Materials by Design:
Three-Dimensional (3D) Nano-Architected Meta-Materials

J.R. Greer
[1]*California Institute of Technology*
Website: jrgreer.caltech.edu

Creation of reconfigurable and multi-functional materials can be achieved by incorporating architecture into material design. In our research, we design and fabricate three-dimensional (3D) nano-architected materials that can exhibit superior and often tunable thermal, photonic, electrochemical, biochemical, and mechanical properties at extremely low mass densities (lighter than aerogels), which renders them useful and enabling in technological applications. Dominant properties of such meta-materials are driven by their multi-scale nature: from characteristic material microstructure (atoms) to individual constituents (nanometers) to structural components (microns) to overall architectures (millimeters and above).

Our research is focused on fabrication and synthesis of nano- and micro-architected materials using 3D lithography, nanofabrication, and additive manufacturing (AM) techniques, as well as on investigating their mechanical, biochemical, electrochemical, electromechanical, and thermal properties as a function of architecture, constituent materials, and microstructural detail. Additive manufacturing (AM) represents a set of processes that fabricate complex 3D structures using a layer-by-layer approach, with some advanced methods attaining nanometer resolution and the creation of unique, multifunctional materials and shapes derived from a *photoinitiation-based chemical reaction* of custom-synthesized resins and thermal post-processing. A type of AM, vat polymerization, has allowed for using hydrogels as precursors, and exploiting novel material properties, especially those that arise at the nano-scale and do not occur in conventional materials. The focus of this talk is on additive manufacturing via vat polymerization and function-containing chemical synthesis to create 3D nano- and micro-architected metals, ceramics, multifunctional metal oxides (nano-photonics, photocatalytic, piezoelectric, etc.), and metal-containing polymer complexes, etc., as well as demonstrate their potential in some real-use biomedical, protective, and sensing applications. I will describe how the choice of architecture, material, and external stimulus can elicit stimulus-responsive, reconfigurable, and multifunctional response.

Selected relevant publications:

1. Portela, C.M., Edwards, B.W., Veysset, D. *et al.* Supersonic impact resilience of nanoarchitected carbon. ***Nature Mater.*** https://doi.org/10.1038/s41563-021-01033-z (2021).

2. Xia, X., Afshar, A., Yang, H., Portela, C.M., Kochmann, D.M., Di Leo, C.V., Greer, J.R. "Electrochemically Reconfigurable Architected Materials" ***Nature,*** 573 (7773) 205 (2019).

3. Narita, K., et al. "3D Architected Carbon Electrodes for Energy Storage" ***Advanced Energy Materials***; 11 (5) (2021)

4. Yee, Daryl W.;Citrin, Michael A. et al. "Hydrogel-Based Additive Manufacturing of Lithium Cobalt Oxide" ***Advanced Materials Technologies*** 6 (2) (2021)

5. Yee, D., Lifson, M., Greer, J.R. "Additive Manufacturing of 3D Architected Multifunctional Metal Oxides" ***Advanced Materials* 31**, 1901345 (2019).

6. Vyatskikh, A., Ng, R. C., Briggs, R., Greer, J.R. "Additive Manufacturing of High-Refractive-Index, Nanoarchitected Titanium Dioxide for 3D Dielectric Photonic Crystals" ***Nano Letters*** 20 (5) (2020)

7. Portela, C. Vidyasagar, A., Greer, J.R., Kochmann, D. "Extreme mechanical resilience of self-assembled nano-labyrinthine materials" ***Proceedings of the National Academy of Sciences, USA*** 117 (11) (2020)

8. Portela, C.M., et al "Supersonic Impact Resilience of Nano-architected Carbon" ***Nature Materials*** (accepted, 2021)

9. L. R. Meza, S. Das, J. R. Greer "Strong, Lightweight and Recoverable Three-Dimensional Ceramic Nanolattices" ***Science* 345**, 1322-1326 (2014)