

Microscale Sorbent Sheets for Rapid Extraction and Analysis of Volatiles

CNF Project Number: 2513-16

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Research Group Website: <http://blogs.cornell.edu/winechemistry/>

Primary CNF Tools Used: VersaLaser Engraver/Cutter Tool

Abstract:

The quality and safety of raw agricultural products is often determined by small molecules present at trace, sub-part-per-million levels. Measurement of these components during production and manufacturing is critical – and sometimes compulsory – for ensuring a healthy, palatable, and safe food supply. Gold-standard methods like chromatography coupled to mass spectrometry (MS) are slow, expensive and must often be performed off-site, and rapid methods often suffer from poor selectivity or sensitivity. Our group has previously demonstrated that etched sorbent sheets (SPMESH) can be used for rapid parallel extraction prior to direct analysis in real time mass spectrometry (DART-MS). This SPMESH-DART-MS approach can achieve part-per-trillion detection limits in <30 s per sample. Using tools available through the Cornell NanoScale Facility (CNF), we have explored the impact of varying the etch pattern on the performance of SPMESH sheets. For square apertures, an optimum aperture size of 1.5 mm was observed. At lower and higher aperture sizes, a decrease in sensitivity and increase in detection limits was observed. Sensitivity and detection limits could be further improved by using circular mesh patterns. These findings will lead to improved throughput and better sensitivity for trace level volatiles.

Summary of Research:

The odors associated with common foods, beverages, and fragrances are due to range of odorants, many present at concentrations as low as a part-per-trillion (nanogram-per-Liter, or ng/L). Because of these low concentrations, analysis of these trace volatiles often requires initial steps to

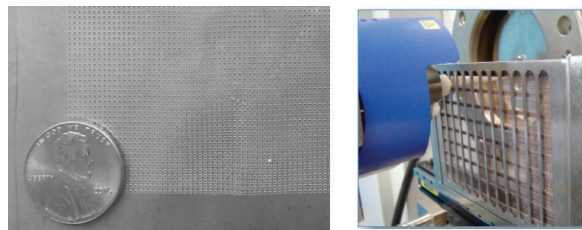


Figure 1: Example of an etched silicone SPMESH sheet produced at the CNF.

concentrate them and remove interferences, followed by analysis by techniques like gas chromatography – mass spectrometry (GC-MS). GC-MS analyses often require 30 min per sample, and represent a common bottleneck in characterization of large numbers of samples. So-called “ambient-ionization” – MS techniques like direct analysis in real time (DART) are much faster than GC-MS, but coupling automated extraction approaches to DART-MS has not been straightforward. To overcome this, our group developed an approach called Solid Phase Mesh Enhanced Sorption from Headspace

(SPMESH) which is readily coupled to DART-MS. Our group used the VersaLaser Cutting Tool at the CNF to generate mesh patterns on poly(dimethylsiloxane) (PDMS) sheets (Figure 1). We could then position the sheets over multiwell plates pre-loaded with samples, e.g. macerated grapes (Figure 2). The silicone sheets then absorbed the volatiles in the headspace above each well in parallel. Following extraction, the SPMESH sheet with extracted volatiles is then transferred to an automated positioning stage. Using representative odorants, we have previously reported that SPMESH-DART-MS can analyze 24 samples in 8.5 min with detection limits in the ng/L range.

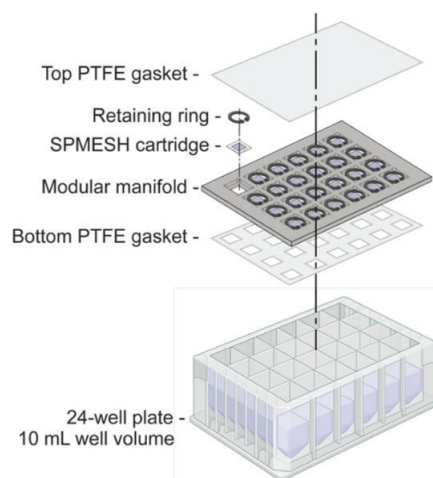


Figure 2: Diagram of the SPMESH assembly. Following parallel headspace extraction, the SPMESH manifold can be transferred to ambient ionization – mass spectrometry (AI-MS, e.g., DART-MS) for rapid characterization.

