

Redistribution Layers on Glass Wafers

CNF Project Number: 3018-22

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Affiliation(s): Mosaic Microsystems, LLC.

Primary Source(s) of Research Funding: U.S. Department of Defense (DOD), Customer Contracts

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Research Group Website: <https://www.mosaicmicro.com/>

Primary CNF Tools Used: ABM Mask Aligner, CHA Mark 50 E-beam Evaporator, Class 1 Photolithography Spinners, Class 2 Photolithography Spinners, GCA AS200 Stepper, Glen 1000 Resist Strip, Hamatech Wafer Processor(s), Heidelberg MLA 150 Maskless Aligner, Oxford 82 RIE, Oxford PECVD, PT 720-740 RIE, YES Asher

Abstract:

Glass substrates have excellent electrical and mechanical properties which have led to an increasing interest for their use in advanced microelectronic and photonic packaging applications. Glass substrates offer a very low loss tangent at GHz frequencies, while being moisture insensitive and dimensionally stable. This work outlines a novel approach for fabrication of interposers using thin glass (200 micron and below), normally difficult to handle in standard processes. The process yields void-free, hermetic, copper-filled precision through glass vias (TGVs), along with redistribution layer (RDL) fabrication with up to three metal redistribution layers per side. Furthermore, Mosaic Microsystems is developing various methods to integrate photonic waveguides with thin glass interposers to match high-speed electronics packaging with high-speed photonic communication.

Conclusions and Future Steps:

We have successfully built upon our previous processes to fabricate multi-layer RDL thin glass interposers by incorporating precision thin film resistors, optical waveguides, and microfluidic channels. Future work will continue to improve upon our processes at CNF to deliver upon our customer's needs.

Summary of Research:

Processing thin glass wafers 100 mm, 150 mm, and 200 mm in diameter using the conventional silicon processing equipment at the CNF is made possible through Mosaic's patented Viafirm® bonding technology. This has allowed Mosaic to complete multiple RDL fabrication projects that leverage a lift-off processing method using the photoresist spinners and the ABM Mask Aligner for contact alignment. Or using the GCA AS200 Stepper for features that require near micron resolution.

Furthermore, our team has successfully developed and characterized processes for the fabrication of highly precise thin film resistors, optical waveguides, and incorporating microfluidic channels into the thin glass interposer.

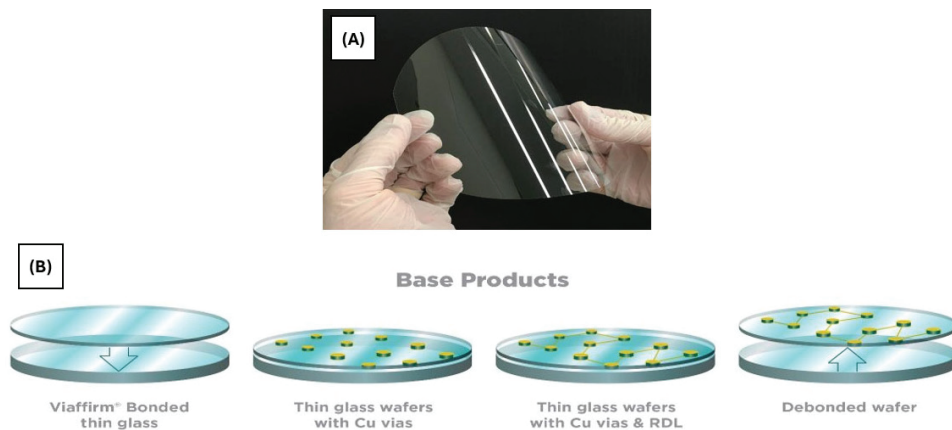


Figure 1: (A) Demonstration of the flexibility of thin glass. (B) Schematic outlining Mosaic's robust Viafirm® bonding process.

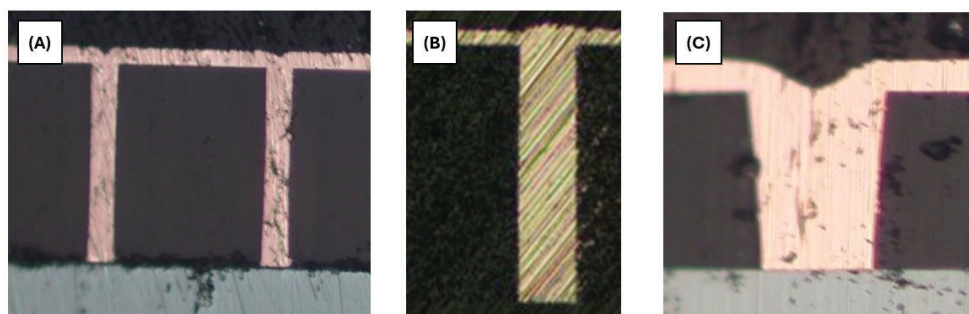


Figure 2: Cross-sections of fully filled copper vias with varying shapes and diameters. (A) 15 μm columnar via, (B) 25 μm columnar via, and (C) 35 μm tapered via.

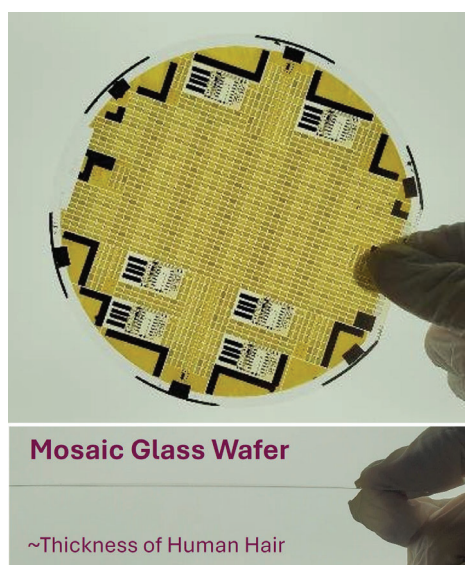


Figure 3: (Top) Example of a fully fabricated thin glass interposer with through glass vias and multiple redistribution layers. (Bottom) Side view of interposer showing the thickness of the thin glass interposer.

