Low-Cost Maskless Photolithography

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Introduction

Photolithography is a core technique in microfabrication, used to pattern microscale features on substrates. It plays a vital role in the production of semiconductors, MEMS devices, and microfluidic systems. Traditional photolithography equipment is costly (often $100K+), bulky, and requires cleanroom infrastructure.

These barriers limit access for educational institutions, researchers, and early-stage startups. As such, there is a growing need for affordable, compact alternatives that can democratize access to microfabrication tools.

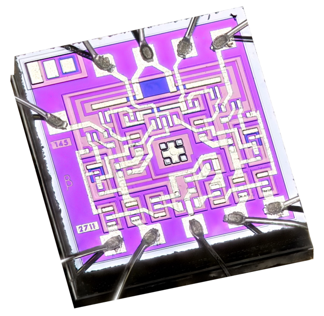

Figure 1: An early silicon chip featuring CMOS transistors etched using photolithography [1].

Apparatus

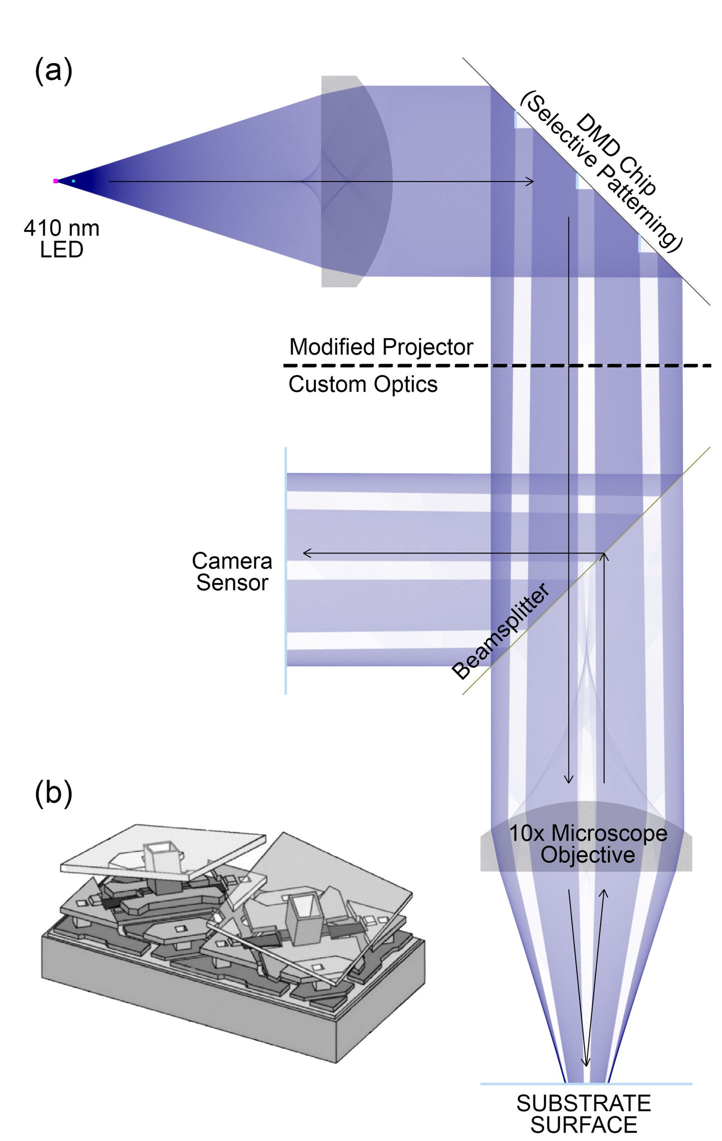

Figure 2: The (a) light path of our lithostepper and (b) a close up of two DMD chip micromirrors used to pattern the light.

Our project builds primarily off of work done previously at Carnegie Mellon University by the HackerFab group on "Lithostepper V2" [2].

Photolithography can be widely sorted into two groups, maskless, and masked. Our maskless process utilizes a modified Texas Instruments projector to digitally mask near-UV light onto our substrate with a MEMS device known as a DMD.

The DMD chip selectively reflects light by tilting an array of micromirrors as seen in Figure 2b [3].

Once masked, the light transmits through a beamsplitter and is demagnified with a 10x microscope objective and viewed through a camera on reflection for focusing and alignment in our custom software.

