SAND2017-0137C

Additive Manufacturing of 3D Structures for Experimental Study of Chemically Reacting Flow

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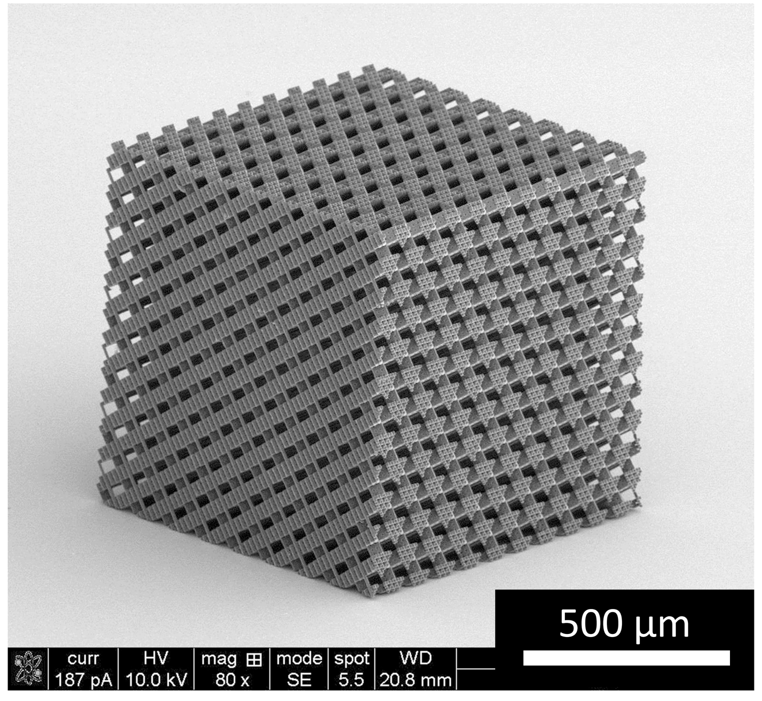
Purpose

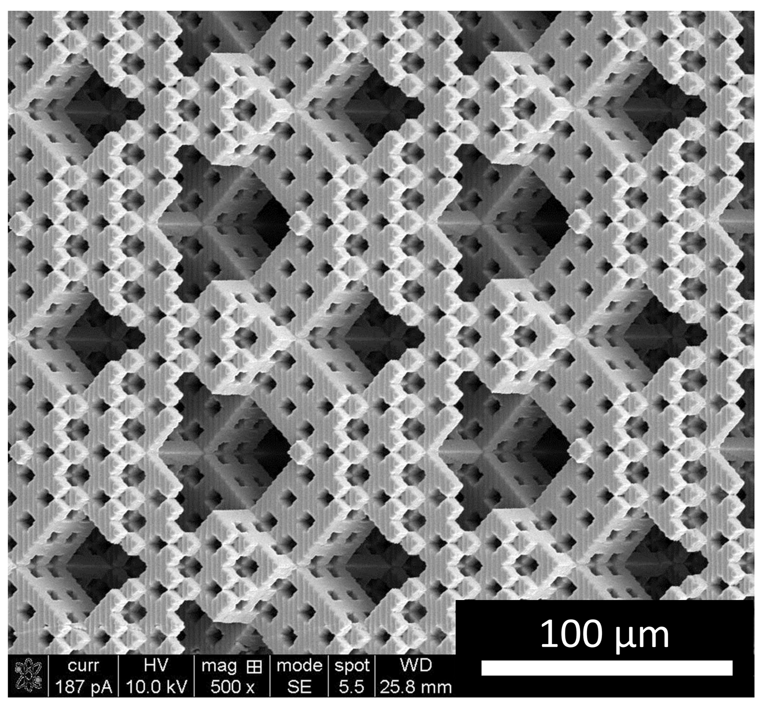
In chemically reacting flow, such as in an automotive catalytic converter, or chromatography columns for chemical analysis and separation, most current implementations use randomly arranged packing material, or 1- or 2-dimensional structures. Theory predicts that well designed 3-dimensional structures could yield more complete reactions or separations, with less catalyst or sorbent material, lower pressure drop, and other desirable properties.[1] However, the proposed structures require design features spanning length scales from µm to cm, and have proven difficult to fabricate. New additive manufacturing methods present a promising path to overcome this obstacle, as recently demonstrated for a similar mechanical engineering problem by Lawrence Livermore Lab.[2]

1. Billen and Desmet, J. Chromatography A 1168 73 (2007)
2. Zheng et al., Nature Mater. 15 1100 (2016)

Technology

Polymer photochemistry is used in a class of manufacturing methods proven at scales from nanometers (in the semiconductor industry) to centimeters (in the medical device industry). Printing in 3D while spanning scales remains challenging. Methods are known to coat or replace polymers with other functional materials such as metals or ceramics. The commercial Nanoscribe two-photon polymerization tool prints micron-scale features well, but requires print times of days to make macroscopic parts. The commercial Autodesk Ember projects images into an absorbing resin, making cm-scale parts with 50 µm resolution in about 1 hour. The Lawrence Livermore technology, while still being developed, is closing the gap between these. This poster presents results from the commercial instruments.

