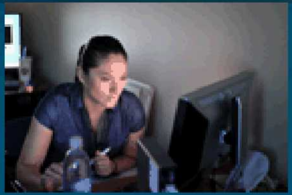
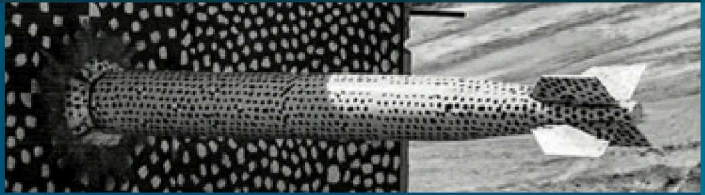
SAND2018-8901C

Methods of Depositing Anti-reflective Coatings for Additively Manufactured Optics





PRESENTED BY

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Outline

- Motivation
- Technical Background
- Selected Materials
- Experimental Procedure
- Film Characterization
- Future Work
- Conclusion

Motivation

- Complex micro-optic systems offer many opportunities for advanced sensing and communications
- Reflections generated at interfaces increase signal loss and feedback
- Anti-reflective coatings (ARCs) are implemented to reduce reflection and improve system function
- Traditional ARCs are typically deposited via atomic layer deposition
  - Non-selective process, exposes entire system to coating material
- Goal: Develop an additive method to selectively deposit anti-reflective coating

Technical Background – ARC Design

- Thin films produce destructive interference of reflected rays of light
- Film parameters for best anti-reflection properties given by:

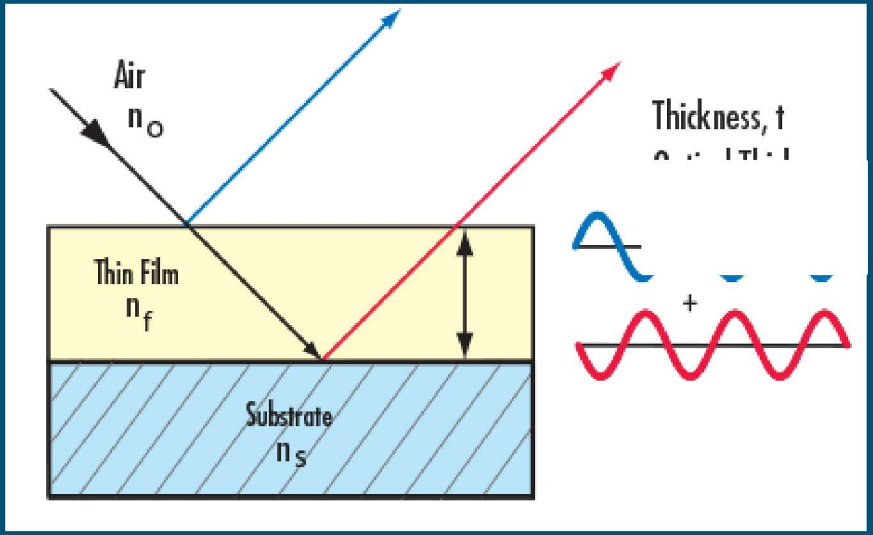
$$n_f = \sqrt{n_o * n_s}$$

$$d_f = \frac{k * \lambda}{4 * n_f}$$

  - This study focused on a wavelength of 850 nm

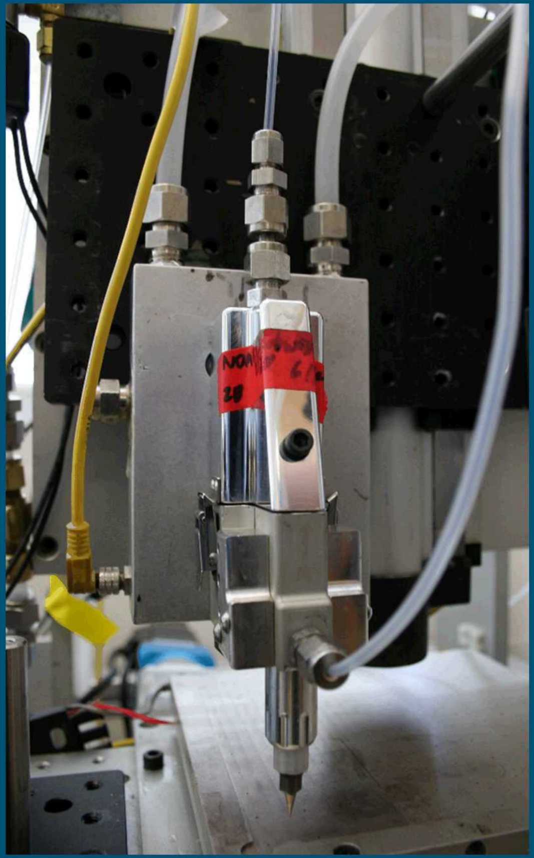
n_f-Refractive index (RI) of film
n_s-RI of substrate
n_0-RI of environment

d_f-Film thickness
λ-Wavelength
k-Odd integer (1,3,5,…)

