Multiple-materials 3D printing for structural electronics

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Structural electronics, which is referred to as a next-generation electronics technology, involves printing of functional electronic circuitries and device across irregular shaped substrates and three-dimensional (3D) architectures, including the robot and the human body. This technology replaces bulky load-bearing or protective structures within a circuitry with smart electronic components - i.e. antennas, sensors, transistors, batteries, conductive traces, and so on - printed directly onto irregular and non-flat substrates which can conform to complex shapes, ensuring optimum space utilization. Structural electronics can eliminate large bulky printed circuit board (PCB) and is expected to provide different and better ways of implementing electronic functionalities into the products.

3D printing, also known as additive manufacturing, is widely regarded as a revolution in manufacturing technology, with significant promise for electronic applications; this field is known as 3D printed structural electronics. However, it is difficult to obtain functional 3D structures for electronics, although we can easily produce plastic or metallic 3D objects with coarse resolution via various commercial 3D printing methods, such as stereolithography (SLA), fused deposition modeling (FDM), or selective laser sintering (SLS). Finding the appropriate printing approach for the achievement of functional 3D structures with high spatial resolution remains one of the major challenges in the field of 3D printed structural electronics.

Here, we demonstrate a novel strategy for multiple-materials 3D printing at room temperature in ambient air conditions. The 3D micro- and nanoarchitectures are printed by an omnidirectional accurate control of a micropipette ("fountain-pen") filled with a solution ("ink"). A simple modulation of the ink leads to 3D printing for multiple-materials, such as graphene, carbon nanotube (CNT), metal oxide, metal and even their composite. The employed printing technique is based on the simple procedure: when the fountain-pen touches the substrate, a meniscus of the ink is created outside its opening and the solvent is evaporated at the same time. As the fountain-pen is pulled away, the meniscus is stretched and its cross section decreases. In case of conducting polymer, CNT, graphene, silver and their composite, microarchitectures are formed by a van der waals force between substances during solvent evaporation. On the other hands, 3D copper microstructures are fabricated by a meniscus-guided electrodeposition. The feature of grown metallic structure (i.e. dense or hollow feature) is controlled by a modulation of applied voltage. As a result, 3D structures of diverse materials are successfully fabricated: the arched wire, the 3D wire-junction and woven structure, the structures corresponding to the letters "KERI", the martial arts artist, and the mesh structure. We believe that this approach paves the way for efficient multi-material 3D printing with high spatial resolution, which will ultimately lead to important advancements in structural electronics.