Manufacturing the Next Material Evolution

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Exciting smart material-derived functionalities have been proposed and realized in often "one-off" laboratory scale quantities, ranging from unusual mechanical or electrical behavior, to biological implants mimicking natural tissue. The ability to place materials with precision and high resolution in arbitrary, 3-dimensional arrangements through nano-manufacturing processes enables the realization of a variety of smart materials and devices whose function is determined by their geometry and structure, rather than a purely intrinsic property of the constituent material. In the vast majority of demonstrations, a fully 3-dimensional smart material was fabricated in a non-scalable fashion. This represents both a challenge and an opportunity for developing new process science and enabling tools that can elucidate – and perhaps help break – the trade-off between the controlled evolution of material properties and production scalability that currently exists in the fabrication of complex smart materials.

Additive manufacturing (AM) describes a class of processes that perform a layer-by-layer "bottom-up" fabrication approach as opposed to traditional top-down, subtractive fabrication such as milling and lathing. Printing-based AM, and in particular micro-scale AM (μ-AM), has received significant attention in recent years as an enabling technology capable of revolutionizing the way we manufacture electronics, biosensors, and optics. Recent advancements have resulted in new opportunities for the use of AM and μ-AM in the development of smart materials for functional devices. The design flexibility afforded by AM to print out-of-plane with variable layering and heterogeneous materials is balanced by interface roughness that may cause imperfections in the material properties. Thus, a maximally versatile manufacturing approach should be capable of closely controlling the spatial distribution of a property down to the micro/nanoscale. Limiting this step change in manufacturing capabilities is the reliance of AM and μ-AM systems on a process monitoring, regulation, and quality control paradigm that is performed post-process and in an ad hoc manner.

In this talk, we discuss some recent developments in process modeling, sensing, and control that aim to break this open-loop paradigm by providing the controls theoretic and process modeling knowledge to develop a robust closed-loop system for measurement and compensatory control of AM processes. In particular, the integration of artificial intelligence provides a novel approach for autonomously directing material synthesis using AM. The autonomous system drives the exploration of the material synthesis space, interprets deviations from the norm, and learns the relationship between the AM process, smart material properties, and functional behavior. These advancements will lead to a new paradigm in the directed evolution of smart materials for advanced electronics, optics, and robotic applications.

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