Development of Engineered Gas Diffusion Layers Via Two-Photon Polymerization

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Primary CNF Tools Used: NanoScribe Photonic Professional GT2

Abstract:

The need for low carbon and carbon-neutral energy sources has become increasingly clear as CO_2 emissions have continued to increase at an impressive rate. Efforts to sequester carbon show some promise, though storage remains a major issue. Utilizing this captured CO_2 in electrochemical reduction reactors can yield valuable products, such as ethanol, propanol, formic and acetic acids, among others.

As these reactors generate these products, however, the gas diffusion layer (GDL) separating the carbon dioxide gas from the cell's electrolyte begins to wet and subsequently flood with the change in product concentration; this flooding behavior severely limits operational lifespan and cell efficiency. In this work, micro-scale additive manufacturing via two-photon polymerization enables the printing of microfluidic devices. These devices were dynamically tested for flow properties via in operando testing and analysis by means of high energy X-ray imaging. The impact of architected geometry with variable surface texturing is explored, as well as the effects of electrolyte composition and surface coatings. The results of this analysis are further used in computational fluid dynamic models to better optimize GDL design to minimize flooding in subsequent designs.

Summary of Research:

In order to manufacture gas diffusion layers, the NanoScribe Photonic Professional GT2 two-photon polymerization printer was used. The high-resolution (< 1 µm voxel size) enabled by this machine allows printed porous structures with pore sizes similar to those of conventional GDLs [1,2]. The GDL designs were comprised of triply periodic minimal surfaces, a type of cubic, repeating lattice structure which is entirely formula driven. nTopology 3D modelling software was used to generate slices of these complex lattices and subsequently assembled in NanoScribe DeScribe slicing software to create a single piece while minimizing processing overhead in DeScribe.

Additively manufactured substrates were designed to serve as an interface between the printed samples and microfluidic fittings to connect the experimental setup to a micropump. These substrates were printed via stereolithography (SLA) in a resin compatible with that used by the NanoScribe GT2 to ensure bonding between printed samples and substrate. Substrates were polished to 3 µm surface finish, enabling consistent results with manual interface finding in NanoWrite.

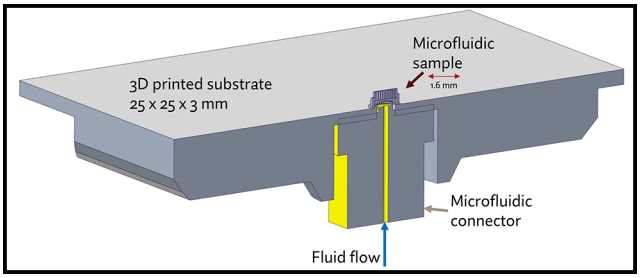

Figure 1: Section view of the microfluidic sample as mounted on the additively manufactured substrate.

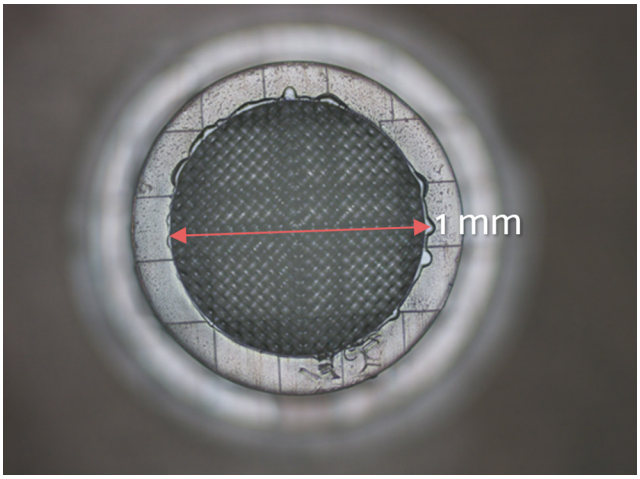

Figure 2: Top view of an as-printed sample. The internal GDL section is 1 mm in diameter with a support structure that is 1.6 mm in diameter.