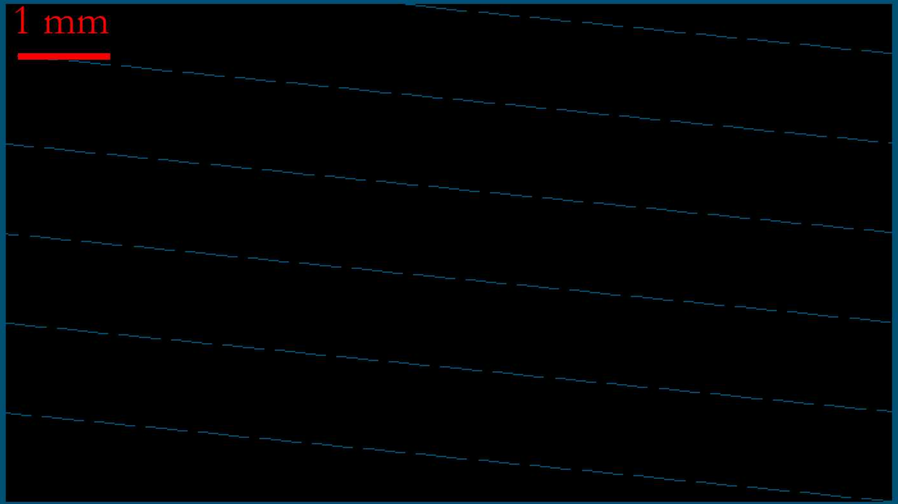


https://www.edmundoptics.com/resources/application-notes/optics/anti-reflection-coatings/

Technical Background – NanoJet Deposition Tool



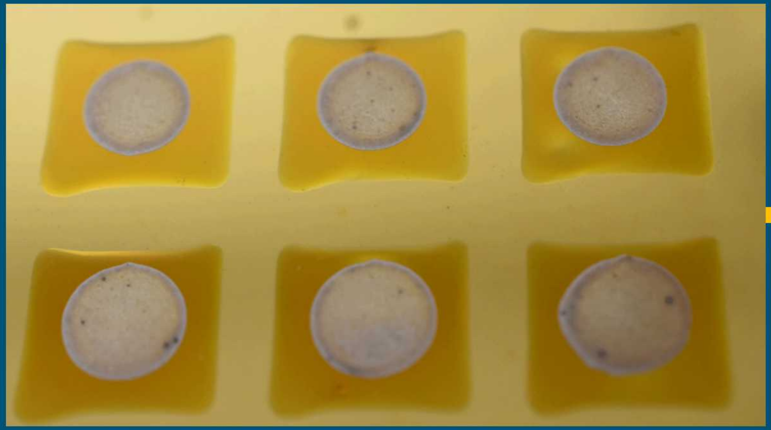
- Aerodynamic focusing of aerosolized materials
  - Conductive nanoparticle inks
  - Dielectric polymers
  - Low viscosity solutions
- Low profile, well focused traces
  - Trace width from 50 to 300 µm
  - Single layer height < 1 µm
- Parameters
  - Aerosol flowrate
  - Sheath gas flowrate
  - Atomizer voltage
  - Focusing tip diameter
  - Focusing tip height



Distribution circuit printed using silver nanoparticle ink

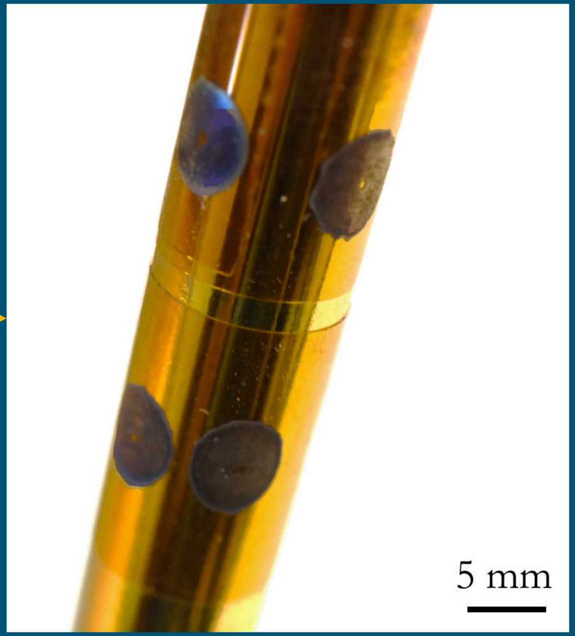
Technical Background – NanoJet Deposition Tool (cont.)

