Abstract. Flexible substrates have many promising applications in sensing, electronics, and electromagnetic shielding and energy storage among many others. Paper can serve as substrate for these kinds of technologies offering a cheaper alternative. In this study, Zinc oxide (ZnO) was successfully deposited on graphite drawn on paper using electrophoretic deposition (EPD). Graphite from commercially-available pencil was drawn on paper. Graphite drawn on paper was used as electrodes for the EPD process. High-voltage power supply was used as source while ground ZnO in acetone was used as suspension in the deposition process. Scanning electron microscopy (SEM) and Energy dispersive x-ray spectroscopy (EDX) results reveal the deposition of ZnO on Graphite. In addition, the electrical contact of the ZnO-graphite interface showed Ohmic behaviour by two-point probe method.

1. Introduction

Zinc oxide has been used for many industrial applications such as catalysts, photocatalytic, photovoltaic, gas sensors, and diodes [1-5]. It is also low cost and nontoxic with a wide band gap of ~3.3 eV [3-5]. Traditionally, ZnO has been deposited on substrates with planar surfaces. However, several applications require deposition on non-flat surfaces. A possible approach for this is to deposit ZnO on a flexible substrate that can cover different types of surfaces. Paper has been used as substrate [6-14] for conducting strips using ink and organic materials. It is one of the most abundant manmade materials and very accessible. It is inexpensive, lightweight, and mechanically flexible. It can be bent and cut into different shapes and sizes to fit and integrate into many applications. Nowadays, commercial functional materials targeting low cost and large volume productions may require the use of inexpensive substrates such as paper.

There are methods to embed functional materials on paper by using binders or by chemical routes among others. The challenge in using such methods is when the application needs patterning and interfacing for electronic applications. Electrophoretic deposition offers advantages of being a versatile yet simple technique used to deposit materials on a variety of substrates. It only uses working electrodes, electrolyte, and power source [15-16]. Moreover, it has also tunable parameters (e.g. deposition time and applied voltage) to obtain enhanced characteristics of the deposited material. The electrodes need to be conducting. This is addressed by drawing graphite on paper. This pen-on-paper method is a straightforward process to draw patterns. The graphite drawn on paper was used as conducting strips for electrophoretic deposition. Graphite is composed of carbon atoms in a layered
structure that exhibits high electrical and thermal conductivity. Graphite has been widely used as conducting filler for materials to improve conductivity [17].

In this paper, graphite was drawn on paper to serve as electrodes for electrophoretic deposition of Zinc oxide. The composition, morphology and electrical characteristics of the samples were studied using scanning electron microscopy, energy dispersive x-ray spectroscopy and electrical-probe method.

2. Experimental details
Electrophoretic deposition was carried out using graphite drawn on paper as conducting electrodes. ZnO powder was ground and mixed with acetone to obtain a 10 mg/mL concentration. This suspension was sonicated for 30 minutes to disperse the particles. ZnO was deposited using an applied voltage of 300 V and 500 V with deposition time of 3 min. After the deposition, the samples were heat treated at 60 °C for 1 hour.

The morphology and composition of the samples were observed using scanning electron microscope and energy dispersive x-ray spectroscopy, respectively. Two-point probe technique was used to obtain the current-voltage (I-V) characteristics of the samples.

3. Results and discussions
ZnO was deposited on graphite drawn on paper via electrophoretic deposition. Figure 1 shows the deposited ZnO on graphite drawn on paper.

![ZnO Graphite](image)

**Figure 1.** Deposited ZnO on pencil graphite drawn on paper (0.5 in x 1.5 in).

Figure 2 shows SEM image of graphite drawn on paper. The film generally shows a uniform surface with flaked structures. The individual graphite sheets have typical planar structures. In commercial pencils, the graphite is mixed with binders to form and this gave variations in the SEM of graphite.