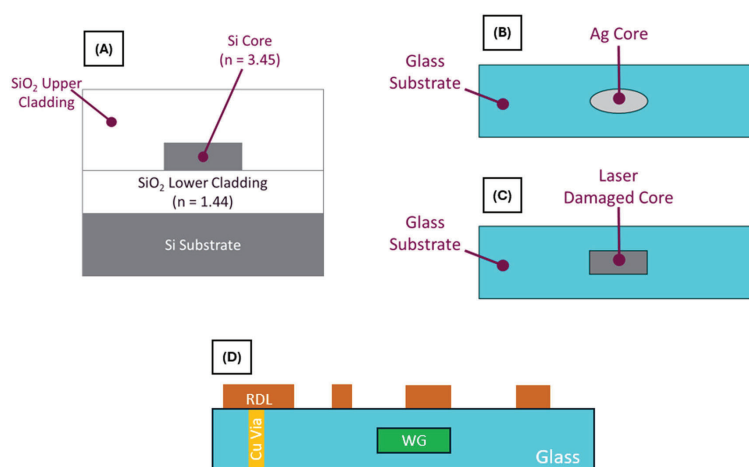


Figure 4: Schematic of various photonic waveguides. (A) Traditional silicon waveguide, (B) Ion-exchange waveguide, (C) Ultrafast laser inscription waveguide, and (D) Integration of electrical and optical communication.

Metal-Containing Resists for Extreme Ultraviolet Lithography

CNF Project Number: 3108-23

Principal Investigator(s): Robert L. Brainard

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Primary CNF Tools Used: JEOL E-beam 6300, Woollam RC2 Spectroscopic Ellipsometer, Zeiss Supra SEM, Zeiss Ultra SEM

Abstract:

Since 2011, our research group has developed Molecular Organometallic Resists for Extreme Ultraviolet Lithography (MORE), a family of amorphous thin-film photoresists based on organometallic compounds containing tin, cobalt, platinum, palladium, bismuth, and antimony.¹⁻⁹ This project focuses on the design, synthesis, and characterization of metal-containing photoresist platforms for advanced Extreme Ultraviolet (EUV) and electron-beam (E-beam) lithography. The objective is to develop high-performance materials suitable for both positive-tone and negative-tone patterning while achieving high sensitivity, high resolution, and low line-edge roughness. During this reporting period, Cornell NanoScale Science and Technology Facility (CNF) resources were used to perform high-resolution electron-beam lithography patterning and scanning electron microscopy characterization of the developed resist platforms. These capabilities enabled systematic evaluation of lithographic performance and pattern fidelity, providing critical insight into structure–property relationships and guiding the optimization of next-generation molecular organometallic photoresists for advanced nanofabrication applications.

Summary of Research:

Platform Selection

We prioritized the development of organometallic resist platforms that demonstrated promising initial positive-tone lithographic performance. Based on these results, we systematically modified molecular structures and optimized processing conditions to improve resist performance, including sensitivity, resolution and pattern fidelity. Structural modifications were guided by understanding the relationship between metal-containing molecular design, film properties, and lithographic

response. These efforts enabled the evaluation of new resist formulations and identification of promising candidates for advanced Extreme Ultraviolet (EUV) and electron-beam (E-beam) lithography applications.

CNF Usage and Progress

Between February 2026 and April 2026, we conducted multiple visits to CNF, steadily increasing the productivity of each session:

Imaging Trips Schedule

- CNF 8: Feb.02, 2026
- CNF 9: April 10, 2026

CNF-#	Dates	# of Resists	Total Wafers	Total Samples	CC	IMG	OM	Best Resolution (nm)
CNF-8	2/2/2026	25	80	320	100	220	58	50
CNF-9	4/10/2026	16	37	148	68	80	61	50

Figure 1: Shows list of experimental details from each visit.

Over the course of the project, we improved our experimental workflow by increasing team participation, implementing pre-experiment planning meetings, and focusing on optimizing high-performing organometallic resist platforms rather than screening new candidates. Increased experience with electron-beam lithography and scanning electron microscopy (SEM) also improved process consistency. Reducing the electron-beam current from 10 nA to 1 nA significantly enhanced pattern fidelity and improved feature visibility in both SEM and optical microscopy.

Technical Achievements

- Developed an atomic force microscopy (AFM)-based method to generate electron-beam (E-beam) contrast curves for quantitative evaluation of resist performance (Figure 2).
- Achieved high-resolution imaging for both positive- and negative-tone resists
- Increased resolution from 50 nm to 20 nm using the JEOL 6300
- Demonstrated excellent line edge roughness (LER) in optimized formulations
- Used RC2 ellipsometry to monitor film thickness pre- and post-development

Successful Use of AFM to Measure E-Beam Contrast

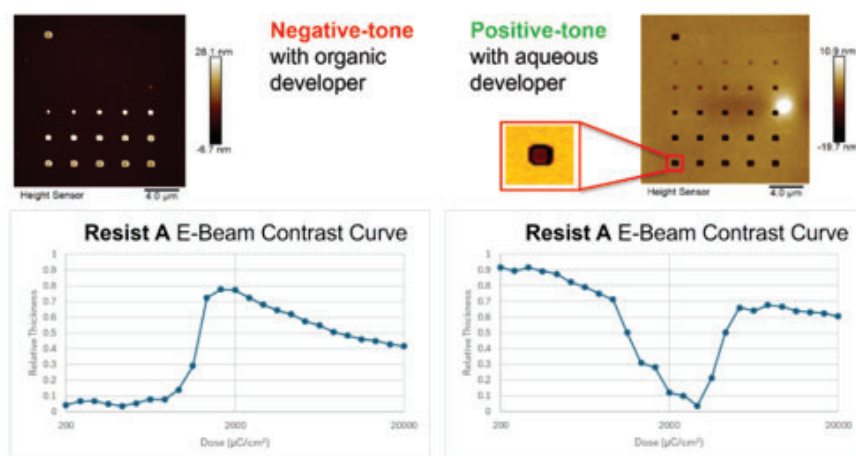


Figure 2: Positive-tone and Negative-tone contrast curve of Resist A.