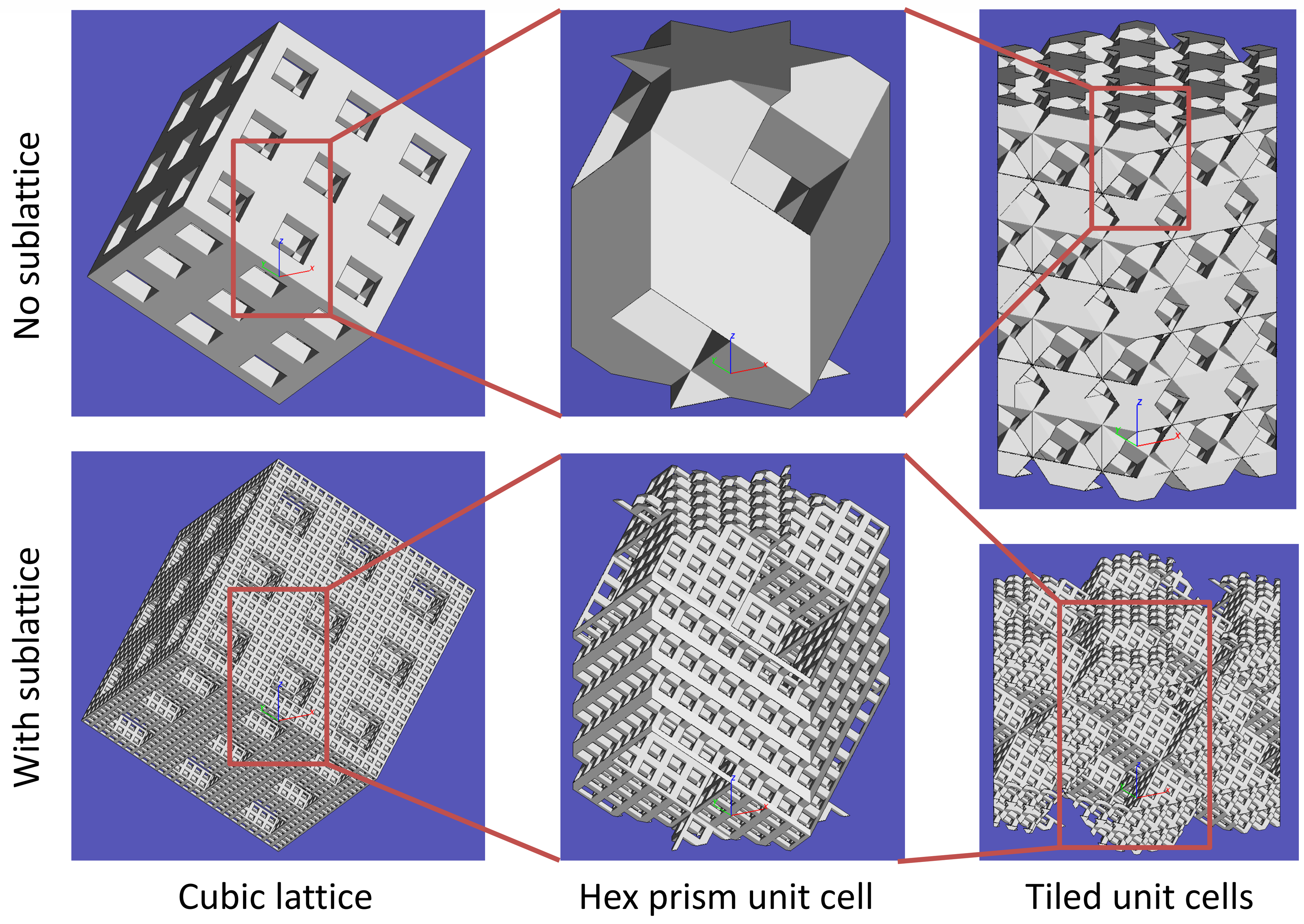




Above: Nanoscribe-printed 0.5-mm cube with 40 µm lattice pores and 8 µm sublattice pores. Right: cm-scale Ember-printed part with 100 µm pores. Far right: Ember-printed part with 250 µm lattice pores and mostly occluded 50 µm sublattice pores, coated with a layer of palladium a few hundred nm thick by an aqueous chemical reduction technique.