![SEM images](image)

**Figure 2.** SEM images showing flat images of graphite drawn on paper at 10kx (a) and 50kx (b) magnification.
Figure 3 shows the SEM images of ZnO deposited on graphite drawn on paper synthesized by electrophoretic deposition at (a) 300 V and (b) 500 V both in 10kx magnification. SEM images showed deposited ZnO particles on graphite. It appears that film deposited with a larger voltage is more compact. On the other hand, figure 4 shows higher magnification SEM images of the samples fabricated at (a) 300 V and (b) 500 V applied voltages. More detailed and distinct structures of the deposited particles from the graphite substrate were observed.

![Figure 3](image1)

**Figure 3.** ZnO deposited on graphite drawn on paper using electrophoretic deposition with applied voltages of 300 V (a) and 500 V (b) both in 10kx magnification.

![Figure 4](image2)

**Figure 4.** ZnO deposited on graphite drawn on paper using electrophoretic deposition with applied voltages of 300 V (a) and 500 V (b) both in 50kx magnification.

Furthermore, the structure and composition of the deposited ZnO on graphite drawn on paper were studied using SEM and EDX, respectively. Figure 5 shows the ZnO particles with varying shapes and sizes on the surface of the graphite substrate. It appears that there are no differences between the deposited particles. This suggests that the voltages used provided sufficient field to transport the particles from the suspension to the electrodes.
Figure 5. ZnO deposited on graphite using electrophoretic deposition at 300 V (a) and 500 V (b) both in 100kx magnification.

Table 1 shows the EDX results for graphite. The dominant composition is C and O. The elemental results for C give 58 wt.% proportion. This comes from the graphite drawn on paper because of the graphitic components. The elements Au and Pd comes from the conductive coating (gold palladium) of sample done for SEM characterization. The other compositions are due to sample contaminations at very low weight proportions.

Table 1. EDX results for Graphite used to be drawn on paper.

| Sample                  | Element | Wt%  | σ    |
|-------------------------|---------|------|------|
| Graphite (drawn on paper)| C       | 58.0 | 1.6  |
|                         | O       | 19.0 | 0.8  |
|                         | Au      | 10.5 | 0.4  |
|                         | Ca      | 4.8  | 0.2  |
|                         | Al      | 3.4  | 0.1  |
|                         | Pd      | 2.1  | 0.2  |
|                         | Si      | 2.0  | 0.1  |
|                         | Fe      | 0.3  | 0.1  |

Table 2 shows the EDX results for deposited ZnO. Zn shows relatively large contributions which come from the deposited particles. The C from graphite still appears in the spectra but the relative composition is lower in contrast with that of table 2 which supports the deposition of ZnO on the surface of graphite. The presence of contaminants such as Si, Na, K and others at relatively low properties reflect impurities from the handling, heat treatment and characterization processes.

Figure 6 shows the current-voltage characteristics of the deposited ZnO on graphite drawn on paper using EPD with applied voltage of 300 V in the forward (figure 6(a)) and reverse (figure 6(b)) bias while figure 7 shows the I-V plots of the sample deposited at 500 V in the forward (figure 7(a)) and reverse (figure 7(b)) bias. The I-V measurements of the fabricated material were measured using two-point probe at room temperature. All plots show highly linear ($r^2 = 0.9996$) behavior. This is a characteristic of Ohmic behavior. The Ohmic contact implies the efficiency for charge transport. This suggests that patterning materials on graphite drawn on paper is possible using electrophoretic deposition.
Table 2. EDX results for the deposited ZnO at different voltages.

| Sample                          | 300 V           |               | 500 V           |               |
|--------------------------------|-----------------|---------------|-----------------|---------------|
|                                | Element Wt% | σ   | Element Wt% | σ   |
| ZnO deposited on graphite drawn on paper using EPD | C   | 20.8 | 2.3 | C   | 33.5 | 1.6 |
|                                | O   | 15.6 | 0.6 | O   | 23.9 | 0.7 |
|                                | Zn  | 54.3 | 1.7 | Zn  | 26.6 | 0.7 |
|                                | Si  | 2.5  | 0.1 | Si  | 6.1  | 0.2 |
|                                | Al  | 1.8  | 0.1 | Al  | 5.8  | 0.2 |
|                                | Na  | 3.6  | 0.6 | Na  | 3.2  | 0.3 |
|                                | K   | 0.3  | 0.1 | K   | 0.4  | 0.0 |
|                                | Ca  | 0.6  | 0.1 | Ca  | 0.3  | 0.0 |
|                                | Fe  | 0.3  | 0.1 | Fe  | 0.2  | 0.1 |
|                                | Ti  | 0.3  | 0.1 | Ti  | 0.2  | 0.0 |

Figure 6. I-V plots of the deposited ZnO on graphite drawn on paper using EPD with applied voltage of 300 V in the (a) forward and (b) reverse bias.

