High-Resolution Projection Micro-Stereolithography (PμSL) for Advanced Target Fabrication

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This project advances the state of the art in 3-D target fabrication by using Projection Micro-Stereolithography (PμSL), first developed at the University of California, Los Angeles (UCLA) and the University of Illinois, Urbana-Champaign (UIUC). PμSL is a low-cost, high-throughput, microscale, stereolithography technique that uses a Digital Micromirror Device (DMD™ Texas Instruments) or a Liquid Crystal on Silicon (LCoS) chip as a dynamically reconfigurable digital photomask.

PμSL is capable of fabricating complex 3-D microstructures in a bottom-up, layer-by-layer fashion. A CAD model is first sliced into a series of closely spaced horizontal planes. These 2-D slices are digitized in the form of a bitmap image and transmitted to the LCoS. A UV LED illuminates the LCoS, which acts as a dynamically reconfigurable photomask and transmits the image through a reduction lens into a bath of photosensitive resin. The resin that is exposed to the UV light is then cured and anchored to a platform and z-axis motion stage. The stage is lowered a small increment and the next 2-D slice is projected into the resin and cured on top of the previously exposed structure.

Figure 1 shows a schematic of this process. This layered fabrication continues until the 3-D part is complete.

The process has been shown to have the capability to rapidly generate complex 3-D geometries. Applying this concept to target fabrication problems and advancing PμSL capability with respect to these issues constitutes the primary focus of the research. PμSL performance such as resolution, materials, geometries, and substrates, will be greatly improved by the following research directions:

1. Incorporation of a far-field superlens (FSL) to enhance resolution to the tens of nanometer-scale (well below the diffraction limit of UV light) enabling the first ever 3-D, nanoscale, fabrication system.
2. Incorporation of multiple DMD or LCoS assemblies to generate fully 3-D digital holograms enabling rapid throughput nanoscale features.
3. Use of laminar flow microfluidic systems to more optimally deliver and distribute photosensitive resins enabling fabrication with multiple materials.
4. Creation of a coupled optical-chemical-fluidic model resulting in an empirically validated design tool.

Project Goals

Our goals for FY2009 included:

1. Use of the new LLNL PμSL system to rapidly fabricate 3-D components.
2. Fabrication and integration of a superlens to demonstrate the capability for improved resolution; integration with PμSL.
3. Validation of the baseline coupled optical-chemical model.
4. Inclusion of fluid motion in the coupled model to study the impact of moving components in the liquid resin bath.
5. Initial demonstration of microfluidics with PμSL to demonstrate the capability to fabricate with multiple materials.

Relevance to LLNL Mission

Target fabrication for the National Ignition Facility (NIF) and other stockpile stewardship physics experiments

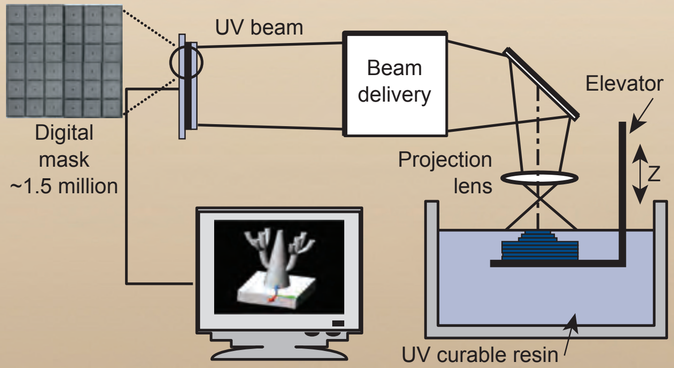

Figure 1. Schematic of a baseline PμSL system.

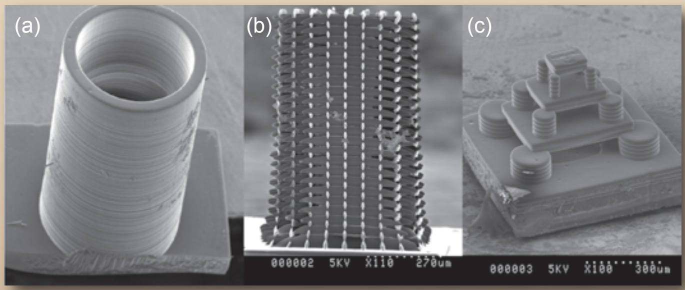

Figure 2. SEM images of (a) 300-μm cylinder, (b) lattice structure, and (c) 3-D components with overhanging features.

has been a critical factor in limiting the scope of tests that can be conducted. Research efforts across LLNL have focused on developing new fabrication techniques that can generate meso- to microscale targets with micro/nanoscale precision and features. Although much progress has been made, several key target features have been difficult to achieve. High resolution PμSL has the potential to directly impact the limitations and may also have great benefit to the newly emerging LIFE program at LLNL, which has its own set of target fabrication challenges. An ancillary impact of this work is to enable a host of new MicroElectroMechanical Systems (MEMS) devices never before conceived due to the rapid, high-resolution, fully 3-D nature of the technique.

FY2009 Accomplishments and Results

Significant progress has been made during FY2009, including:

Fabrication of many 3-D components of interest to the target community. Figure 2 highlights some of these pieces, including cylinders, lattice structures, and fully 3-D parts with overhanging features. Features as small as 5 μm have been demonstrated.

Fabrication and demonstration of a working plasmonic superlens. A scan of two slits in a substrate with spacing smaller than the wavelength of illuminating light (spacing = 200 nm) shows this phenomenon. Figure 3 shows a scan from a near field scanning optical microscope (NSOM) for the double slit geometry with the superlens material (thin film silver). Without the superlens the slits cannot be distinguished; however with the thin film of silver present, the two slits can clearly be seen as indicated by the peaks in the plot.

Validation of the optical-chemical model. Measurements from fabricated parts compared favorably to the predictions of the numerical model. In addition, fluid motion physics is now incorporated into the model.

Demonstration of microfluidics with PμSL. This is shown in Fig. 4, where a microfluidic channel was used to deliver a liquid monomer slurry with silica particles. The slurry was polymerized with a high loading of the silica and then the component flowed out of the microfluidic channel while another was fabricated in its place.

FY2010 Proposed Work

Expected achievements and goals for FY2010 include 1) integration of a plasmonic superlens with the LLNL system; 2) fabrication of nanoscale components; 3) continued improvements to structures for the target community; 4) fabrication of components with multiple materials; 5) extension of the model to light scattering from nanoparticles in suspension; and 6) use of the model as a design tool.

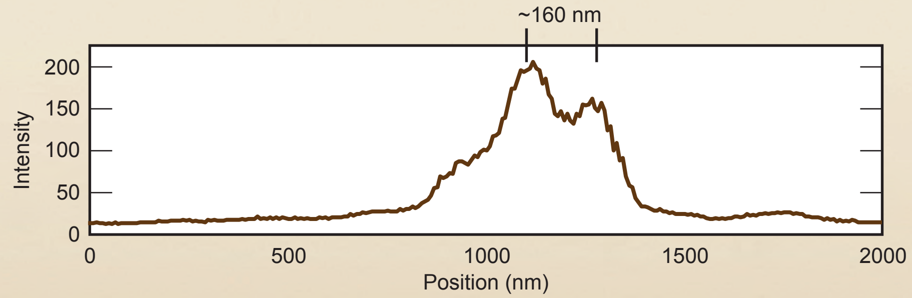

Figure 3. NSOM output for a superlens able to distinguish two slits spaced at 200 nm using 405-nm light.

Figure 4. Fabrication with a silica slurry in a microfluidic channel.