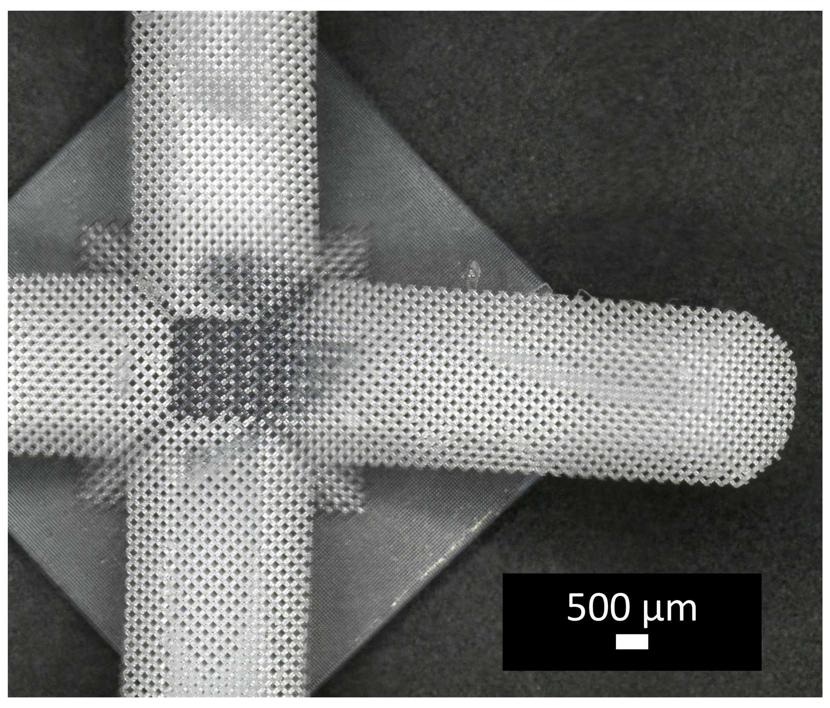
Designs

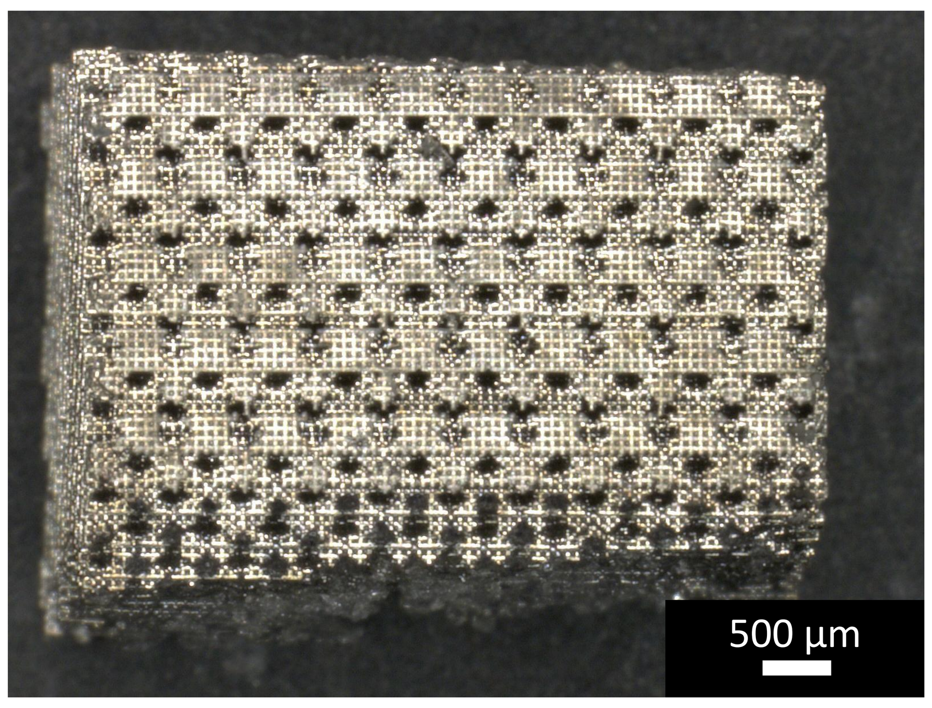
Our desired structure will have part sizes on the mm to cm scale, flow channels on the 100 µm scale, and diffusion channels on the 10 µm scale. When printing at their resolution limit, 3D printers are best at making simple lattice structures, so we use a cube-edge lattice as a building block. We align the flow direction along the cube space diagonal so that all flow paths have the same angle vs. the flow direction, and the solid fraction does not vary along that direction. To easily make a variety of part shapes, we have identified a hexagonal prism-shaped unit cell aligned with this direction that can be tiled and cropped as needed.



Results and Discussion

We have printed hierarchical lattices on both the Nanoscribe and Ember with a 5:1 ratio of large to small pores. The Nanoscribe requires 6 hours to print a 0.5 mm cube. Because it sequentially solidifies a sub-µm^3 volumes, use of a sparser sublattice would improve print speed. The Ember prints much more quickly. Obtaining 50 µm pores has proven much more challenging than 100 µm pores. The faster print speed has yielded enough test parts to allow demonstration of a method to coat its parts with a uniform layer of palladium, a catalytic and hydrogen-absorbing metal.





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NNSA National Nuclear Security Administration

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SAND No. 2011-XXXXP