- Tool has been utilized to produce micron-scale electronics
- Capability to produce conformal components and coatings
  - Capacitor printed on perimeter of cylindrical rod
  - Enables selective deposition of materials onto complex, novel structures



5 mm

Planer capacitor of printed Ag pad, polyimide dielectric, and Au wafer substrate



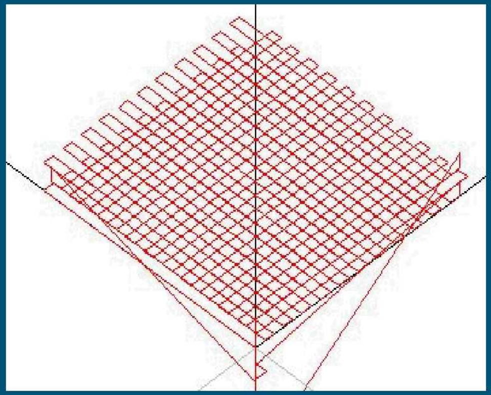
Cylindrical capacitor of printed Ag pad, Kapton dielectric, and Au coated cylindrical substrate

Selected Materials

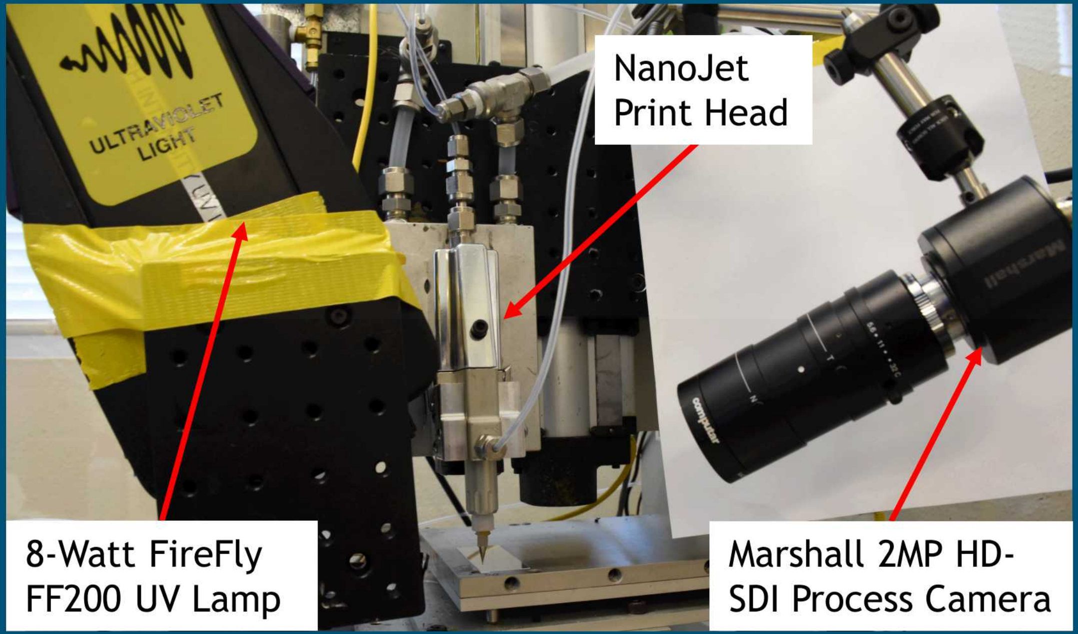
- Norland Optical Adhesive 89 (NOA 89) utilized as primary film material
  - UV curable material
  - Well established refractive index – 1.51
  - Low viscosity (15-20 cP)
  - Highly transmissive of wavelengths >~450 nm
- Isobutyl acetate used as diluting agent
  - Volatile and non-toxic solvent
  - Believed to completely evaporate from solution during atomization or shortly after deposition onto heated substrate
- NOA 89 was diluted with isobutyl acetate to both lower viscosity in order to promote atomization and to decrease deposition rate to deposit thinner films
- Two solutions of these chemicals, mixed at different ratios were tested:
  - 1:14 NOA 89:Isobutyl acetate
  - 1:20 NOA 89:Isobutyl acetate

Experiment Procedure – Deposition Protocol

- Cross-hatched tool path, alternating axis of motion between layers
- UV curing during deposition and between layers to achieve precure of deposited material
- Platen heated to 60°C to drive off solvent
- 335µm tip diameter held at 2.5mm above substrate
- Materials deposited onto Si wafer substrate
- Films deposited as 5mm x 5mm test geometries



Tool path of 5mm x 5mm sample film



NanoJet deposition system

Experiment Procedure – Deposition Protocol (cont.)