Conclusions and Future Steps:

Our CNF trips became increasingly effective as the team-built process familiarity and focused on materials with the most promise. Key future work includes:

- Continued exploration of new organo-molecular resists.
- Further dose optimization and LER analysis.
- Testing of various development protocols on positive and negative tone resist platforms.
- Continued e-beam lithography and SEM imaging of optimized resists.

References:

- [1] M. Sortland, J. Hotalen, R. Del Re, J. Passarelli, M. Murphy, T. S. Kulmala, Y. Ekinici, M. Neisser, D. A. Freedman, and R. L. Brainard, "Platinum and palladium oxalates: positive-tone extreme ultraviolet resists," *J. Micro. Nanolithogr. MEMS MOEMS*, 14 (2015) 043511.
- [2] M. Wilklow-Marnell, D. Moglia, B. Steimle, B. Cardineau, H. Al-Mashat, P. Nastasi, K. Heard, A. Aslam, R. Kaminski, M. Murphy, R. Del Re, M. Sortland, M. Vockenhuber, Y. Ekinici, R. L. Brainard, D. A. Freedman, "First-row transitional-metal oxalate resists for EUV," *J. Micro/Nanolith. MEMS MOEMS*, 17 (4) (2018) 043507.
- [3] B. Cardineau, R. Del Re, M. Marnell, H. Al-Mashat, M. Vockenhuber, Y. Ekinici, C. Sarma, D. Freedman, R. Brainard, "Photolithographic properties of tin-oxo clusters using extreme ultraviolet light (13.5 nm)," *Microelectronic Engineering* 127, 44-50 (2014).
- [4] R. Del Re, J. Passarelli, M. Sortland, B. Cardineau, Y. Ekinici, E. Buitrago, M. Neisser, D. A. Freedman, and R. L. Brainard, "Low-line edge roughness extreme ultraviolet photoresists of organotin carboxylates," *J. Micro/Nanolith. MEMS MOEMS* 14(4), 043506 (2015).
- [5] M. Wilklow-Marnell, D. Moglia, B. Steimle, B. Cardineau, H. Al-Mashat, P. Nastasi, K. Heard, A. Aslam, R. Kaminski, M. Murphy, R. Del Re, M. Sortland, M. Vockenhuber, Y. Ekinici, R. L. Brainard, D. A. Freedman, "First-row transitional-metal oxalate resists for EUV," *J. Micro/Nanolith. MEMS MOEMS* 17(4), 043507 (2018).
- [6] J. Passarelli, M. Sortland, R. Del Re, B. Cardineau, C. Sarma, D. Freedman, R. Brainard, "Bismuth resists for EUV lithography," *J. Photopolym. Sci. Technol.* 27(5), 655-661 (2014).
- [7] J. Passarelli, M. Murphy, R. Del Re, M. Sortland, J. Hotalen, L. Dousharm, Y. Ekinici, M. Neisser, D. Freedman, R. Fallica, D. A. Freedman, R. L. Brainard, "Organometallic carboxylate resists for extreme ultraviolet with high sensitivity," *J. Micro/Nanolith. MEMS MOEMS* 14(4), 043503 (2015).
- [8] M. Murphy, A. Narasimhan, S. Grzeskowiak, J. Sitterly, P. Schuler, J. Richards, G. Denbeaux, R. L. Brainard, "Antimony photoresists for EUV lithography: mechanistic studies," *Proc. SPIE*, 10143, EUVL, 1014307 (2017).
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Bonding 4in Silicon Wafers

CNF Project Number: 3307-25

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Affiliation(s): Geegah Inc.

Primary Source(s) of Research Funding: Geegah Inc.

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Research Group Website: www.geegah.com

Primary CNF Tools Used: MOS Clean Bench & Tanks, Schott IR Inspector, Suss SB8e Substrate Bonder

Abstract:

Geegah is investigating ultrasonic imaging of embedded patterns at the bonded interfaces. Bonded Silicon wafers are a useful tool for exploring embedded patterns in Silicon. Here we present our initial development efforts to evaluate the bond quality between unpatterned wafers.

Summary of Research:

Two double side polished wafers were used for the bonding process. It was critical that the wafers had a bow of less than 30 micrometers and total thickness variation (TTV) of less than 5 micrometers [1][2][3]. The commercial wafers that were used during these experiments had a bow of less than 10 micrometers.

The two Silicon wafers were prepared by first processing in the MOS clean station followed by the spin rinse dryers. Bond quality is highly dependent on surface cleanliness. The wafers were cleaned in a fresh MOS clean station chemical batch to ensure a high-quality clean.

After the MOS cleaning, the wafers were immediately placed into the SB8e bonder. The 0anodic_BPSG_Si_NOSPACERS recipe was used. This heated the chamber to 100 °C, vacuumed down to five millibar, heated up to 300 °C, and then forced the wafers together. The step where voltage was applied to the wafers was skipped since it shorted the high voltage supply and caused the recipe to time out. The bonded wafers can be removed from the chamber after the cooling process has completed.

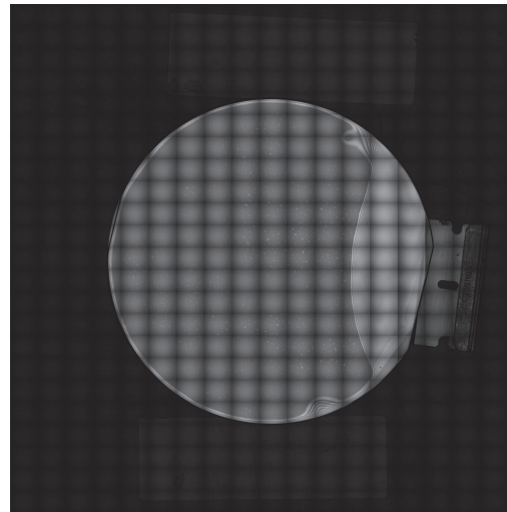


Figure 1: Bonded wafers with speckles and blade test (Schott IR, coax stitched image).

