

Fabrication of Silica Microtoroid

CNF Project Number: 3316-25

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Primary CNF Tools Used: Electron-Beam Lithography (JEOL-9500X), SC4500 Odd-Hour/Even-Hour Evaporator, Yes Asher, Oxford PECVD, Oxford Cobra ICP Dielectric, Oxford 100 ICP Dielectric Etcher, PT770 Etcher – Left Side (Metal Etch), Disco Dicing Saw, Filmetrics F50, Microscope BX50

Abstract:

The primary objective of this research is fabricating a silicon nanostructured cavity device using Cornell NanoScale Science and Technology Facility (CNF) via high-precision micro- and nanofabrication processing. Building on preliminary work by the PI, post-fabrication characterization and performance metrics were evaluated at Binghamton University to determine the operational efficiency of the enhanced nanoscale design.

Summary of Research:

The fabrication process for the silicon nanostructured cavity device utilizes a bi-layer electron-beam lithography (EBL) process in combination with metal depositions to produce a metallic hard mask on the substrate. The overall objective is to establish a reliable and reproducible fabrication process capable of producing high-resolution nanoscale features for experimental characterization. Initial efforts concentrated on completing tool training, establishing process parameters, and optimizing each fabrication step to ensure process reliability before device fabrication.

The first stage of the project involved substrate preparation, cleaning, and resist processing. Since the available reference values for several fabrication tools required recalibration, the deposition and etch rates for silicon deposited by plasma-enhanced chemical vapor deposition (PECVD) and chromium were tested using pre-purchased wafer samples. Multiple calibration samples were fabricated and characterized to establish accurate process parameters. Film thicknesses were measured using the Filmetrics, allowing deposition and etch recipes to be refined before device fabrication commenced.

Once these procedures were completed, the silicon substrates were cut using the DISCO dicing saw to prepare individual samples for chromium deposition by electron-beam evaporation. Throughout the fabrication

process, several challenges related to contamination and reproducibility were encountered and addressed. Following the dicing procedure, microscopic black particulates were consistently observed on the substrate surface as shown in Figure 1.

To remove potential organic contamination, the samples underwent oxygen plasma cleaning using the YES Asher system. Additional troubleshooting was performed to identify the origin of the remaining surface particles. Several potential contamination sources were investigated, including debris generated during the dicing process, particulate contamination from nitrogen blow guns and squeeze bottles containing acetone or isopropyl alcohol (IPA). Each processing step was carefully evaluated to minimize contamination and improve overall sample cleanliness before lithographic processing.

Following substrate preparation, hydrogen silsesquioxane (HSQ) electron-beam resist was spin-coated onto the samples. The resulting resist thickness was measured using a KLA K7 profilometer through a scratch-test method to verify that the deposited film met the desired specifications. During the initial EBL exposure trials, unexpected substrate damage was observed after development as shown in Figure 2. Subsequent process analysis revealed that the damage originated from an unfavorable interaction between IPA and methyl isobutyl ketone (MIBK) used during the HSQ process. The HSQ was modified by using pure MIBK, eliminating the observed substrate damage and significantly improving process stability.

Chromium deposition by electron-beam evaporation was also carefully managed to preserve the integrity of the hard mask. Because chromium forms an oxide when exposed to air, deposition schedules were coordinated to minimize the time between evaporation and EBL exposure. Reducing air exposure helped maintain film quality and improved consistency throughout later

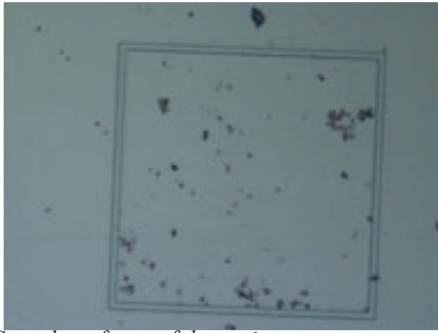


Figure 1: Snapshot of part of the cavity structure exposure with dirty particles appearing on the substrate



Figure 2: Snapshot of sample with the MIBK and IPA mixture with HSQ that is damaged

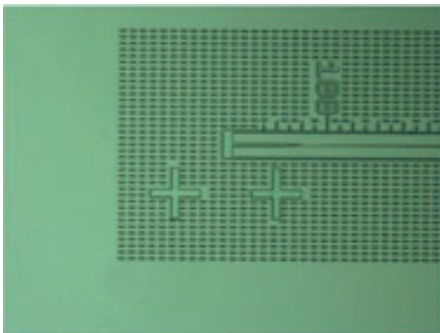


Figure 3: Snapshot of a part of cavity structure of the first layer from EBL, where there is minimal debris but appears there was some damage done in the middle of the structure. The exposure was completed using pure MIBK and HSQ.

processing stages. Following implementation of these process improvements, a satisfactory first-layer EBL exposure was successfully achieved with minimal surface contamination and well-defined lithographic features. Minor curvature of several pattern lines was observed near the center of the exposure field. This issue is believed to result from differences in beam calibration and exposure dose between the CNF electron-beam lithography system and the instrumentation previously used during process development. Rather than representing a fabrication failure, this exposure provided valuable information regarding dose sensitivity and beam alignment under the current process conditions.

Current work is focused on refining the EBL exposure parameters in collaboration with CNF technical staff to improve pattern exposure and accuracy. Additional efforts are directed toward optimizing process timing, minimizing contamination risks, and transitions between fabrication tools to increase overall process efficiency. These improvements are expected to enhance fabrication reproducibility and support the successful realization of the complete silicon nanostructured cavity device for subsequent experimental characterization at Binghamton University.

Conclusions and Future Steps:

For the next phase in our research, we focus on completing device fabrication for experimental evaluation at Binghamton University, with a targeted completion in early fall. Planned technical steps at CNF include calibrating the etch rates via ICP etching and scanning electron microscopy (SEM). Subsequently, the second electron-beam lithography (EBL) layer will be patterned, followed by e-beam silver deposition and a lift-off process. Any required process adjustments will be coordinated with CNF technical staff to ensure optimal device sample result before any process will begin.