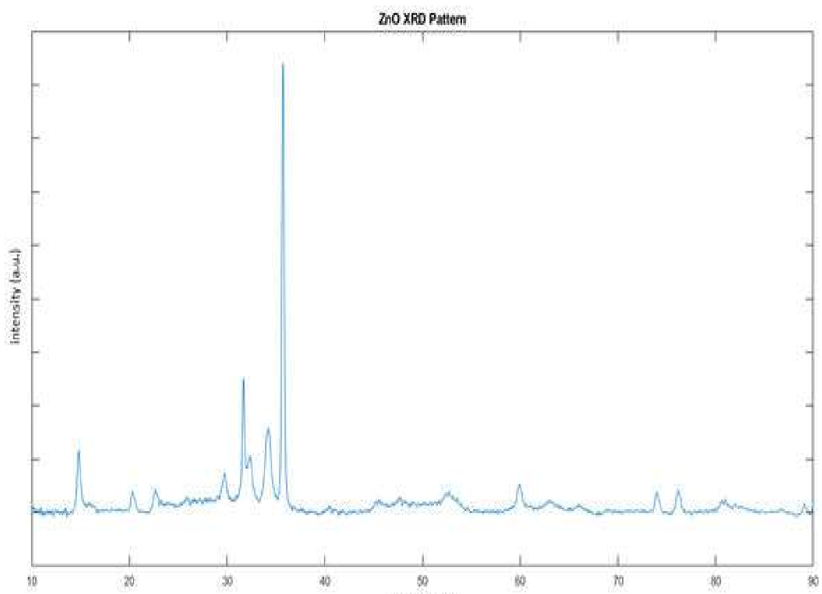


Fig 4: X-ray diffraction pattern for Zno/PDMS thin film

3.2. PRESSURE SENSING TESTS

The fabricated flexible piezoelectric sensors are initially tested for force measurements. The force sensing is possible because of the compressive strain experienced by the thin PDMS/ZnO transducer deposited ZnO electrodes. In these experiments, the change in resistance and voltages by the compression due to air pressure were monitored and logged with a compound LCR meter and digital multi-meter respectively. The flexible sensors are secured with pressure test and the pressure is applied directly on the sensor using the aligned air locking system with pressure gauge and sensor positioning system manually experimented shown in fig5.

Fig 5: Manually assembled pressor applicator with gauge and control

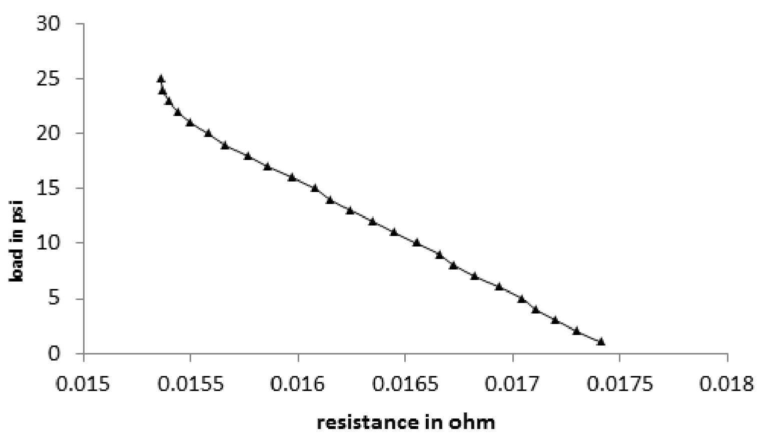


Fig 6: Output responds of sensor with respect to applied pressure in psi and Change in resistance in ohm respectively

For the first set of test, the applied pressure of 1psi. The value was confirmed with the Interlink pressure sensing gauge. For the second set of tests, the initial applied force was increased gradually upto 20 psi by increasing the pressure at start point of the sensor. The force values of 1 psi to 20psi the resultant sensor output as shown in fig 6 and fig 7 correspondingly. As this confirms that the output resistance increases with the magnitude of the applied pressure.