The Schott IR Inspector was used to inspect the quality of the bond. Lower quality bonds usually have small speckles of trapped moisture, as seen in Figure 1, which also illustrates the blade test applied to qualitatively assess the strength of the bond. Dust trapped between the wafers when bonding can be seen in Figure 2 due to the fringe pattern created around it. Finally, Figure 3 shows the good bonding results we achieved with minimal speckles and fringes.

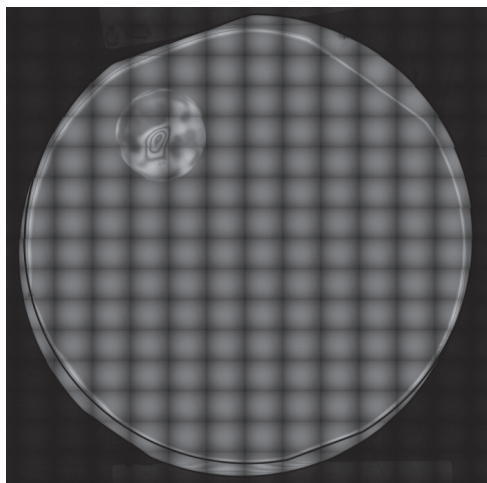


Figure 2: Bonded wafers with speckles and blade test (Schott IR, coax stitched image).

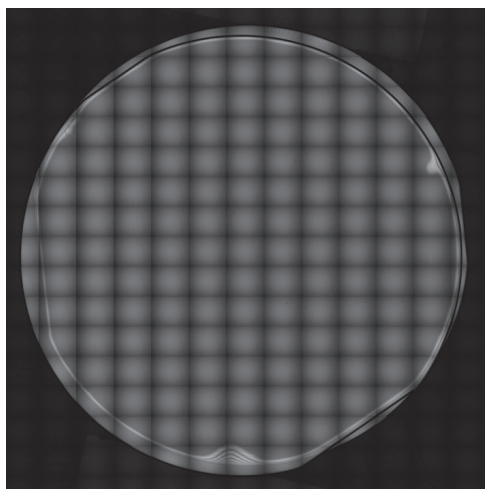


Figure 3: Bonded wafers with no speckles/fringes (Schott IR, coax stitched image).

Conclusions and Future Steps:

A simple process for bonding Silicon wafers was successfully developed using tools at the Cornell NanoScale Facility. Future steps include reducing the SB8e bonding temperature down to room temperature, which could reduce bonding time as it avoids a slow cooldown step in the bonder recipe.

References:

- [1] H Moriceau et al 2010 Adv. Nat. Sci: Nanosci. Nanotechnol. 1 043004.
- [2] Maszara, W. P., Jiang, B. L., Yamada, A., Rozgonyi, G. A., Baumgart, H., & De Kock, A. J. R. (1991). Role of surface morphology in wafer bonding. Journal of Applied Physics, 69(1), 257-260. doi:10.1063/1.347760.
- [3] U. Gösele, Q.-Y. Tong. 1998. SEMICONDUCTOR WAFER BONDING. Annual Review of Materials Research 28:215-241. <https://doi.org/10.1146/annurev.matsci.28.1.215>.

Characterization of 200mm Silicon Dioxide Etch Recipes

CNF Project Number: CNF Staff
Principal Investigator(s): Aaron Windsor

Affiliation(s): Cornell Nanoscale Facility

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Primary CNF Tools Used: Gamma Automatic Coat-Develop Tool, ASML PAS 5500/300C DUV Wafer Stepper, Glen 1000 Resist Strip, KLA P7 Profilometer, Dektak XT Profilometer, Plasma-Therm Takachi HDP-CVD, Oxford 100 ICP Plasma Etcher.

Abstract:

Over the past year, the CNF has expanded many of our tools to accommodate 150mm and 200mm sized wafers. What we quickly learned is that some of our etch recipes for 100mm sized wafers did not directly translate when scaled up to larger wafers. An example of this was etching 200mm silicon dioxide (SiO_2) wafers on the Oxford 100. Our initial test with difluoromethane (CH_2F_2) using the 100mm wafer recipe was not promising, but after some vacuum adjustments, we were able to etch at a rate of ≈ 96 nm/min. The CHF_3/O_2 oxide recipe etches at a rate of ≈ 53 nm/min. For larger molecular fluorocarbons such as C_4F_6 and HFO-1234ze(E), the existing 100mm recipes deposited polymer. By adding oxygen and argon, we can currently etch SiO_2 on 200mm sized wafers using HFO-1234ze(E) at a rate of ≈ 78 nm/min.

The 100mm C_4F_6 and HFO-1234ze(E) recipes both deposited polymer instead of etching the SiO_2 . By adding argon to enhance the ion bombardment and oxygen to reduce polymer formation, we were able to etch SiO_2 using HFO-1234ze(E) at a rate of ≈ 78 nm/min. The etch rates for all three 200mm sized wafer were lower than the 100mm sized wafer rates reported in our 2025 paper (1), but the selectivity to UV 210 DUV resist were much higher. Tables 1 & 2 show, the etch depths for both the CH_2F_2 and CHF_3/O_2 were 3.5-5% lower two-inches from the center and 8-12% lower three-inches from center. Future work will focus on improving etches rates and etch uniformity for all three etches.

Summary of Research:

The CNF has made a conscious effort to expand our capabilities for processing larger diameter wafers. For some equipment such as the Oxford PECVD and CHA Mark 50, this is an easy switch, but for most tools, this requires much more effort. For the Oxford 100, staff must take the tool down and exchange the 100mm ceramic clamp with the 200mm clamp and adjust the alignment of the load arm.

Initial tests on etching SiO_2 on 200 mm sized wafers started with the same difluoromethane (CH_2F_2) SiO_2 etch recipe used in our HFO-1234ze(E) 2025 paper (1). Early results using this etch recipe were not promising until we returned the vacuum exhaust on the Oxford 100 from the scrubber to the tool's original path. This exhaust switch improved the SiO_2 etch rates by 20 nm/minute. We ran a two, five, and ten minutes CH_2F_2 etch and the results were consistent with a center etch rate of ≈ 96 nm/min. The 100mm CHF_3/O_2 recipes etches SiO_2 at ≈ 53 nm/min with similar etch uniformity. The selectivity to UV 210 DUV resist was 10.5:1.

