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To cite this article: Milad Ghalamboran et al 2017 J. Phys.: Conf. Ser. 939 012016

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The electrophoretic deposition of ZnO on highly oriented pyrolytic graphite

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Abstract. Intensive research has been conducted on ZnO thin and thick films in recent years. Such layers, used in different electronic devices, are deposited utilizing various methods, but electrophoretic deposition (EPD) has been chosen because of the advantages like low energy consumption, economical superiority, ecofriendliness, controllability, and high deposition rate. Here, we report electrophoretically depositing ZnO layers onto highly oriented pyrolytic graphite. Well-dispersed and stable ZnO suspensions are used for the deposition of continuous and even layers of ZnO on the substrate. ZnO powder is dispersed in acetone. The electric field applied is in the 250 V/cm to 2000 V/cm range. The morphology of the deposits are studied by SEM at the different stages of the deposition process.

1. Introduction
Electrophoretic deposition (EPD) is one of the most attractive methods employed to form thin or thick films of ceramic materials on conductive substrates [1-3]. Compared to other deposition techniques, EPD has advantages of lower energy consumption, economical superiority, higher growth rate, and ecofriendliness. The method is applicable for production of both dense and porous coatings on a variety of substrates with different shapes, sizes, and surface properties [4, 5]. In addition, nanostructured materials such as carbon nanotubes [6], graphene nanosheets [7], and metal oxide (MO) nanorods [8] have been successfully developed by EPD processing.

MOs are the building blocks for fabrication of chemical sensors, effectively functioning as substrates, heating elements, and sensing pellets in their structure [9-15]. Furthermore, MOs have shown promising efficacy in energy harvesting field and are ideal candidates for utilization in numerous optoelectronic devices including radiation detectors, solar cells, and display panels [16-20]. Zinc oxide, having wide applications in electronic and optoelectronic devices, is of particular interest [21].

Graphene, a 2-dimensional network of carbon hexagons, is viewed as the way to atomic-scale electronics. Excellent properties such as visible transparency, high thermal and electrical conductivity, mechanical strength, and chemical stability have given rise to intense research in the field of graphene electronics [22, 23]. Highly oriented pyrolytic graphite (HOPG) is a layered semimetal, consisting of many graphene sheets stacked on each other. In this work, HOPG is utilized to assess the functionality of the EPD process for forming oxide layers on graphene sheets. ZnO is electrophoretically deposited on the conductive HOPG substrates and the deposits are characterized by scanning electron microscopy (SEM) images.
2. Experimental
Analytical grade ZnO powder is used as purchased (Merck Millipore, 108846). Absolute acetone is used for the EPD process. In order to attain $5 \times 10^{-4}$ wt% suspensions, 1 mg of ZnO powder is dispersed in 250 mL of acetone. The container of the suspension is placed in an ultrasonic bath for 30 minutes. The electrophoresis cell includes a 50 mL borosilicate glass beaker and the aluminum electrodes. Electrodes are tightly covered by aluminium foils, and an HOPG flake ($3 \times 3$ mm$^2$) is placed on the cathode electrode. The apparent surface areas of both cathode and the anode are 2 cm$^2$. The distance between cathode and anode is 4 mm. The schematic diagram of the experimental setup is shown in figure 1. The voltage source is a regulated DC power supply, and current variation is recorded by monitoring the voltage drop on a contact resistor.

3. Results
The temporal variation of the EPD cell current is presented in figure 2. These curves can be used for the calculation of cell conductivity and determining contamination levels. Current variations are recorded immediately after applying the EPD voltage between the cathode and anode. According to this curve, the current decreases with the duration of deposition. The measurements and the tests are carried out at room temperature (25°C).

Figure 3 shows the SEM image of the deposits on the HOPG substrate. Images (a) and (b) are related to the deposition at 250 V/cm and 2000 V/cm, respectively. According to the previous reports [24], the electrophoretic deposition rate increases with the applied voltage up to a certain level, it decreases with voltage afterwards. Figure 4 shows the relationship between the weight of ZnO deposit on the cathode and the established electric field. ZnO particles formed a porous surface layer at 250 V/cm. the deposited layer becomes denser by increasing the field.

![Figure 1. Schematic diagram of the experimental setup used for the EPD of ZnO.](image-url)
**Figure 2.** The variation of the cell current with the time of deposition at the stated applied voltages.

**Figure 3.** The SEM micrographs of ZnO on multilayer graphene formed 10 minutes after the application of the cell voltage, which is 100V in (a) and 800V in (b).
4. Conclusions
The results of our preliminary experimental work on the electrophoretic deposition of ZnO on multilayer graphene is reported. It was shown that the deposition rate increases with the field applied up to a certain level. Afterwards, the trend is different and deposition rate decreases with the field. The reason for this behaviour is presently under investigation.

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