As the exposure area on our device is roughly 840 x 525 µm, the substrate being patterned must be tiled to achieve useful exposures.

This is accomplished using a spring loaded XYZ stage seen in Figure 3 which has been modified and motorized to position the substrate. Our stage is capable of mechanical repeatability in the range of 5 µm allotting for a final overlay error of ~2 µm.

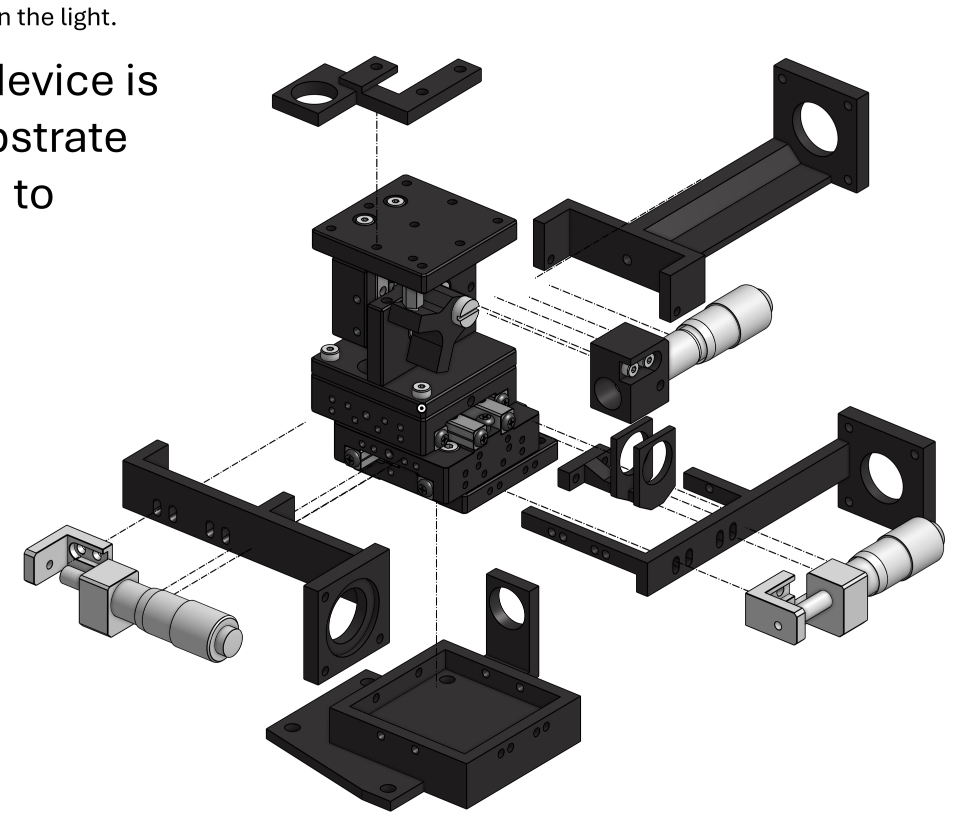

Figure 3: View of the key parts inside the motorized XYZ stage.