Optimization of SPMESH mesh pattern geometry has not been previously reported. Using the VersaLaser Cutting Tool, we prepared PDMS meshes of varying aperture shape (circular, square), size, and surface areas. We then used DART-MS to evaluate two target volatiles. We determined that maximum signal and the lowest detection limits were achieved with an aperture size of 1.5 mm. A decrease in sensitivity and increase in detection limits was observed at lower and higher aperture sizes, and further improvements could be achieved with circular mesh apertures in place of square apertures. This is likely because the optimum mesh pattern allows for maximum extraction and desorption from the interior faces of the SPMESH sheet. The optimum mesh could improve detection limits by 20-fold (Figure 3).

Conclusions and Future Steps:

In summary, optimization of the geometry of laser-etched SPMESH sheets can result in improved performance for high-throughput analysis of trace level volatiles.

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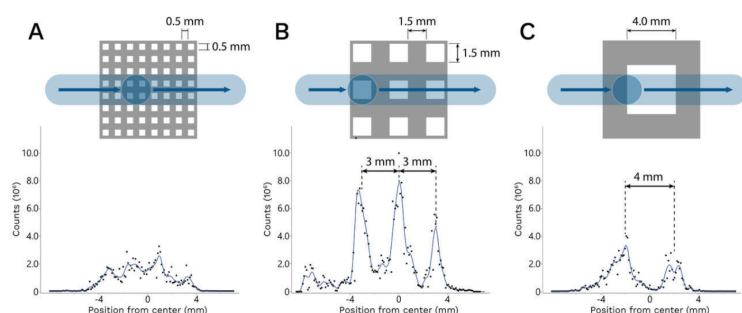


Figure 3: Chronograms of 0.5 x 0.5 mm (aperture x gauge) (A), 1.5 x 1.5 mm (B), and 4 x 4 mm (C) SPMESH cartridges following extraction of a 1 $\mu\text{g/L}$ 3-isobutyl-2-methoxypyrazine (IBMP) standard. Depictions of DART scan paths for each SPMESH geometry are shown over each chronogram.

Identifying Sources of Per- and Polyfluoroalkyl Substances in Photolithography Wastewater

CNF Project Number: 2938-21

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Primary CNF Tools Used: Suss Gamma Resist Cluster, ASML DUV Stepper, Oxford 100 ICP Dielectric, PlasmaTherm Versaline Deep Silicon Etch

Abstract:

Per- and polyfluoroalkyl substances (PFASs) are contaminants of concern to environmental and human health¹. Organofluorine-containing chemicals are widely used in semiconductor manufacturing processes such as lithographic patterning, etching, and stripping, among others²; however, their release from specific fabrication processes are not well understood. While previous work focused on PFASs in wastewater and photolithography materials, putative sources such as plasma etching processes and scrubber blowdown have been underexplored. This study investigated PFAS formation during plasma etching of silicon wafers using various fluorinated etch gases. We performed thirty-five plasma etch experiments and collected aqueous blowdown samples from a plasma-wet scrubber connected to two plasma etch tools. The samples were analyzed for total fluorine (TF), fluoride (F⁻), and 29 target PFASs. The goal of this project was to demonstrate if plasma etching processes are a source of PFASs and other organofluorine compounds in semiconductor fabrication facilities (fabs) emissions.

Summary of Research:

A variety of PFASs and other organofluorine-containing compounds are used during semiconductor manufacturing,² and emissions of PFASs from fabs are of emerging concern. While most previous studies have focused on PFASs in fab wastewater samples or specific materials used during photolithography,^{3,4} other potential PFAS sources, such as plasma etch processes, remain underexplored.

Fluorine inputs to plasma etch processes include both organofluorine-containing materials coated on the wafers (e.g., photoresists) and fluorinated gases. Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), commonly used for silicon wafer etching,

introduce fluorine into the system. The exhaust gas from these processes is treated with wet scrubbers, where PFASs can partition into aqueous scrubber blowdown. We hypothesize that fluorinated gases used in plasma etch processes generate fluorine radicals that react with organic chemicals deposited on the wafer surface to form PFASs, which are then released in the exhaust, potentially a key source of PFASs measured in fab wastewater effluent.

We designed experiments to (1) demonstrate the formation of PFASs during plasma etching and transport to aqueous scrubber blowdown; and (2) identify the specific process conditions influencing PFAS formation. Three key process variables were investigated: (1) wafer coating (bare silicon wafer vs. photoresist-coated silicon wafer), (2) choice of fluorinated etching gas, and (3) plasma etching tool (Figure 1). We coated 4-inch silicon wafers with 500 nm of UVTM 210 Positive DUV photoresist using the Gamma Photoresist Cluster. The ASML DUV Wafer Stepper was used for edge-bead removal.