Figure 7. I-V plots of the deposited ZnO on graphite drawn on paper using EPD with applied voltage of 500 V in the (a) forward and (b) reverse bias.

4. Conclusion
In this study, we have successfully deposited functional material on paper using electrophoretic deposition. In order to have a low cost, mechanically flexible, and very accessible substrate, paper was used. Inexpensive and nontoxic ZnO was deposited on paper. The fabrication process, which is
electrophoretic deposition, is very simple which includes controllable parameters (e.g. deposition time and applied voltage). Graphite was used as the intermediate material that is drawn on paper and was used as the electrodes in the EPD process. SEM-EDX observations confirmed the presence of ZnO accumulations on the surface of the graphite on paper. The current-voltage plots show a linear, Ohmic behaviour, confirming electrical contact between the deposited ZnO and graphite on paper.

Acknowledgement
This work was supported by the UPLB Basic Research Grant and the UP System Emerging Interdisciplinary Research Program (OVPAA-EIDR C06-035).

References
[1] Khoza P B, Moloto M J and Sikhwivhilu L M 2012 J. Nanotechnol. 2012
[2] Sulciute A and Valatka E 2011 Mater. Sci. 18 318-24
[3] Schmidt-Mende L and MacManus-Driscoll J L 2007 Mater. Today 10 40-8
[4] Nam G, Baek S and Park I 2014 J. Alloy Compd. 613 37-41
[5] Shalyapina A Y, Soloveva A Y, Zaporozhets M A, Khokhlov E M, Plotnichenko V G, Savilov S V, Egorov A V, Nikolaichik V I, Buslaeva E Y, Rustamova E G, Avilov A S and Gubin S P 2013 Russ. J. Inorg. Chem. 58 354-60
[6] Dogome K, Enome T and Isogai A 2012 Chem. Eng. Process. 68 21-5
[7] Yao B, Yuan L, Xiao X, Zhang J, Qi Y, Zhou J, Zhou J, Hu B and Chen W 2013 Nano Energy 2 1071-8
[8] Ren T, Tian H, Xie D and Yang Y 2012 Sensors 12 6685-94
[9] Eder F, Klauk H, Halik M, Zschieschang U, Schmid G and Dehm C 2004 Appl. Phys. Lett. 84 2673-5
[10] Zschieschang U and Klauk H 2015 Org. Electron. 25 340-4
[11] Yang L, Rida A, Vyas R and Tentzeris M M 2007 IEEE Trans. Microwave Theory Tech. 55 2894-901
[12] Russo A, Ahn B Y, Adams J J, Duoss E B, Bernhard J T and Lewis J A 2011 Adv. Mater. 23 3426-30
[13] Phan H, Dao D V, Dinh T, Brooke H, Qamara A, Nguyen N and Zhu Y 2015 IEEE Int. Conf. on Micro Electro Mechanical Systems (MEMS) 28 (Portugal: Estoril/IEEE) p 825-8
[14] Hu L, Choi J W, Yang Y, Jeong S, Mantia F L, Cui L and Cui Y 2009 Proc. of the National Academy of Sciences of the United States of America 106 21490-4
[15] Hanaor D, Michelazzi M, Chenu J, Leonelli C and Sorrell C 2011 J. Eur. Ceram. Soc. 31 2877-85
[16] Corni I, Ryan M P and Bocaccini A R 2008 J. Eur. Ceram. Soc. 28 1353-67
[17] Wu X, Qi S, He J, Chen B and Duan G 2010 J. Polym. Res. 17 751-7