Results

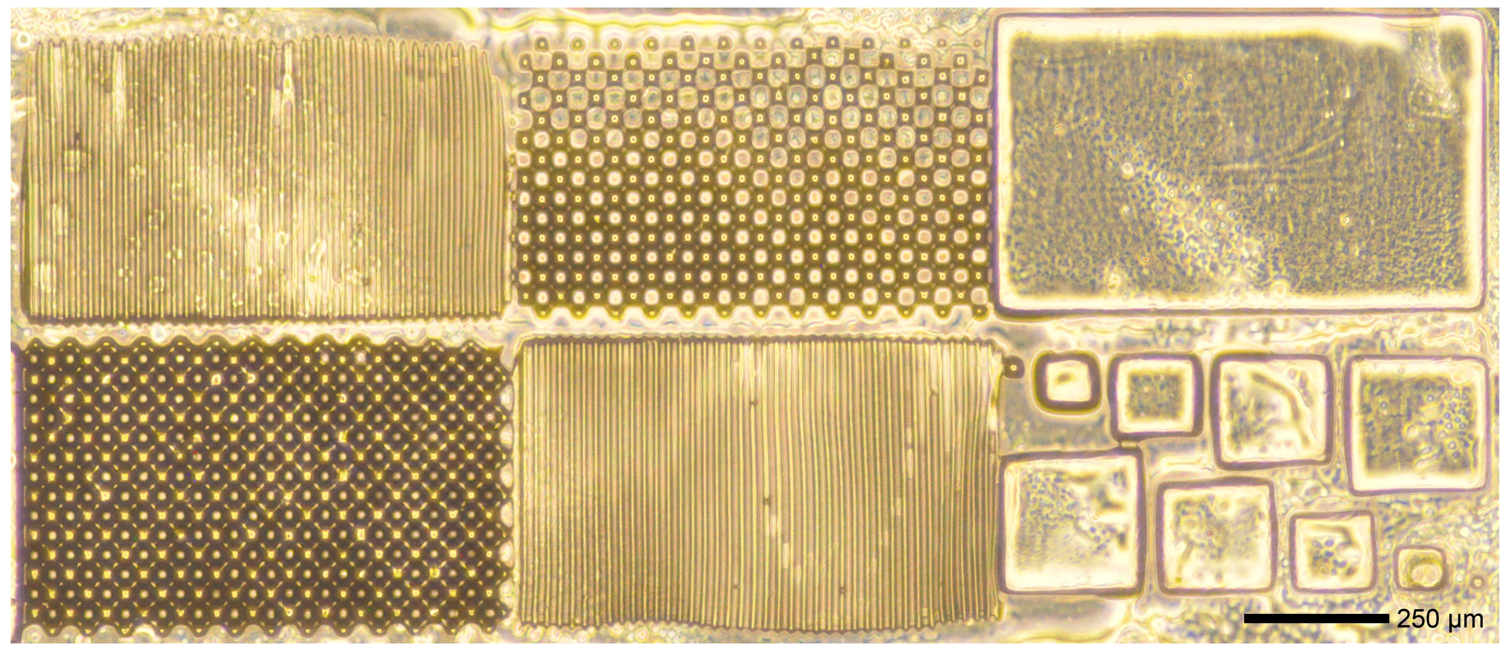

Figure 4: A multi-patterned etch closely tiled together.

While in a traditional photolithography process a chemical known as photoresist is patterned on the surface of a substrate [4], our device is capable of patterning any UV curable chemical. Our group pursued exposure of UV curable 3D printer resin onto glass. A series of tiled 30 second exposures can be seen in Figure 4 demonstrating the ability to use a variety of patterns and to tile along the substrate surface.

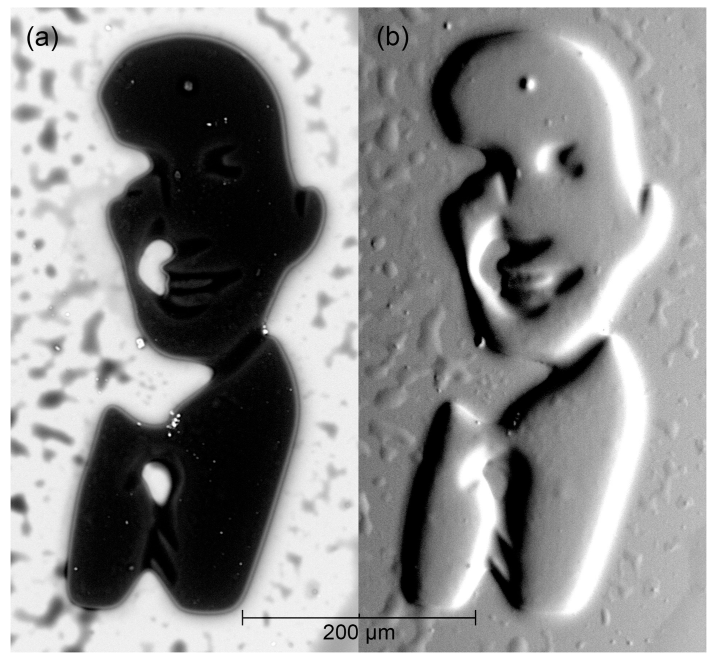

Figure 5: A ~200µm wide profile of Dr. Tony Butterfield under (a) BSD and (b) topographical SEM imaging.

