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Short Communication

Gas Sensors Developed by FDM 3D Printing Technology: A New Perspective

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Abstract

Fused Deposition Modeling (FDM) 3D printing technique can be considered as an efficient technology for the production of functional three-dimensional devices in micro/nanoelectronics, such as gas sensors. The production of gas sensors via FDM 3D printing is promising in the Materials Science domain, due to the simplicity of the manufacturing method, with a diversity of geometries and formulation possibilities of semiconductors embedded in polymeric matrices. In addition, other aspects such as improved sensor sensitivity and stability, justify the exploration of the technique for the production of new gas sensors design. In this context, this communication presents a brief study about gas sensing devices developed by FDM 3D printing technology, and the perspectives of this research topic in the literature.

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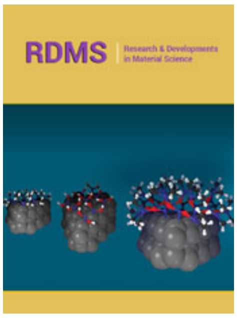

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Introduction

Fused Deposition Modeling (FDM) 3D printing is an Additive Manufacturing (AM) production technique, which consists of the addition of successive layers of a thermoplastic melted polymer (initially in the form of cylindrical filaments with a defined diameter) over a flat deposition surface of a 3D printer, which allows to form projected three-dimensional objects [1].

FDM 3D printing provides repeatability and dimensional reliability in the execution of complex projects in a short time period, with a high degree of precision, in addition to the possibility of recycling the materials that remain from the process [1,2]. These attributes contribute significantly into the reducing of the manufacturing costs. Filaments based on poly (lactic acid) (PLA), poly(ethylene terephthalate) (PET) and poly(acrylonitrile-butadiene-styrene) (ABS) are the most used in FDM 3D printing applications. As predicted by Wohlers Associates, the FDM 3D printing market has in the last decade growth exponentially, where about 50% of the investments are forecast to manufacture profitable products [3].

In recent years, FDM 3D printing has been gaining prominence in the area of micro/nanoelectronics as an open field of research, both in academia and in industry, as a result of the development of unconventional polymeric filaments with electrical/electronic properties [4]. Electronic circuits, supercapacitors, photocatalysts and gas sensors are some examples of potential applications in this area [5-7].

FDM 3D printing is an emergent 3D printing technology for manufacturing custom gas sensors. The process to produce filaments for gas sensor applications is similar to that of conventional filaments, but with the need to incorporate additives with electrical/electronic and optical properties into the filament matrix [4]. Semiconducting nanomaterials, such as metal oxides and carbon materials have been used as the preferred additives in order to produce personalized, flexible and/or miniaturized gas sensor devices, with high surface area/volume ratio. As operation principle of these sensors, variations in the concentration of a gas in the surrounding atmosphere can be translated into electrical signals, as a result of the chemical reactions with gas molecules on the semiconductor surface.

Recent advances on FDM 3D printing-developed gas sensors

The data search for the study on gas sensor devices developed by FDM 3D printing technology was carried out in the Scopus scientific database (May, 2023). The general search was carried combining “gas sensor” and “fused deposition modeling” keywords, looking for them in the title, in the abstract or in the keywords of the literature reports. Although FDM 3D print technique has been widely disseminated in the literature since 2015 for the manufacture of various types of sensors, the use of this technology for the development of gas sensors is still in its early stages. Few works were revealed by the search using the mentioned terms: this is an indication that studies with gas sensors produced by the FDM technique are an open research and development fields. Among the most impacting works found in the literature, some are here presented and discussed.

A recent study [7] showed a new copper oxide (CuO)-based gas sensor for ammonia (NH_3) detection at room temperature. PLA was blended with copper (Cu) particles and extruded into a filament form, used to print a PLA/Cu composite. Then, the material was calcined in a muffle oven to form scaffold structures of copper oxide (CuO). The sensor showed high sensitivity with active porous sites for enhanced gas adsorption, linear electrical response, and functional stability greater than 3 months, in the range of 25-65% The gas detection mechanisms were attributed to the adsorption of oxygen species on the CuO surface, or to direct electron transfer between NH_3 molecules and the semiconductor. By their part, other researchers [8] used FDM 3D printing to develop a metal oxide-based sensor capable of detecting volatile organic compounds. They produced PCL/tungsten trioxide (WO_3) pellets that were used for producing 3D printing filaments applied to print the sensors. The experiments demonstrated excellent sensitivity in the detection of isobutylene and ethanol gases, in the ppm range.

Other works focus their studies on humidity sensing devices [9,10]. Kalsoom’s group printed sensors, from the production of ABS filaments containing boron-doped diamond. The devices showed rapid response to variations in humidity, with stability and sensitivity repeatability in the range of 11-97% of relative humidity, for up to 12 test cycles [9]. Mohamed’s group used a commercial carbon nanotubes/ABS filament to print an optical based humidity sensor [10]. Devices with this composite filament showed good sensitivity, with linearity in the relative humidity range from 45% to 80%.

A method for printing 3D conductive objects using graphene oxide (GrO) composite filaments was patented by Giesbers et al. [11]. The inventors developed printed materials with an electrical conductivity of the order of 10^1-10^6S/cm.

Conclusion

Literature results show that the production of gas sensors by FDM 3D printing is under development, concomitantly with the development of new 3D printing filaments with enhanced electrical properties. In the literature, there was found a preference on the use of metal oxides and carbon based materials as responsible for sensing. The use of metal nanoparticles, metal oxide nanocomposites, and other carbon materials (such as fullerenes), are some of the eminent possibilities for the development of these sensors, given their already known physicochemical properties.

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Conflict of Interest

The authors declare no conflict of interest.

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