Table 1: 200mm Etch Uniformity for a Ten-Minute, CH₂F₂ etch: Center of the wafer 966nm.

Distance from Center	1" from Center (nm)	2" from Center (nm)	3" from Center (nm)
North	966	933	890
South	951	921	868
West	950	927	877
East	960	915	857

*Table 1.***Table 2: 200mm Etch Uniformity for a Ten-Minute, CHF₃/O₂ etch: Center of the wafer 532nm.**

Distance from Center	1" from Center (nm)	2" from Center (nm)	3" from Center (nm)
North	542	509	500
South	530	521	519
West	535	543	530
East	528	509	490

*Table 2.***References:**

- [1] A. Windsor, J. Clark, G. McMurdy, E. Joseph, R. Syvert, R. Olson and J. Cha, J. Vac. Sci. Technol. B 43, 2 (2025).

Etching Fused Silica with Low Global Warming Potential HFO-1234ze(E)

CNF Project Number: MENG CNF

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User(s): Svanik Ravi

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Primary CNF Tools Used: ABM Mask Aligner, AJA Sputter 1, AJA Sputter 2, Glen 1000 Resist Strip, KLA P7 Profilometer, Oxford 100 ICP, PT 720-740 RIE, Zeiss Supra SEM, Zeiss Ultra SEM

Abstract:

The semiconductor industry is currently having to reevaluate reactive ion etch processes to comply with the yearly reductions of hydrofluorocarbons (HFCs) mandated by the American Innovation and Manufacturing (AIM) Act. This, along with global supply chain concerns, has increased interest in the use of alternative etch gases, more specifically, replacing high global warming potential (GWP) gases such as difluoromethane (CH_2F_2), trifluoromethane (CHF_3) and other HFC legacy gases used for etching dielectrics. After demonstrating that the low GWP, hydrofluoroolefin, HFO-1234ze(E) (trans-1,3,3,3 tetrafluoropropene) is an effective etch gas for reactive ion etching thermal silicon dioxide (SiO_2), this work focuses on etching 10-20 μm deep microfluidic channels in amorphous SiO_2 , fused silica (FS). Early etch trials were promising but etches deeper than 1 μm would result in polymer deposition in the channels. By increasing the DC bias applied to the electrode, channels could be etched beyond 1 μm . At a DC Bias of 70 V, channels were etched over a depth of 9 μm with a chromium hard mask selectivity of 45:1.

Summary of Research:

The optical transparency of FS has always been an attractive option for high resolution microfluidic and micro-optic devices, but fabricating microstructures with FS is challenging, especially reactive ion etching deep channels. Hydrofluorocarbons (HFCs) such as CH_2F_2 and CHF_3 have been used in the past for reactively ion etching SiO_2 , but with the emergence of the American Innovation and Manufacturing (AIM) Act, semiconductor manufacturers are mandated to reduce their production and consumption of HFCs by 85% by 2036 (1-3). Our current geopolitical climate has further complicated the use of HFCs by creating global supply chain issues for semiconductor materials and gases. Combined, these issues have driven research into exploring possible replacements for HFC etch

gases. The CNF currently uses a CH_2F_2 recipe for deep FS etches. The ICP power is set at only 1500 W which lowers the etch rate (100nm/min) but maintains good chromium mask selectivity (43:1) for deeper etches. In the past, a CHF_3/O_2 was used but this recipe involved heating the power electrode from 10° C to 50° C. This recipe had a higher etch rate of 188nm/min, but a much lower chromium mask selectivity ($\approx 20:1$).

One potential alternative for the use of HFC gases is the use of low-GWP hydrofluoroolefins (HFOs) (4). HFOs are chlorine free, unsaturated organic compounds composed of carbon, hydrogen, and fluorine with at least one carbon double bond ($\text{C}=\text{C}$). Unlike the HFCs and other saturated halohydrocarbon refrigerants, HFO double bonds are molecularly less stable and have a significantly shorter atmospheric lifetime. (5)

In 2025, HFO-1234ze(E) (trans-1,3,3,3 tetrafluoropropene) was shown to be an effective etch gas for wet thermal oxide. (6) This work will be focused on etching between 10-20 μm microfluidic channels into FS using HFO-1234ze(E) and the effects DC bias has on etch rate, mask selectivity and wall angle.

Experimental

An AJA sputtering tool was used to deposit a 200nm chromium hard mask on four-inch FS wafers. The hard mask was patterned on an ABM contact aligner using Shipley 1813 photoresist. The chromium mask was reactively ion etched in a Plasmatherm 740. After removing the resist, the FS was etched on an Oxford PlasmaLab 100 ICP380 system using the same SiO_2 HFO etch recipe used in the 2025 paper (Table 1) with only the DC bias minimum changing. Channel depths were measured on a KLA P7 profilometer after each five-minute etch until the hard mask began to disappear. All final channel depths were measured after removing the remaining chromium by soaking in Transene 1020AC chromium etch.

Chamber Pressure	4 mTorr
HFO-1234ze(E)	20 sccm
Helium	80 sccm
Minimum DC Bias	30V
Forward Power	60W
ICP Power	3000W
Electrode Temperature	10° C

Table 1: Original SiO₂ Etch Recipe for HFO-1234ze(E).

