Nanomaterials for Additive Manufacturing (AM) of Electronic Devices

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Prof. Lyudmila Turyanska, Associate Professor from the Center for Additive Manufacturing, Faculty of Engineering, University of Nottingham, United Kingdom was the third speaker of the BAS Plenary Session. Prof. Turyanska presented on the topic "Nanomaterials for additive manufacturing (AM) of electronic devices". Under her main topic, she discussed "Perovskite – graphene heterostructures: exploring charge transport in injecting printed devices". As a start, she explained about their facility, the Centre for Additive Manufacturing (CfAM), and their programs. At CfAM, they are interested in three areas: single material systems, next-generation "multifunctional" AM, and computational methods/ design. Single material systems include techniques such as powder bed and vat polymerization. Next-generation "multifunctional" AM includes techniques such as binder jetting, polymer jetting, high-temperature metal jetting, and nano-scale manufacturing. The computational studies are focused on topology optimization, lattice design, and modeling. The properties of the material can be predicted via computational methods before they are manufactured. AM is important in many industries such as automobile and space where there is crucial weight limitations for material without compromising their mechanical properties. Different types of material are focused; polymer, powders (magnetic, Cu, SLM specific), biomaterial, and low dimensional material. These materials have many applications including healthcare and electronics. Prof. Turyanska focused her plenary talk on the low dimensional material and their integration with additive manufacturing (3D printing) of devices. She discussed their work on 0D perovskite nanocrystals, 2D/0D heterostructures for photon sensors and LEDs, and additive manufacturing of functional material. It is advantageous that the properties of the low-dimensional materials are tunable. Prof. Turyanska first discussed perovskite nanocrystals (NCs). Extensive research is done on MAPbX3 films for photovoltaics to improve their efficiency to harvest solar energy in solar cells. However, one of the main disadvantages of MAPbX3 is poor stability in the air, moisture, and UV. The aim of Prof. Turyanska's work is to develop all-inorganic halide perovskite NCs consisting of Cs and Pb as the metal and halide as the non-metal CsPbX3 (X = I, Br, Cl or mixed). To tune the NC properties halide composition can be manipulated. The all-inorganic halide NCs are more stable compared to those that contain organic components. The stability of the NC is adjusted by improving the surface of it. The nano properties depend on the surface-to-volume ratio. Therefore, unimproved surfaces are detrimental to the overall performance of the NCs. The improved surfaces can be measured by improved optical properties such as strong absorption in the UV-Vis range, widely tunable band gap, and high quantum yields. One of the approaches used to improve the stability of the NCs is to have a good choice of capping ligands, which are used to passivate the NC surface by passivating dangling bonds. A good choice of capping ligands has functional groups that allow stronger binding and passivate the surface defects, or they block the accessibility of moisture. 2,2'-iminodibenzoic acid (IDA) was the first choice of a capping agent. IDA is synthesized in solution from inexpensive precursors, passivates the dangling bonds, has post-synthesis ligand replacement that helps to improve quantum yield and stability, and has tunable band gap through halide composition. Then, dimethyldioctadecylammonium (DDAB) and OA/OLA were used as the capping agents which contain halides. These halides containing capping agents result in higher stabilities of NCs. However, there was still an organic component as the capping agent. A core/shell approach of synthesis was taken to synthesize NC with a fully inorganic core which is epitaxially capped with another layer. By changing these layers and controlling their composition the lattice stains are avoided and the defects of the core are passivated. The core is responsible for the improved optical properties and quantum yield of the NC, FAPbBr3/CsPbBr3, which was synthesized for the first time. This approach is heavily used in quantum dot synthesis which is used for optoelectronics. The composition changes in halide also allowed the color tuning of the white LEDs. Further, perovskite layer allows the photoresponsivity to be tuned in the UV-visible range as a function of the perovskite composition in graphene devices. The photoresponsivity reached 16^6 A/W in these devices. The work will continue to improve the response time and the wavelength range. Integration of low dimensional materials with additive manufacturing technologies offers exciting prospects for development of the next generation of optoelectronic and healthcare devices. The inkjet deposition of 0D and 2D materials to fabricate heterostructure devices, including devices such as transistors and sensors on flexible substrates was demonstrated. A model of charge transport was developed through printed nanomaterial networks to explain their electrical properties and to inform the design optimization for required performance and functionality.