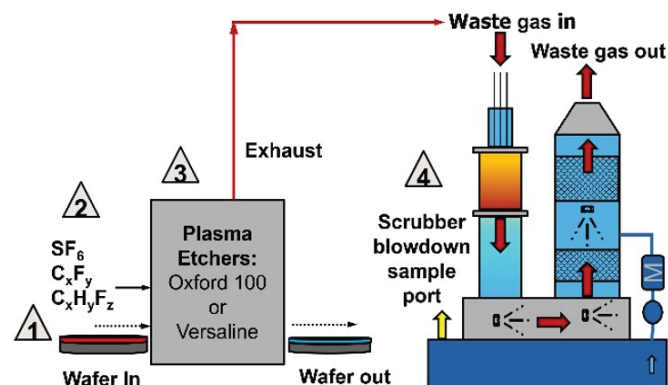


Figure 1: Schematic of the plasma etching and scrubbing process. The resulting exhaust from a plasma etch is routed to a scrubber system. Scrubber blowdown is collected for PFAS analysis.

Etching experiments were conducted for each of the six fluorinated gases studied: CH_2F_2 , CHF_3 , C_4F_8 , C_4F_6 , SF_6 , and $\text{C}_3\text{H}_2\text{F}_4$ (a low global warming potential alternative gas that demonstrated to meet semiconductor manufacturing performance objectives⁵). Each fluorinated gas experiment was conducted on both bare silicon and photoresist-coated wafers using each etching tool: the PlasmaTherm Versaline Deep Silicon Etch, which uses the Bosch process, and the Oxford 100 ICP Dielectric tool. Finally, blowdown samples were collected two hours after the completion of each etching experiment from the GST Durian “plasma-wet” scrubber with its plasma feature deactivated to isolate PFAS contributions of the etching process alone. Additionally, “pre-etch” samples were collected from the scrubber water tank before any etching to account for background PFAS concentrations.

We analyzed the scrubber blowdown and baseline samples for TF, F-, and target PFASs. The pre-etch TF concentrations for the etching experiments conducted in the Oxford tool (n=28) ranged from 0.17 to 3.16 mg/L, and in the Versaline tool (n=7) from 0.13 to 1.17 mg/L. The post-etch TF concentrations ranged from 0.34 to 9.99 mg/L for the Oxford tool and from 0.17 to 18.2 mg/L for the Versaline tool. Figure 2 shows the distribution of TF concentrations in pre-etch and post-etch scrubber water samples. For both etchers, post-etch samples exhibited higher median TF concentrations and greater variability than pre-etch samples. Fluoride concentrations accounted for 25-95% of TF, with an average of 71%. Summed concentrations of target PFASs ranged from <LOQ to 136 $\mu\text{g/L}$ for the pre-etch samples and from 0.01 to 928 $\mu\text{g/L}$ in the post-etching samples. Perfluorocarboxylic acids (PFCAs), a PFAS class of regulatory concern, dominated the target PFAS profiles in all etching-related scrubber samples, comprising over 50% of the total target PFASs, with trifluoroacetic acid (TFA) being the dominant compound in all cases. Target PFASs accounted for 0.1-77% of the total organic fluorine (TOF) in the samples suggesting the presence of additional unidentified organofluorine compounds. These findings highlight the role of plasma etching processes as a source of organofluorine compound in fab emissions.

Conclusions and Future Steps:

We conclude that (1) plasma etching processes generate fluorinated compounds that are captured in scrubber blowdown water, as demonstrated by elevated TF, F- and PFAS concentrations in post-etch samples; and (2) observed variability in TF, F-, and PFAS concentrations suggests that process conditions influence organofluorine emissions. Future steps will focus on: (1) increasing the number of replicates for each experimental condition to improve statistical power and better characterize experimental variability; (2) performing statistical analyses to identify patterns in the data and determine which process variables best explain the variability; and (3) conducting additional etching experiments while including more low global warming potential etching gases and different photoresist formulations to further evaluate their influence on organofluorine emissions.