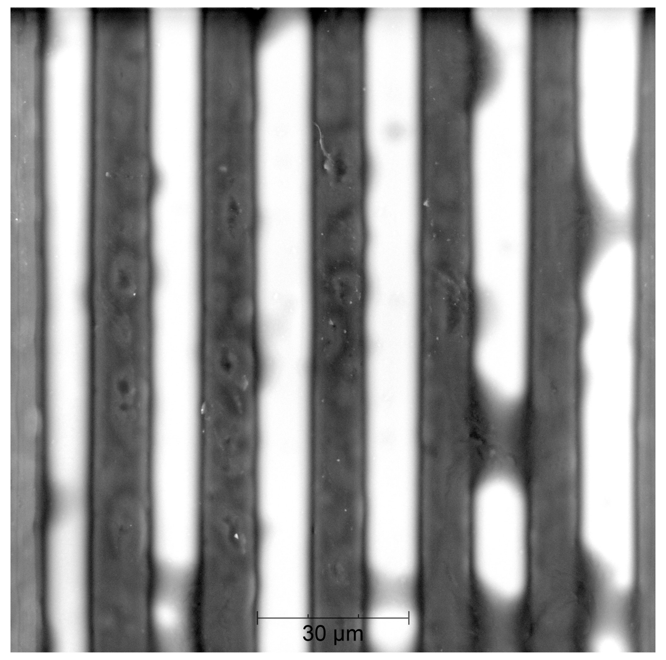

Figure 6: Line exposures at ~10µm width seen under BSD SEM imaging.

The use of resin in place of photoresist limits the achievable resolution, but as shown in Figure 5 and 6, we were able to achieve details in our resin patterns down to the 10 µm scale, our original resolution target.

Using Rayleigh's criterion [5], the critical dimension, which represents the best resolution achievable by our optical setup, can be found, corresponding to roughly twice the resolution achieved by groups pursuing similar projects with photoresist.

$$CD = k_1 \frac{\lambda}{NA} = 0.61 \frac{410\ \text{nm}}{0.25} = 1 \mu m$$

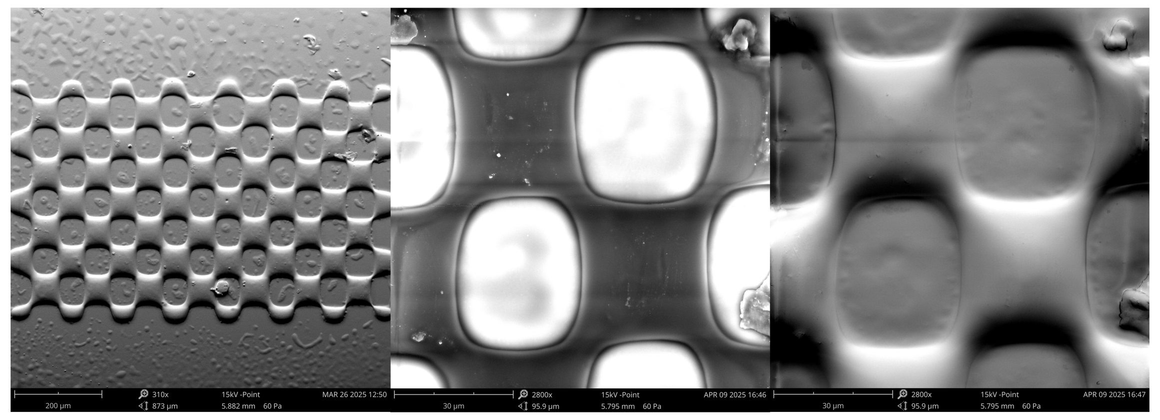

Figure 7: 65 µm grid exposures analyzed under various SEM modes.

