The critical role of multi-modal and multi-scale measurements in driving development of practical additive manufacturing

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Additive manufacturing (AM) of metals is a rapidly growing advanced manufacturing paradigm that promises unparalleled flexibility in the production of parts with complex geometries. This enhanced flexibility enables mass customization, improved performance, reduced manufacturing and system costs, and new opportunity spaces. However, major challenges remain in the areas of reproducibility, reliability, and performance of AM components. Solutions to these challenges require research-infrastructure development investments, and many existing efforts are focused on the critical role of computer simulations and the multiscale, multimodal measurements required to guide and validate these simulations. Examples include development of high-performance computer codes for AM simulation (ExaAM) as part of the DOE Exascale Computing Project, the Additive Manufacturing Benchmark Series led by NIST, and the AM simulator developed by the Advanced Photon Source.

I will describe some of the critical physics that underlies metal AM with a primary focus on the multi-modal, multiscale measurements that are required to validate corresponding computer simulations. Synchrotron X-rays are playing a significant and expanding role in this space, but substantial improvements over existing capabilities are needed. Projects that I will discuss include simultaneous laser absorptivity and x-ray imaging of laser melt pool evolution; in situ USAXS/SAXS/WAXS measurements of microstructure evolution during post-build AM heat treatments; combined synchrotron, neutron, and lab-based residual stress measurements; and progress towards using synchrotron X-rays to probe residual stresses and solid-state processes in situ within complete 3D builds.