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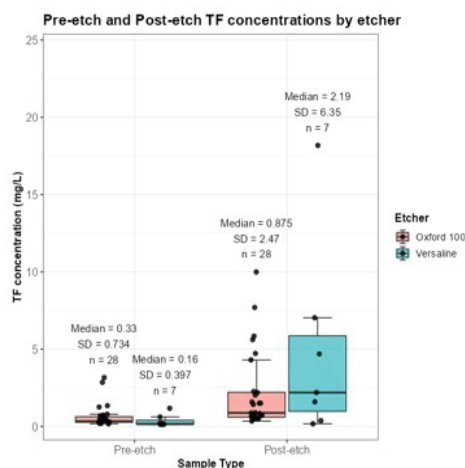


Figure 2: Boxplots showing TF concentrations in pre-etch and post-etch scrubber blowdown samples collected from the Oxford and Versaline etching systems.

New High Resolution Resists for EUV Lithography

CNF Project Number: 3137-23

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Primary CNF Tools Used: ASML PAS 5500/300C DUV Wafer Stepper, JEOL 6300 E-Beam Lithography, P10

Abstract:

Extreme ultraviolet lithography (EUV) lithography is a very important technology for achieving the patterning goals of advanced lithography nodes with sub-15 nm feature sizes. Conventional chemically amplified photoresists (CARs) used in photolithography typically employ ionic photoacid generators (PAGs) which form superacids after exposure to light. In contrast, next generation double amplification resists (DARs) based on poly(4-bromophthalaldehyde) (PPA), employ non-ionic PAGs. In this report, the performance of developed trimellitic imide (TMI) non-ionic PAGs were evaluated using polymers prepared for CAR and DAR resist systems and their patterning performance was investigated using DUV (KrF) exposure and characterized by AFM and SEM microscopy. Comparative results indicate that the DARs displayed higher contrast and faster photospeed compared to the CARs. These findings highlight the potential of TMI PAGs for next generation PPA based DAR systems.

Summary of Research:

The continuous development by the semiconductor industry towards next generation nodes have raised the requirements of photoresist materials that can achieve resolution below the 20 nm scale with high photospeed below 20 mJ cm⁻².¹ Conventional chemically amplified resists (CARs) mostly utilize ionic PAGs which have high sensitivity and acid generation efficiency.²⁻³ However, self-immolative double amplification resists (DARs) have emerged as an attractive resist system due to their unique acid catalyzed amplification mechanism. Like CAR systems, DARs contain acid sensitive organic polymer poly(4-bromophthalaldehyde) (PPA) and PAG which generate protons after light exposure.

The generated proton catalyzes depolymerization of PPA into low molecular weight 4-bromophthalaldehyde monomer, which is readily soluble in organic solvents as shown in Figure 1.⁴⁻⁵

This rapid unzipping depolymerization mechanism of polymer to monomer requires catalytic amounts of acid, resulting in high sensitivity of DARs compared to CAR systems.⁶ Apart from these advantages, the higher sensitivity of DARs requires optimization of acid strength of PAGs to achieve balanced lithographic performance. In this case, non-ionic PAGs provide promising pathways for optimization, as their acid generation efficiency and acidity can be tailored by modifying molecular

structure. In this study, a series of TMI-based non-ionic PAGs were designed and synthesized. Further, these TMI PAGs were incorporated into CAR and DAR systems, and their lithographic performance such as sensitivity and patterning capability was systematically studied.

Result and discussion:

To evaluate the lithographic performance of CAR and DAR systems, polymer matrices and TMI PAGs with different substituents (as shown in Figure 2(a) and (b)) were formulated separately as CAR (1-5) and DAR (1-5). DAR formulation was prepared using cyclohexanone as a solvent whereas CARs employed a 50:50 PGME/PGMEA mixture. The resist thin film was prepared by spin-coating onto 4-inch silicon wafers to achieve a final film thickness of 50-70 nm. The coated films were soft baked on a hot plate at 70°C for 60 s (DARs) or 110°C for 60 s (CAR-5), followed by exposure using a 248 nm ASML stepper. After exposure, the wafers baked at 90°C (DARs) or 115°C (CAR-5) for 60 s. Further development was carried out using the isopropanol (DARs) or 2.38 wt% aqueous tetramethylammonium

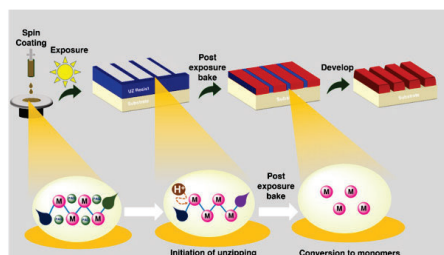


Figure 1: Lithographic process and depolymerization mechanism of PPA resist.