Engineered GDL samples were printed in two parts on the NanoScribe GT2. First, a lower quality base layer was printed to form a support structure for the gas diffusion layer. This layer used the 25X Medium Feature Swift Mode to decrease printing time. Once this support structure was printed, the GDL was printed with the 25X objective Medium Feature Solid Mode for maximum part strength and resolution. The substrate pore directly below the samples, seen in Figure 1, enabled short development times in propylene glycol monomethyl ether acetate (PGMEA) by enhancing transport of uncured resin from the structure. Samples were developed for 30 to 60 minutes in PGMEA then 15 to 30 minutes in isopropyl alcohol (IPA). Prior work with samples printed flush to the substrate required in excess of 36 hours of development time in PGMEA and 12 hours in IPA. A finished sample, shown in Figure 2, is illustrative of the type of lattice structures developed for this experiment. After air drying, half of the samples were sent for perfluoroalkoxy alkane (PFA) coating, with the remainder uncoated for comparison purposes.

Samples were tested at Argonne National Lab's Advanced Photon Source using the 2-BM beamline. A 2 mm by 1 mm field of view was maintained while capturing at 400 frames per second in order to capture dynamic fluid flow throughout the structure. Samples were tested with pressure-driven water flow to determine flooding behavior. Pressure was ramped from 0 to 200 mBar in most cases, resulting in flow rates of approximately 2 µL/min. After data capture, XCT data was reconstructed with Tomopy and Tomocupy [3,4]. The pressure and flow rate were compared to the flooding behavior of each design.

Preliminary results validate the expected effect of the hydrophobic coating, with significantly decreased flooding compared to uncoated samples. Figure 3 demonstrates the clear difference in flooding behavior in coated versus uncoated samples, validating the coating process.

Further work is ongoing to determine the impact of lattice morphology on GDL flooding.

References:

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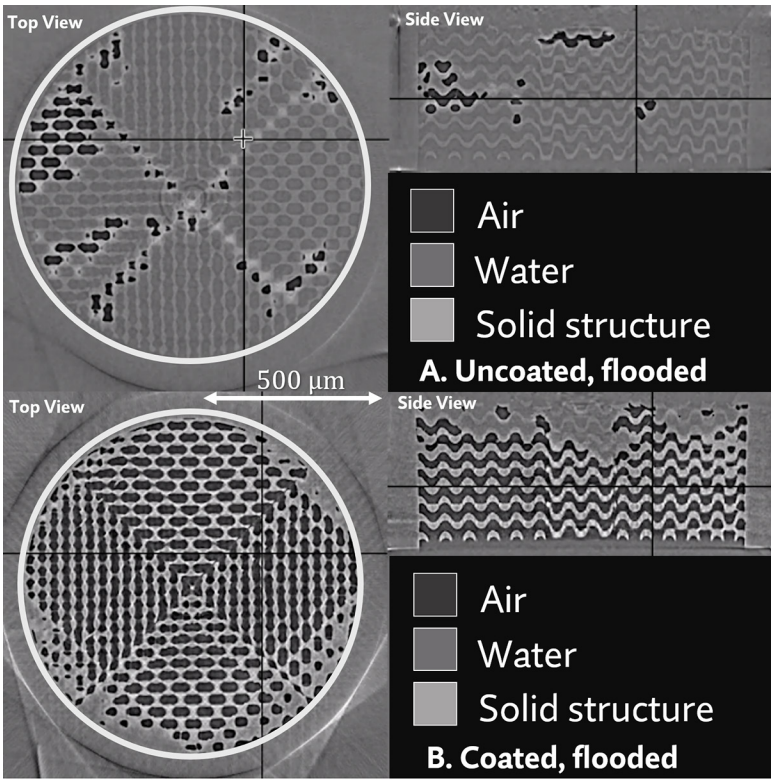

Figure 3: Real-time XCT reconstruction of an uncoated sample (top) and a PFA coated sample (bottom) during in operando *testing with water. Flooding is significant in the uncoated sample.*