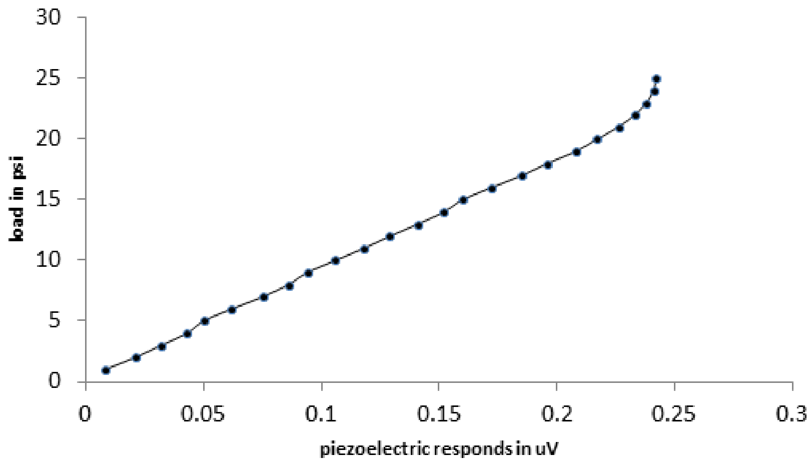


Fig 7: Measured output responds of sensor with respect to applied pressure in psi and change in resistance in ohm respectively

The output voltage is observed to increase with applied pressure and retracing it in same order. The output voltage from the device shows the ability of material to produce a voltage by sensing a pressure stress. The sensitivity of this particular sensor is calculated by using formula

$$sensitivity\ of\ the\ sensor = \frac{output\ voltage}{\text{input pressure (psi)}}$$

Manually regulated pressure applied into the device producing a small delay will causes a step by step increase in voltage. The Results obtained from this device shows the capability of fabricated PDMS/ZnO material to act as a piezo-electric pressure sensor.

CONCLUSION

From the above discussion the proposed thin film sensor was designed and fabricated around the fundamental principle using fabrication and characterization of flexible piezoelectric type pressure sensing device using ZnO thin film as the sensing active layer. This resembles the advantages in high flexible to access the nodes, high sensitivity, low responds time. These type of sensors are used as tactile movement sensing, and it has application with nano generators due to its electrical responds

REFERENCES

[1] C. Grimaldi, P. Ryser, S. Strässler, Gauge factor enhancement driven by heterogeneity in thick-film resistors, J. Appl. Phys. 90 (2001) 322–327. [30] G. Ambrosetti, I. Balberg, C. Grimaldi, Percolation-to-hopping crossover in conductor-insulator composites, Phys. Rev. B 82 (2010).

[2] S. ˇ Meskinis, ˇ A. Vasiliauskas, K. Slapikas, ˇ R. Gudaitis, S. Tamulevicius, ˇ G. Niaura, Piezoresistive properties and structure of hydrogen-free DLC films deposited by DC and pulsed-DC unbalanced magnetron sputtering, Surf. Coat. Technol. 211 (2012) 172–175.

[3] E. Peiner, A. Tibrewala, R. Bandorf, H. Lüthje, L. Doering, W. Limmer, Diamond-like carbon for MEMS, J. Micromech. Microeng. 17 (2007) S83–S90.

[4] H. Fan, D. Yang, L. Sun, Q. Yang, J. Niu, Z. Bi, et al., Structural and electrical evolution of He ion irradiated hydrocarbon films observed by conductive atomic force microscopy, Nucl. Instr. Methods Phys. Res. Sect. B-Beam Interactions Mater. Atoms 312 (2013) 90–96.

[5] F. Hui, M. Lanza, Scanning probe microscopy for advanced nanoelectronics, Nat. Electron. 2 (2019) 221–229.

[6] Xin Ma, Xiaoshan Tong, Peng Guo, Yulong Zhao, Qi Zhang, Hanchao Li, Rende Chen, Aiying Wang, MEMS piezo-resistive force sensor based on DC sputtering deposited amorphous carbon films, Sensors and Actuators A: Physical, Volume 303, 2020, 111700, ISSN 0924-4247, https://doi.org/10.1016/j.sna.2019.111700.

[7] Xiaoting Zhang, Minh-Quyen Le, Van-Cuong Nguyen, Jean-François Mogniotte, Jean-Fabien Capsal, Daniel Grinberg, Pierre-Jean Cottinet, Lionel Petit, Characterization of micro-ZnO/PDMS composite structured via dielectrophoresis – Toward medical application, Materials & Design, Volume 208, 2021, 109912, ISSN 0264-1275, https://doi.org/10.1016/j.matdes.2021.109912.

[8] R.G. Lehmann, S. Varaprath, C.L. Frye, Degradation of silicone polymers in soil, Environ. Toxicol. Chem. 13 (1994) 1061–1064, http://dx.doi.org/10.1002/etc. 5620130707.