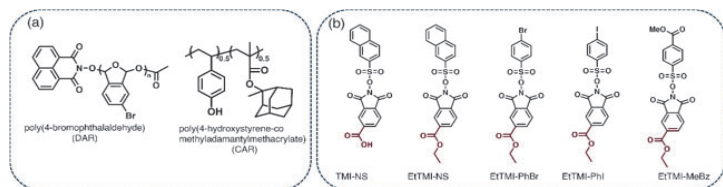


Figure 2: (a) Polymer matrices, (b) TMI PAGs used in this study.

hydroxide (TMAH) solution (CAR) and resulting film thicknesses were measured using ellipsometer.

The KrF contrast curves of the CAR formulations (Figure 3a) showed poor contrast for CAR-1 and CAR-2 whereas for CAR-3 to CAR-5 still required relatively higher dose-to-clear values. The poor contrast and reduced sensitivity are likely due to limited miscibility and weaker acid strength of TMI PAGs in CAR system. In contrast DAR formulations (Figure 3b) showed significantly higher sensitivity and faster photospeeds, particularly DAR-4 and 5.

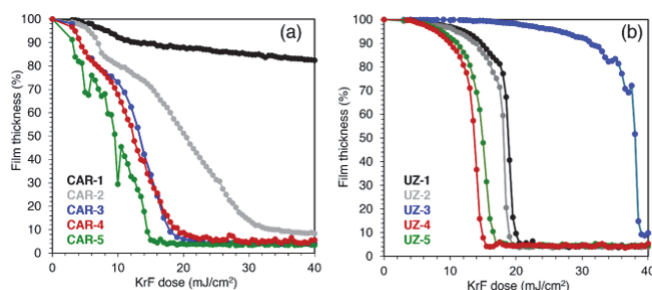


Figure 3: DUV contrast curves of (a) CAR (1-5), (b) DAR (1-5) formulations. Adopted from Ref.⁶.

As shown in Figure 4, the DAR systems exhibited different responses at an exposure dose of 25 mJ cm⁻², clearly demonstrating that the photospeed and acid strength of TMI PAGs can be tuned by modifying their substituents. DAR-3, which contained the least sensitive PAG, exhibited poor pattern formation under the same conditions. Even though TMI PAGs generally displayed low contrast with CARs, CAR-5 formulation successfully produced lithographic patterns, highlighting the versatility of TMI PAGs even in non-compatible systems. These obtained results are consistent with theoretical predictions of acid strength associated with different TMI substituent groups. By systematically changing the TMI substituents, we have successfully tuned photospeed of DARs, demonstrating clear structure-property relationship between PAG design and lithographic performance.

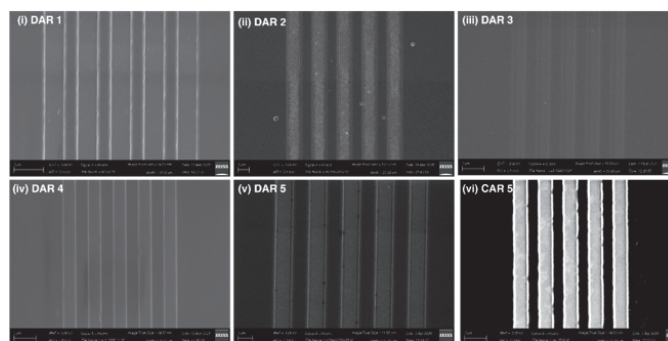


Figure 4: SEM images of (i-v) DAR (1-5) resist; (vi) CAR-5 resist using DUV lithography at exposure dose 25 mJ cm⁻². Adopted from Ref.⁶

Conclusions and Future Steps:

As a part of this work, we have developed series of TMI PAGs and investigated their sensitivity and patterning performance with both CAR and DAR systems. Based on theoretical and experimental results, iodine (EtTMI-PhI) and electron withdrawing (EtTMI-MeBz) based TMI PAGs are promising candidates in DAR resist system. Current efforts are directed toward PAG chain end initiators and PAG functionalized monomers to develop a single component PPA resist platform for next generation EUV lithography.

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Effects of Confinement on Crystallization of Molecular Glasses

CNF Project Number: 3287-25

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Primary CNF Tools Used: Woollam Ellipsometer

Abstract:

Investigations were conducted comparing indomethacin crystal growth rates in bulk films and nanocomposites as a function of temperature. It was found that nanoconfinement slowed the crystal growth rates, but these effects were diminished as temperature increased above the glass transition temperature. Ellipsometry was used to characterize the films, but this characterization faced challenges.