Conclusions and Future Steps:

The initial five-minute etch using the original 2025 HFO recipe etched over 1µm of FS with an etch rate of 201.8nm/min. A channel depth of 3.1µm was achieved before the mask was etched through. For the next trial, the DC bias minimum was lowered from 30V to 20V with similar results after five-minutes of etching, but subsequent etches resulted in the channels filling with brown polymer. The polymer was removed in a high-power oxygen plasma, but the polymer would redeposit when the HFO recipe was run again. From literature, the polymer layer forms in the beginning of the etch as fluorine anions bond and passivate the SiO₂ surface. (7,8) Ions from the plasma then interact with the fluorinated surface resulting in polymer/FS removal. The ion energy can be influenced by increasing the DC bias of the etch. DC bias is the voltage difference between the plasma and the wafer surface that accelerates positive ions towards the power electrode and substrate. The Oxford 100 manual states that the RF generator toggles between the forward power and DC bias settings. (9) DC bias effects not only etch rate, but selectivity and the degree of sidewall angle. The original recipe's DC bias minimum was set at 20V so by increasing DC bias, the ion surface interactions should also increase, removing polymer and increasing etch channel depth. Table 2 illustrates the affect DC Bias had on FS etch depth and chromium mask selectivity. Both etch depth and selectivity increased as the DC bias increased up to 70V. At 70V, the channel depth was 9.1µm with a selectivity of 45:1. Above 70V, the selectivity decreased. This decrease could be due to insufficient neutral passivation or substrate heating which will reduce selectivity. (8) It is important to note that with all the DC bias changes, the etch rates were consistently ≈ 200nm/min. This demonstrates that the DC Bias effected the mask selectivity and not the FS etch rate. In addition, the

DC Bias (Volts)	Maximum Etch Depth (µm)	Selectivity to Chromium Mask
20	1.0	5:1
30	3.1	16:1
50	6.2	31:1
70	9.1	45:1
100	5.9	29:1
130	5.9	29:1

Table 2: The effects of DC Bias on fused silica channel etch depth etched and selectivity.

improved selectivity enabled deeper FS etches. A cross-section of the 70V DC bias etch measures a sidewall angle of the is 74.6° (Figure 1).

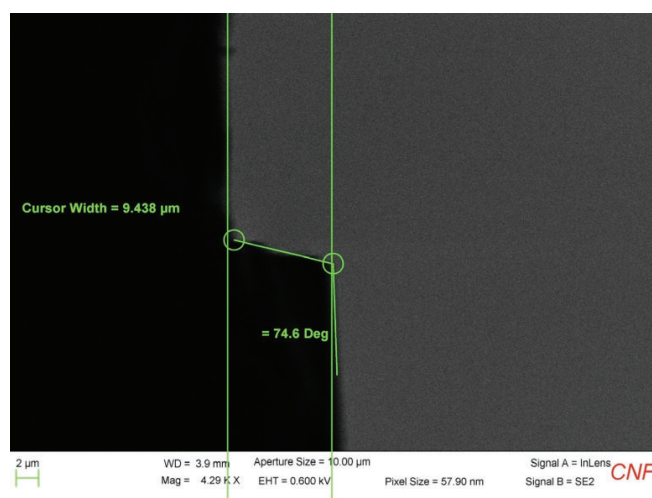


Figure 1: Cross-section of a 9µm fused silica channel etched with HFO-1234ze(E) (*trans*-1,3,3,3- tetrafluoropropene) with a DC bias minimum of 70V.

This work has demonstrated that HFO-1234ze(E) is an effective etch gas for FS. The established recipe has a higher etch rate and better selectivity than CH₂F₂ and CHF₃. The effects of increasing the ion bombardment/DC Bias are critical for etching beyond 1µm. Deeper etches may be achieved with different and/or thicker hard masks. In their 2015 paper, Pedersen and Huff were able to etch 100µm FS holes with a 20µm electroplated nickel hard mask. (7) Future work will examine the effects of including oxygen and argon into the plasma chamber that has on edge depth and sidewall angle.

References:

- [1] A. Windsor, J. Clark, G. McMurdy, E. Joseph, R. Syvert, R. Olson and J. Cha, J. Vac. Sci. Technol. B 43, 2 (2025).

Characterization of PFAS Free PAGs in Photoresist

CNF Intern: Landon Cheung

Student Affiliation: Tompkins Cortland Community College (TC3)

Summer Program(s): 2026 Cornell NanoScale Facility Summer Internship

Mentor(s): Chris Ober, Professor Zhong, Sherri Ellis

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Summer Program Website(s): <https://www.cnf.cornell.edu/education/reu/2026>

Abstract:

The reduction of PFAS ‘forever chemicals’ has been of recent focus for the semiconductor industry for both legislative and environmental concerns. These chemicals, containing -CF₂- or -CF₃ bonds¹, are difficult to break down due to high bond energy and thermal stability. PFASs are of concern to the environment due to this property, building up in the biosphere and interfering with biological systems. Recent legislation is pushing for the removal of PFASs in the semiconductor industry leading to the need for PFAS free photoresists². This project focuses on the performance of PFAS-free PAGs in photosensitive resists, which may match or outperform their PFAS counterparts and factors that influence it.

Summary of Research:

Photosensitive resists generally have four steps: pre-bake, exposure, post exposure bake (PEB), and development. In the baking stages, temperature and time affect the results and properties. Exposure is influenced by dosage, mJ or uC/cm², given to the photoresist and correlates with resist thickness. Overexposure also poses a concern with cross-linking, causing the photoresist to become insoluble and harder to remove than an adequately exposed area. Proper development ensures that the exposed or unexposed sections, depending on whether a positive or negative resist is utilized, dissolve completely.

One of the tests uses a PFAS free PAG-bound ESCAP resist with an array of resolution tests that varied the dose using the ASML 5500 DUV stepper. The stepper is capable of resolution down to 200 nm, setting the best possible result. The criteria for a good resist are development through the thickness of the resist and smooth edges that follow the original pattern. However, due to effects such as corner rounding, optical diffusion, acid diffusion, and optical proximity effects, small features will have more pronounced rounding and imperfections when compared to the original mask.

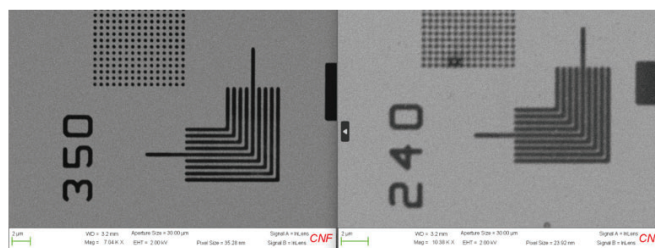


Figure 1: DUV resolution comparison at 350 nm and 240 nm.

Figure 1 compares a good result in a DUV in the bulk of the feature at 350 nm, compared to expanded lines on 240 nm. The rounded corners and ends of the lines test show the optical and chemical effects of photolithography. Figure 2 has good features at 300 nm and continually decreases in quality down to 250 nm. 300 nm has clear edges with some variations, overall a good result. 280 nm has noticeably less quality, with more jagged edges and some sections bridging on the sides. Under 280 nm is unviable, having too much inconsistency.