[9] A. Sirelkhatim, S. Mahmud, A. Seeni, N. Kaus, L. Ann, S. Bakhori, H. Hasan, D. Mohamad, Review on zinc oxide nanoparticles: antibacterial activity and toxicity mechanism, Nano-micro Lett. 7 (2015) 219–242, http://dx.doi.org/10. 1007/s40820-015-0040-x.

[10] Z. Wang, Nanostructures of zinc oxide, Mater. Today 7 (2004) 26–33, http:// dx.doi.org/10.1016/s1369-7021(04)00286-x.

[11] Dogan Sinar, George K. Knopf, Disposable piezoelectric vibration sensors with PDMS/ZnO transducers on printed graphene-cellulose electrodes, Sensors and Actuators A: Physical, Volume 302, 2020, 111800, ISSN 0924-4247, https://doi.org/10.1016/j.sna.2019.111800

[12] Q.Liu, M.Q.Le, C.Richard, R.Liang, P.J.Cottinet, J.F.Capsal, Enhanced pseudo piezoelectric dynamicforce sensors based on inkjet – printed electro strictiveter polymer, Organic Electron. 67(2019)259–271, https://doi.org/10.1016/j.orgel.2019.01.028.

[13] D. Sinar, G.K. Knopf, Cyclic liquid-phase exfoliation of electrically conductive graphene-derivative inks, IEEE Trans. Nanotechnol. 17 (2018) 1020–1028, http://dx.doi.org/10.1109/TNANO.2018.2849264.

[14] E. Hobbs, M. Keplinger, J. Calandra, Toxicity of polydimethylsiloxanes in certain environmental systems, Environ. Res. 10 (1975) 397–406, http://dx. doi.org/10.1016/0013-9351(75)90035-3.

[15] S. Ertel, B. Ratner, A. Kaul, M. Schway, T. Horbett, In vitro study of the intrinsic toxicity of synthetic surfaces to cells, J. Biomed. Mater. Res. 28 (1994) 667–675, http://dx.doi.org/10.1002/jbm.820280603.

[16] A. Moezzi, M. Cortie, A. McDonagh, Aqueous pathways for the formation of zinc oxide nanoparticles, Dalton Trans. 40 (2011) 4871–4878, http://dx.doi. org/10.1039/C0DT01748E.

[17] A.N.P. Madathil, K.A. Vanaja, M.K. Jayaraj, Synthesis of ZnO nanoparticles by hydrothermal method, in: Nanophotonic Materials IV. Presented at the Nanophotonic Materials IV, International Society for Optics and Photonics, 2007, http://dx.doi.org/10.1117/12.730364, p. 66390J.

[18] R. Kac¸ ar, S.P. Mucur, F. Yıldız, S. Dabak, E. Tekin, Highly efficient inverted organic light emitting diodes by inserting a zinc oxide/polyethyleneimine (ZnO:PEI) nano-composite interfacial layer, Nanotechnology 28 (2017), 245204, http://dx.doi.org/10.1088/1361-6528/aa6f55.

[19] V. Koutu, L. Shastri, M.M. Malik, Effect of NaOH concentration on optical properties of zinc oxide nanoparticles, Mater. Sci. 34 (2016) 819–827, http:// dx.doi.org/10.1515/msp-2016-0119.

[20] B. Wang, Y.C. Jiang, R. Zhao, G.Z. Liu, A.P. He, J. Gao, Piezoresistive effect observed in flexible amorphous carbon films, J. Phys. D Appl. Phys. 51 (2018), 175304.

[21] A. Singh, S. Das, M. Bharathkumar, D. Revanth, A. Karthik, B. Sastry, V. Rao, Low cost fabrication of polymer composite (h-ZnO + PDMS) material for piezoelectric device application, Mater. Res. Express 3 (2016), 075702, http:// dx.doi.org/10.1088/2053-1591/3/7/075702.

[22] X. Ma, P. Guo, X. Tong, Y. Zhao, Q. Zhang, P. Ke, et al., Piezoresistive behavior of amorphous carbon films for high performance MEMS force sensors, Appl. Phys. Lett. 114 (2019). [23] E. Peiner, A. Tibrewala, R. Bandorf, S. Biehl, H. Lüthje, L. Doering, Micro force sensor with piezoresistive amorphous carbon strain gauge, Sens. Actuators A-Phys. 130-131 (2006) 75–82.

[23] M. Birtane, H. Tuna, The evaluation of plantar pressure distribution in obese and non-obese adults, Clin. Biomech. 19 (2004) 1055–1059, http://dx.doi.org/ 10.1016/j.clinbiomech.2004.07.008.