Summary of Research:

There is growing interest in applications of small molecular amorphous solids, which necessitates improving the stability of such systems against crystallization. Nanoconfinement has been promising in this regard^{1–4}. As far we are aware, literature has been limited to studies of crystallization occurring below the glass transition temperature, where many molecules exhibit “diffusionless” growth, characterized by growth faster than would be predicted by diffusion⁵. Above the glass transition, by contrast, crystal growth rates are limited by diffusion.

In this investigation, the well-studied pharmaceutical glass-former indomethacin (glass transition temperature, $T_g=42^\circ\text{C}$) was confined in nanoparticle composites via a method known as Capillary Rise Infiltration (CaRI) by first spin coating a silica nanoparticle (10-nm or 100-nm) film onto a substrate and then spin coating indomethacin on top of the nanoparticle film^{6,7}. For comparison, indomethacin was also coated directly onto the bare substrate. All films were then annealed allowing for infiltration into the nanoparticle films. Films were then monitored for crystal growth by polarized light microscopy during storage at 25°C , 50°C , 75°C .

Figure 1 shows images under polarized light of typical crystals seen on each type of sample when stored at room temperature, which could be measured over time to give crystal growth rates. Growth was linear over several data points. Figure 2 shows $\log(\text{growth rate})$ as

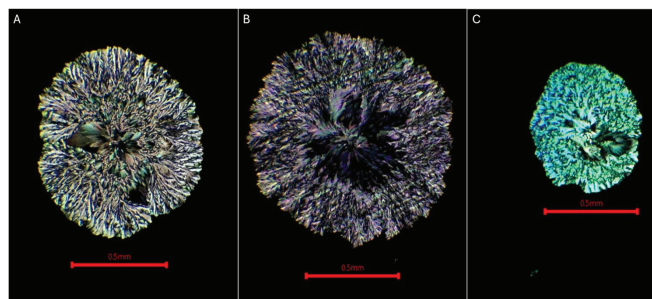


Figure 1: Indomethacin crystals under polarized light grown after storage under ambient temperature in a desiccator on bulk film (A), 100-nm nanoparticle nanocomposite (B), and 10-nm nanoparticle nanocomposite (C).

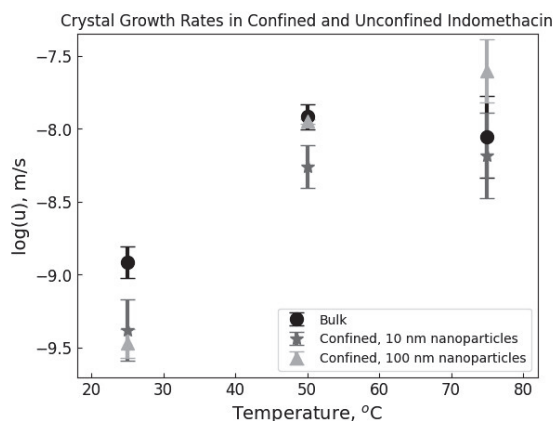


Figure 2: Log of growth rate (m/s) versus temperature ($^\circ\text{C}$) for crystal growth in indomethacin bulk films and films confined to 10-nm and 100-nm nanocomposite films. Error bars represent standard deviations of at least five repeat measurements per data point.

a function of temperature for each of the three sample types (unconfined, confined in 100-nm nanoparticle film, and confined in 10-nm nanoparticle film). At low temperatures, the data shows the expected result of a decreased growth rate as a result of confinement, but this effect is eliminated as the temperature is increased.

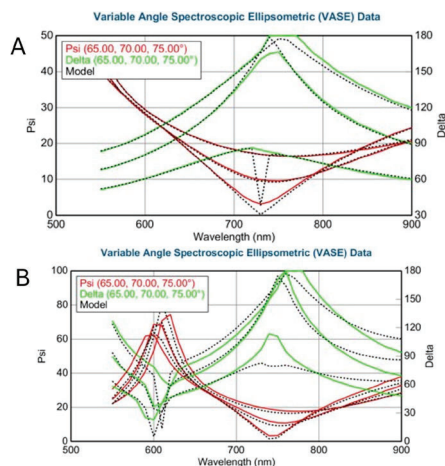


Figure 3: Psi and Delta data for variable angle data showing experimental data and Cauchy model fits for bulk indomethacin film (A) and annealed nanocomposite of indomethacin infiltrated into 10-nm nanoparticles. While figure A shows a unique fit, B shows one of many results that is relatively well-fit to data by varying the fit parameters of interest.