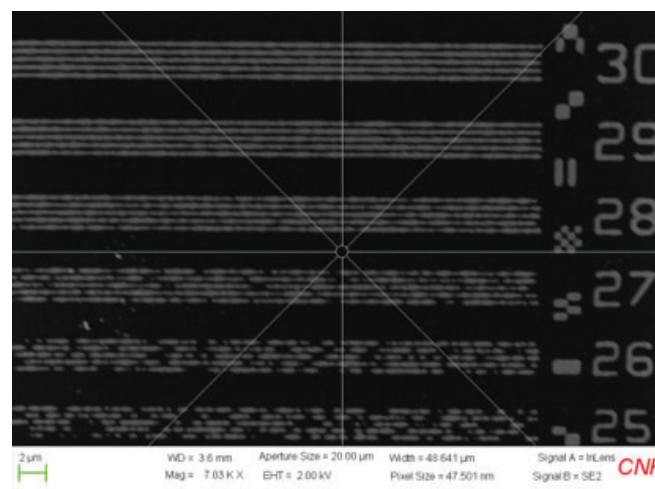


Figure 2: DUV resolution test at approximately 115.5 mJ/cm² with good results at the top starting at 300 nm and getting worse as you go down to 250 nm..

E-beam photoresists were tested in lieu of EUV due to the mechanism of how EUV PAG resists work. They rely on secondary electrons to create an acid that allows for the photomask to become more soluble. Using the Nabity NPGS and Zeiss Supra SEM, the electron beam skips to the secondary electron state, bypassing the need for EUV radiation to generate secondary electrons. This was used to test resolution and how thorough the thickness the photoresist exposures are. Using AFM, each dose's height map is recorded then digitally processed. Using Gwyddion, the major steps are background slope removal, averaging the depth of the exposure development, and normalizing using the thickness of the resist (fig. 3). This gives us the exposure thickness of the resist. The P3 PAG (fig. 4) was tested, with the best resolution of the set at 500 nm (fig. 3).

Conclusions and Future Steps:

This research shows room for improvement for using PFAS-free PAGs, with up to 90 nm of improvement potential for DUV on the ASML 5500. The main limitation with testing is how fast the PAGs can be synthesized, with only enough being made for one or two samples per week. These characterizations show a significant step in moving toward PFAS-free photoresists by utilizing PFAS-free PAGs. However, more testing and improvements to the process are needed before they can be applied and reduce PFASs in the environment.

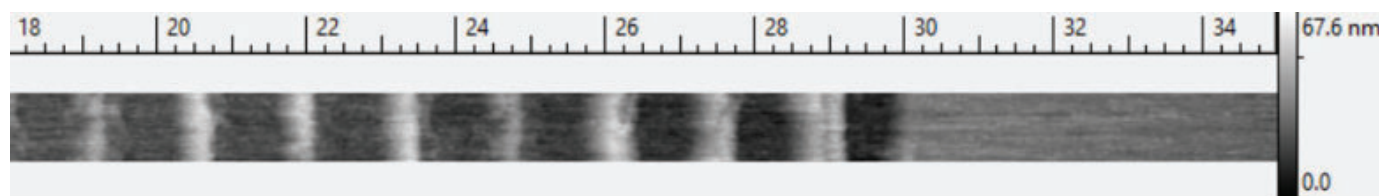
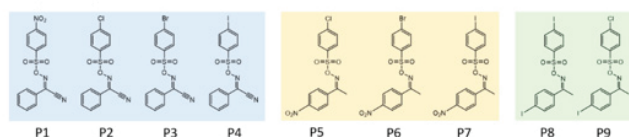


Figure 3: Ebeam resolution test with 500 nm line distance and width. Dose of 125 uC/cm² for the tested setup of 110°C for 240s.

Design and Synthesis of PFAS-free non-ionic imino-sulfonate PAGs



Design and synthesis of PFAS-free non-ionic imido-sulfonate PAGs

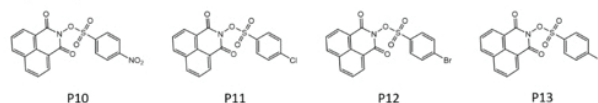


Figure 4: PFAS free PAG chemicals. Report on identification of PFAS-free non-ionic PAGs as solubility switch groups in photoresists. Task #: 3244.001. Christopher K. Ober; Yu Zhong.

References:

- [1] OECD (2021), Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance, OECD Series on Risk Management of Chemicals, OECD Publishing, Paris, <https://doi.org/10.178>
- [2]. Environmental Protection Agency. (2019). EPA PFAS action plan (EPA 823-R-18-004). U.S. Environmental Protection Agency. [epa.gov](https://www.epa.gov/pfas)

Diamond CVD, NanoBOND/DEBOND System, and Furnace Characterization

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Summer Program Website(s): <https://www.cnf.cornell.edu/education/reu/2026>

Primary CNF Tools Used: MOS Clean Bench & Tanks, MRL E2 CMOS Wet Oxide, MRL B3 LPCVD LTO, Woollam RC2 Spectroscopic Ellipsometer, Filmetrics F50, Bruker DektakXT Profilometer, Zeiss Gemini SEM, Zeiss Ultra SEM, Keyence VHX-7100 Digital Microscope, NanoBOND 200, NanoDEBOND 200

Abstract:

Summer project goals included work on the Nordtech funded Seki Diamond chemical vapor deposition tool and the Nordtech funded OnNano NanoBOND 200 and NanoDEBOND 200 system. The goal with the Seki Diamond tool was to characterize and perform a hardware assessment of the tool. The work completed on that project was the development of a nanodiamond seed crystal coating process, essential for serving as a nucleation point for diamond chemical vapor deposition. Project time was limited when the tool was shut down for repair. This caused a pivot to the NanoBOND 200 and NanoDEBOND 200 system. The task was to perform a hardware assessment of the system and develop processes for operation, with the ultimate goal being a complete operating manual.

