ELECTRONICS

Validation of a First Digitho Programmable Photomask Prototype

CNF Project Number: 318324
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Primary CNF Tools Used: GCA 5X g-line Stepper, GCA AS200 i-line Stepper

Abstract:

This report outlines the validation of a novel programmable photomask concept leveraging liquid crystal display (LCD) technology for dynamic UV lithography. Conducted at the Cornell NanoScale Facility, the evaluation focused on assessing the system's compatibility with standard g-line and i-line steppers, as well as its ability to support reconfigurable exposure processes. The results highlight the potential of LCD-based photomasks to serve as flexible, low-cost alternatives to conventional chrome masks, opening pathways for rapid prototyping and adaptive lithographic workflows in microfabrication.

Summary of Research:

The growing demand for reconfigurable and cost-effective lithographic tools has prompted exploration of alternatives to static, photolithography-grade chrome masks. In this context, the programmable photomask evaluated in this project integrates an LCD panel capable of modulating UV light in real time, combined with an embedded photodiode for synchronized exposure control. This approach seeks to enable dynamic patterning, reduce reliance on mask fabrication cycles, and facilitate multi-step or adaptive processes within research and development environments. An overview of the photomask structure and components is provided in Figure 1.

The prototype was tested using both g-line and i-line stepper systems at CNF to determine its operational compatibility with established lithography platforms. These tests demonstrated that the system could be integrated without requiring modification to tool workflows or introducing risk to equipment. The ability to maintain wireless communication and reliably update displayed images in response to UV exposure pulses marks a key step toward practical deployment in cleanroom settings.

In addition to confirming mechanical and communication compatibility, the campaign evaluated the core optical performance of the mask with the g-line stepper. Measurements confirmed sufficient UV transmittance (~20% for white pixels, 6–8% for black pixels) and contrast (>60%) for lithographic patterning, with successful image cycling and exposure repeatability demonstrated on resist-coated wafers. Results from these exposure tests are illustrated in Figure 2, while microscopy analysis of the patterned resist confirms a minimum resolved feature size below 100 µm, as shown in Figure 3.

The system also showed the ability to perform basic grayscale patterning through modulated exposures, reinforcing its suitability for early-stage prototyping and multi-depth resist structuring. These findings position LCD-based programmable photomasks as promising enablers of adaptable lithography workflows, with ongoing improvements aimed at enhancing resolution, synchronization robustness, and spectral compatibility.

Conclusions and Future Steps:

The successful validation of the LCD-based programmable photomask under real-world lithographic conditions marks a promising step toward more agile and cost-efficient fabrication workflows. By demonstrating compatibility with both g-line and i-line steppers, maintaining stable wireless communication, and delivering consistent image cycling during UV exposures, this system underscores the feasibility of deploying reconfigurable photomasks in advanced microfabrication environments.

While the current implementation relies on an LCD panel, which is limited to g-line and unsuitable for i-line exposure due to its lack of transparency below 400 nm, future versions of the system are expected to incorporate MEMS-based modulators. These alternatives offer the potential for higher optical performance, broader spectral compatibility—including true i-line transparency—and improved spatial resolution. Such advances would enable programmable photomasks to reach application domains currently limited to traditional chrome masks.

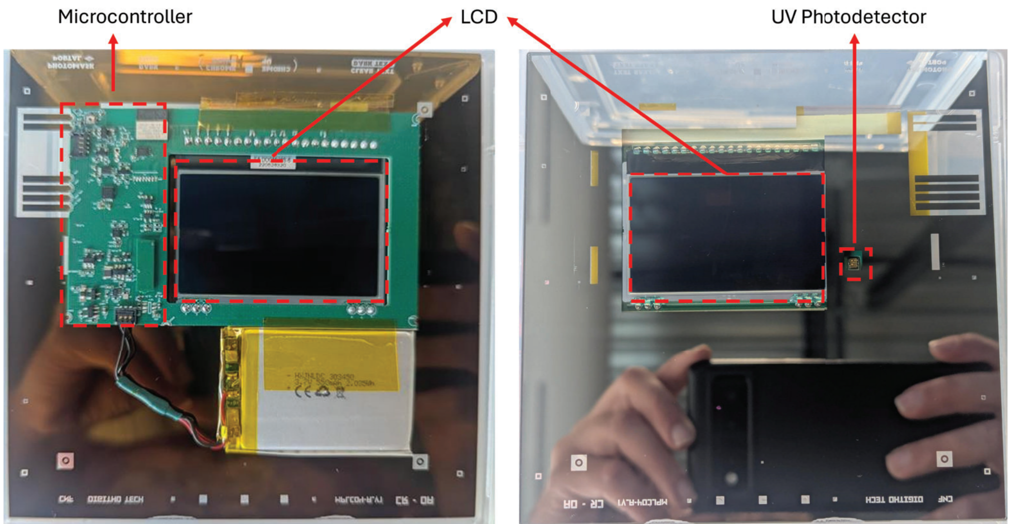

Figure 1: Bottom -side (left) and Top-side (right) views of the programmable photomask based on an LCD panel. The LCD (central red box) modulates UV light during exposure, while the integrated photodiode (rightmost red box) detects UV flashes to trigger image updates. The Bottom side includes control electronics and a rechargeable battery for wireless operation.

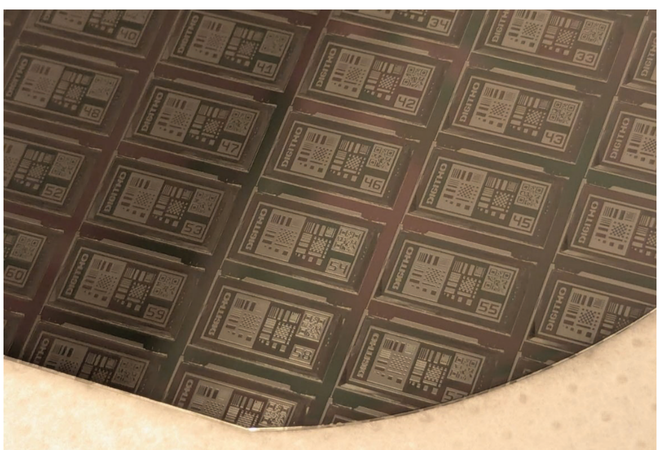

Figure 2: Photograph of a silicon wafer coated with photoresist and exposed using the programmable LCD photomask. Each rectangular field corresponds to a different image in the programmed sequence, demonstrating successful image cycling and pattern transfer during exposure.

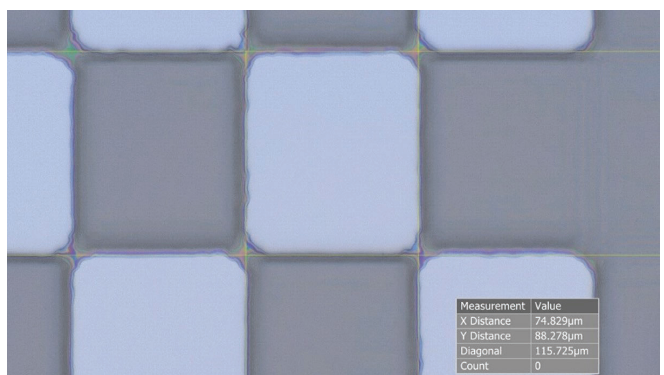

Figure 3: Microscopy image showing one of the smallest resolved features obtained using the programmable photomask. The measured dimensions are approximately 74.8 µm × 88.3 µm, confirming lithographic resolution below 100 µm consistent with LCD pixel limitations.