Figure 3 shows the data collected with the Cornell NanoScale Science and Technology Facility Woollam Variable Angle Ellipsometer. These were modeled using CompleteEase software and a Cauchy model. Unfortunately, as the samples became more complicated by the addition of more layers the addition of fit parameters (Cauchy A, B, and thickness for indomethacin, nanoparticle, and mixed layers) sufficiently complicated the analysis so that a unique fitting difficult to find. Figure 3 does show a fitting consistent with successful infiltration of indomethacin into the nanoparticle packing, modelling bulk indomethacin (3A) to a very low mean squared error (MSE) with unique fitted parameters and the confined sample (3B) with the same Cauchy A and B for indomethacin, where a relatively good fitting is achieved when the thickness for the indomethacin layer is close to zero and most of the thickness is in the mixed indomethacin/nanoparticle layer, but other fits do an equally good job (as measured by MSE). Efforts to overcome this challenge included analysis of samples of nanoparticle layers alone, indomethacin layers alone, and nanocomposites prior to the annealing step in order to better determine parameter values. Careful analysis of further samples may improve the analysis, including repeating the nanoparticle only samples but annealing these (which was not done previously), or a model other than Cauchy may be more appropriate to fit these samples. Given the experimental difference between samples it seems likely that the method was successful in confining the indomethacin, but it remains essential to appropriately characterize this confinement using a tool like ellipsometry, so this work will continue.

Conclusions and Future Steps:

This study revealed that, in indomethacin, confinement in nanoparticle composites does slow crystallization growth as expected, but in a manner dependent on temperature, suggesting a possible dependence on crystallization mode. Characterization of the films using ellipsometry was challenging due to the number of fit parameters involved, but a number of potential next steps to improve fitting are identified.

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iCVD Polymer Microparticle Synthesis Inside a New Liquid Crystal

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Abstract:

Liquid crystals (LCs) can be used as templates to influence polymer morphology during initiated chemical vapor deposition (iCVD). In this study, the liquid crystal TL205 was investigated as a new templating material and compared with the commonly used liquid crystal E7. Polymer was deposited using iCVD under varying deposition parameters, and the resulting morphologies were characterized to determine how polymer growth differed between the two LC templates. Differences in morphology were observed as a function of deposition conditions and LC template, demonstrating that the choice of liquid crystal can influence the resulting polymer structure. To investigate a potential explanation for these differences, the solubility of the monomer in TL205 and E7 was evaluated. The solubility results provide an indication that differences in monomer-LC interactions may contribute to the observed morphological behavior. However, more characterization and experiments are needed to fully determine what is responsible for the differences between TL205 and E7 polymer morphologies.

Summary of Research:

Liquid crystals are materials that have properties of both liquids and crystalline solids. Although they are able to flow like a liquid, their molecules maintain a degree of orientational order. This combination of fluidity and molecular organization makes liquid crystals useful as environments for controlling polymer growth. The molecular organization and chemical properties of a liquid crystal can influence how a polymer forms inside of it. Factors such as monomer solubility,

molecular interactions, and viscosity can affect polymer nucleation, growth, particle size, and morphology. Therefore, changing the liquid crystal could result in changes to resulting polymer particle size, morphology, etc. [1] [2]

Initiated Chemical Vapor Deposition (iCVD) is a solvent-free technique that can be used to synthesize polymers into the liquid crystal. During iCVD, a monomer, divinylbenzene (DVB) and initiator, tert-butyl peroxide (TBPO), are introduced into the chamber, where a heated filament breaks the initiator, into free radicals that initiate polymerization. Because process parameters such as filament temperature, chamber pressure, flow rates, and deposition time can be controlled independently, iCVD provides a useful method for investigating how different process parameters affect polymer formation. [1] The iCVD reactor setup is shown in figure 1.

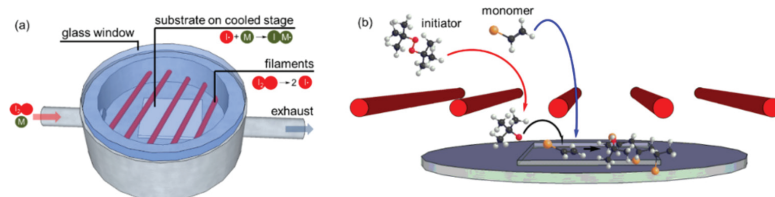


Figure 1: iCVD Reactor Setup.