Future Direction

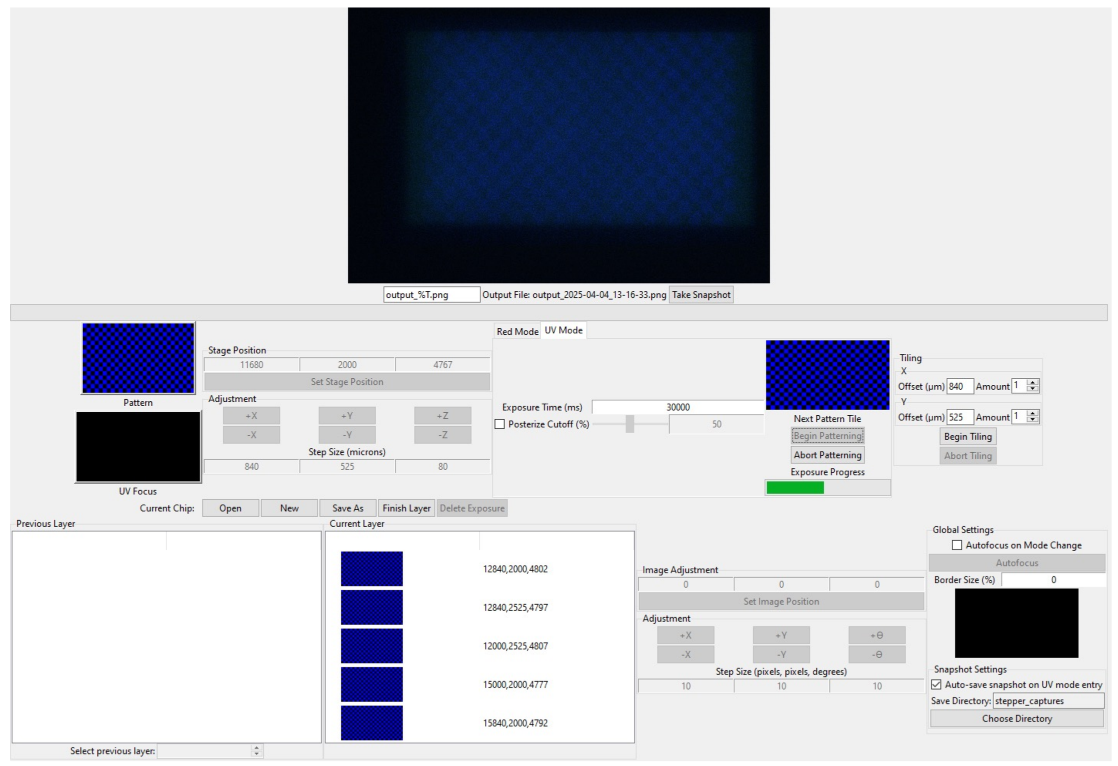

Figure 8: The current custom Python based GUI for using the lithostepper.

A custom GUI (Figure 8) enables live camera viewing, alignment, and exposure control. Future software upgrades—such as improved auto-focusing, distortion correction, and pattern stitching—can significantly enhance performance and usability without need for hardware changes.

The projector uses a custom UV LED PCB (Figure 9), which has failed once due to LED burnout. A more robust light source would improve device reliability. Higher UV intensity could also improve the exposure process.

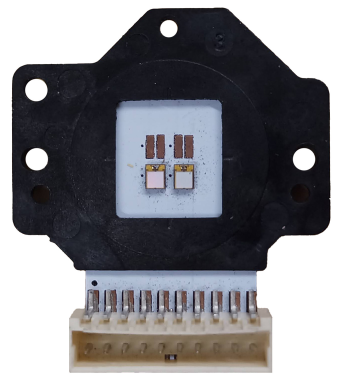

Figure 9: Custom UV-LED PCB.

Further improvements include testing additional photoresists, substrates, and adhesion promoters to boost pattern fidelity. A deeper study of etch variables would improve process consistency. On the hardware side, a more rigid and user-friendly stage could reduce overlay errors and improve alignment.

HackerFab is further developing a custom optical system to eliminate the need for a modified projector, aiming to lower cost, simplify assembly, and improve integration [6].

Acknowledgements

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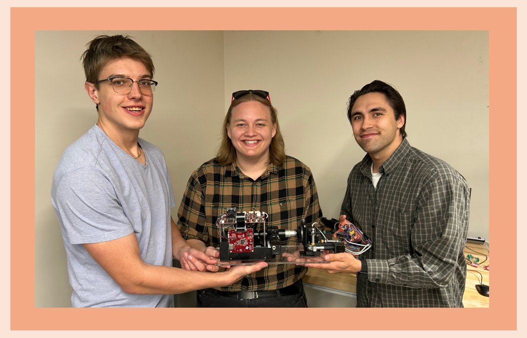

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