Summary of Research:

Nanodiamond Seed Crystal Process

The Seki Diamond tool functions by using a microwave plasma, 99% Hydrogen and 1% methane. In the plasma is a diamond seed crystal which the methane will contact, depositing its carbon atom onto the diamond lattice structure. The remaining hydrogen in the methane molecule will join the existing hydrogen plasma cloud. This reaction builds a layer of diamond, atom at a time on top of a diamond seed crystal. The reaction will only grow diamond on diamond. For this purpose, it is essential to the process that we have proper diamond seed crystals for diamond chemical vapor deposition.

The Seki Diamond tool uses a molybdenum puck as its base for seed crystals. Seed crystals can either be monocrystalline, one large diamond with a singular lattice direction, or polycrystalline, many smaller diamonds with various lattice directions. To initially

characterize the diamond growth rate, polycrystalline seeds were preferred for their much lower cost. The seed crystals are roughly 20nm in diameter, requiring a scanning electron microscope for imaging. This factor meant the original molybdenum puck would have a surface too rough to observe any seed crystal deposition. Instead, two-inch silicon wafers were preferred for their availability and smooth surface, even though they will never be used in the Seki Diamond tool. A ScienceDirect article recommended starting with a 50% dimethyl sulfoxide (DMSO) diamond solution to 50% methanol. A two-inch wafer was placed in this 50/50 solution and moved into an ultrasonic bath for 10 minutes, after the bath wafers were rinsed with more methanol and dried with nitrogen [1]. When this recipe was observed under the Zeiss Gemini SEM560 scanning electron microscope, many of the diamonds had collected into water spots and were not evenly dispersed across the wafer. To solve this the process was modified to see if a lower concentration, different cleaning method, and different sonication times, improved results. The ideal recipe found was a 25%/75% DMSO to methanol solution, sonicated for 15 minutes, and cleaned with isopropanol (Figure 1).

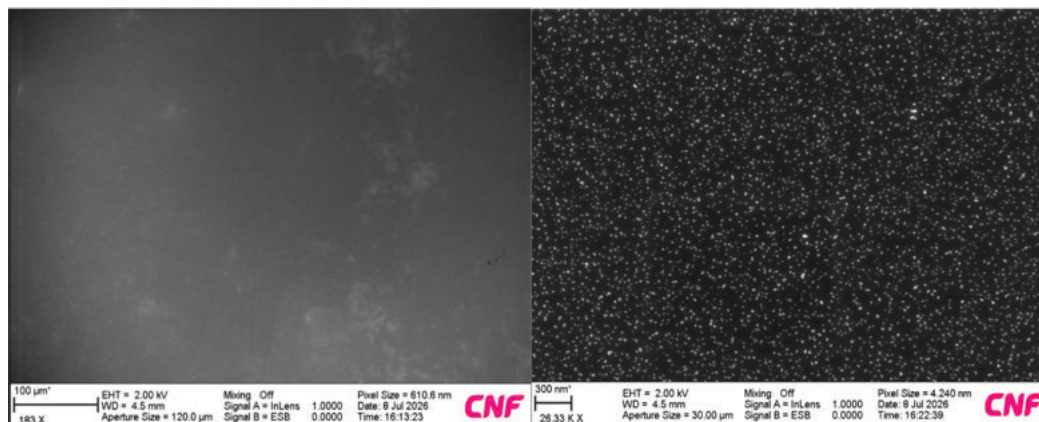


Figure 1: Nanodiamond Seed Crystals. 15 minutes, 25% DMSO, cleaned with IPA.

NanoBOND 200 and NanoDEBOND 200

The hardware assessment for both the NanoBOND 200 and NanoDEBOND 200 involved testing, experimentation, and troubleshooting. The NanoBOND 200 and NanoDEBOND 200 system functions by coating a carrier wafer with a bonding polymer and bonding to either another target wafer or wafer piece. Theoretically the carrier is thicker and stronger than the target, adding structural support as the target undergoes process steps. When the carrier has served its purpose, the bonded stack is then slid apart in the NanoDEBOND 200 tool. Initially much time was devoted to developing a spincoating process for MicroResist, mr-glue-xp bonding polymer. The given process yielded streaking and uneven polymer surfaces. Through trial and error, a two-step spinning recipe was created for the three different carrier wafer sizes, four inch, six inch, and eight inch.

Our operating process had to be adjusted for the original setup of the tool. The NanoBOND 200 has two vacuum chucks, one for the carrier and one for the target, however neither chuck has an included aligning mechanism. To resolve this, a wafer aligner for each chuck was modeled and is being machined. The NanoDEBOND also required other adjustments. One being that during the debond process the carrier is supposed to be held in place on the carrier vacuum chuck not only by vacuum, but by a physical lip impeding the direction of sliding. This lip was measured to be 600 microns thick, 75 microns thicker than a standard four-inch wafer. This led to bonded stacks on four-inch carrier wafers breaking as they hit the lip when debonded. A fix to machine down this lip is on the way. Another critical flaw with the debonder was the lack of any refined wafer removal mechanism. Originally the debonded carrier and target wafers were removed with tweezers or by hand. Since they are oriented vertically and at temperatures over

100 degrees Celsius this is suboptimal. An effective solution was using a vacuum wand to remove the wafers. After the hardware assessment and subsequent solutions, a full manual of operation was made, including all operation steps for spin coating, bonding, and debonding, as well as general information useful for future users.

Furnace Characterization

Additionally, during transition time between projects time was allocated for work on the E2 Wet Oxide furnace and the B3 LPCVD furnace. The goal for the E2 wet oxide was to create a Deal-Grove equation for oxide thickness. This was done using nine trial runs of varying time and temperature. A model was made that can predict thickness with 80% accuracy, which needs more refining before further use. Work on the LPCVD furnace used three runs of 35 wafer batches to measure uniformity across wafer position in the tube. This successfully identified variation is presented in the front of the tube.

References:

- [1] Shenderova, O. A., & ScienceDirect. (2010, March). Seeding slurries based on detonation nanodiamond in DMSO. *Diamond and Related Materials*, Volume 19(2-3), 260-270. <https://www.sciencedirect.com/science/article/pii/S0925963509002830>