In this study, a novel and fluorinated liquid crystal, TL205 (TNI=87-90°C), was investigated as a template for polymer growth, and compared to a standard and well investigated liquid crystal, E7 (TNI=60-63). The goal was to determine how the choice of liquid crystal affects the resulting polymer formations. Experiments using a variety of iCVD parameters revealed a difference in

polymer particle size and morphology between the two liquid crystal templates. After establishing that these findings were consistent among a wide range of process parameters, further experiments were conducted to find the reason for these differences. A solubility test was done to determine if the reason for the different polymer particle sizes and morphologies is due to a difference in concentration of monomer in the different liquid crystals. This study provides insight into how different liquid crystals behave as a template for polymer growth during iCVD.

Experiments were completed with varying filament temperature, initiator/monomer flow rate ratio, and deposition time. In one experiment that gave particularly clear results, the filament was heated to $\approx 300^{\circ}\text{C}$, a high initiator/monomer ratio of 0.7 was used, and a featured deposition time of 120 minutes. In figure 2, the resulting polymer formation when an E7 template was used can be seen. The polymer particles, which are roughly $1.7\text{ }\mu\text{m}$ in diameter, are arranged in an energetically favorable hexagonal array. Qualitatively, the array is ordered, and particles are roughly uniform in size. In figure 3, the resulting polymer formation when a TL205 template was used can be seen. In contrast to when E7 was used, the polymer morphology contains a mixture of hexagonally ordered particles, stray particles, and large clusters of aggregated polymer. The particles were found to be notably smaller, with an average particle size of $\approx 1.3\text{ }\mu\text{m}$. All quantitative analysis of particles was performed using ImageJ/Fiji, and the “Analyze Particle” Function.

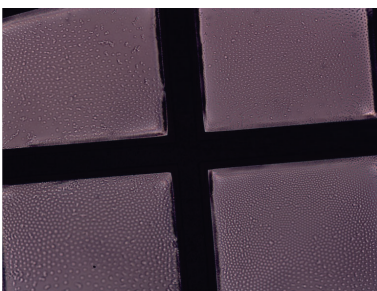


Figure 2: Resulting polymer formation when E7 was used as a template for polymer growth. Neat hexagonal array of polymer particles.

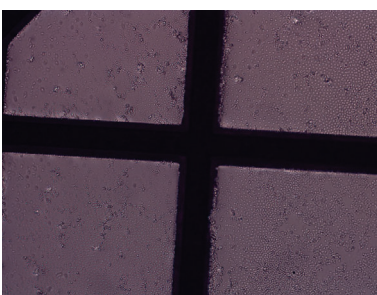


Figure 3: Resulting polymer formation when TL205 was used as a template for polymer growth. Less ordered array of polymer particles. Polymer clusters can also be seen.

is consistent across many varying parameters, the cause for these differences was investigated. Given the fluorinated nature of TL205, it was hypothesized that the monomer, DVB, is less compatible with the TL205 than E7 and there is likely a lower concentration of DVB in TL205 than E7, which would result in smaller particles in TL205 as well as decreased order. This was tested through a two-part solubility test that relies in Henry’s Law, meaning that the pressure of monomer above the liquid crystal is directly proportional to the concentration

of monomer inside the liquid crystal. The conclusion of this study revealed that contrary to the hypothesis, there is a higher concentration of DVB in TL205 than E7. Given the specific parameters of the depositions used in this study, the concentration of DVB in TL205 is 0.429 M, while the concentration is only 0.301 M in E7. While monomer solubility certainly affects polymer formations, more testing needs to be done to determine the cause for the decreased particle size and disorder that is seen when TL205 is used as a template for growth.

Conclusions and Future Steps:

When TL205 is used as a template for polymer growth, smaller polymer particles are formed, and formations are generally more clustered and chaotic than when E7 is used as a template for polymer growth. The reason for this is not due to increased monomer solubility in E7 compared to TL205 as we hypothesized, and more testing of LCs needs to be done to determine the reason for the differences in polymer morphology.

Concentrations with my deposition conditions	E7	TL205
Concentration of DVB in LC	0.301 M	0.429 M

Figure 4: Results of solubility test.

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