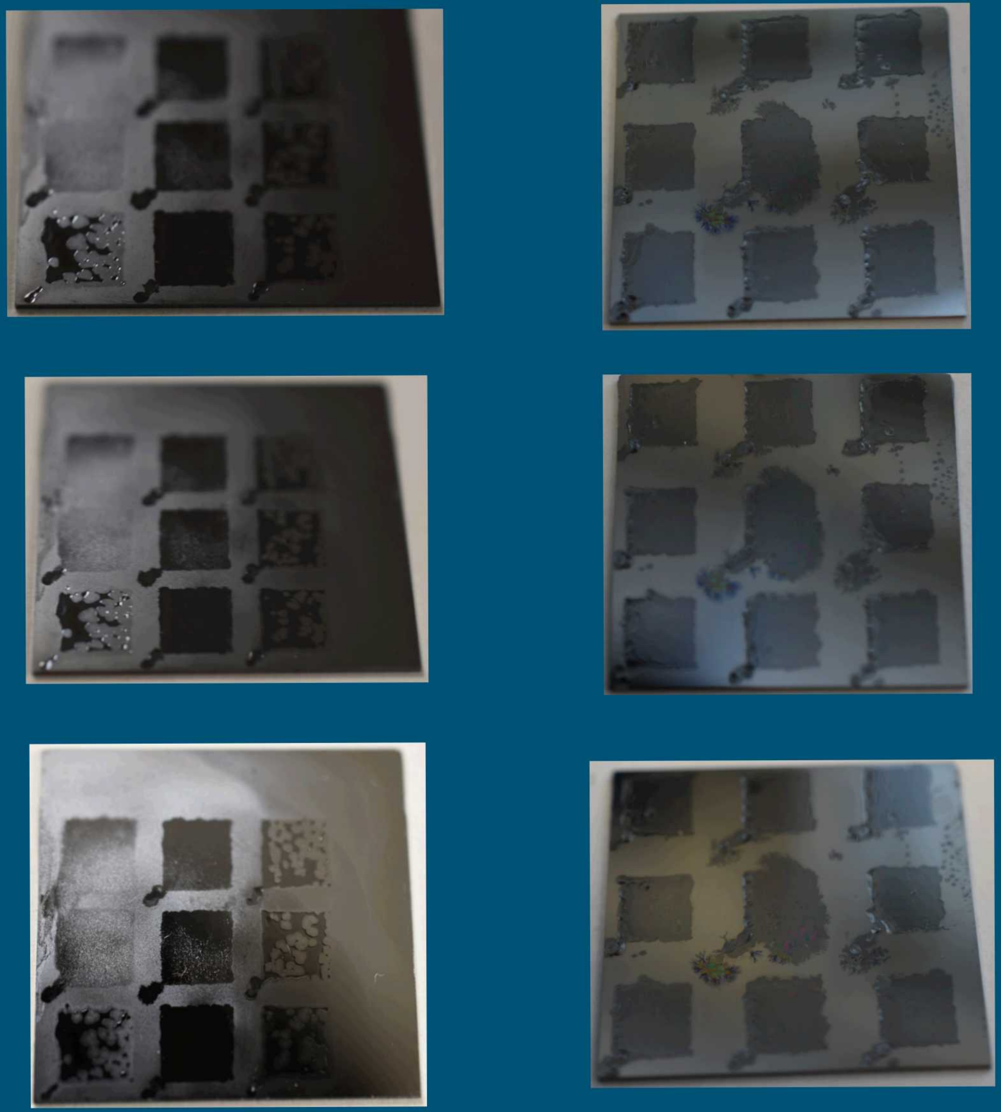
- Deposition parameters varied depending on concentration of material being deposited

NOA 89:Isobutyl Acetate Concentration	1:14	1:20
Print Speed (mm/min)	220	180
Infill Spacing (mm)	0.140	0.200
Aerosol Flow Rate (sccm)	14.0	12.0
Sheath Flow Rate (sccm)	11.0	10.0
Atomizer Voltage (V)	41.5	45.0
Substrate Temperature (℃)	60	60
UV Lamp Output (% output)	10	30
Time Delay Between Layers (sec)	180	180

Experiment Procedure – Sample Processing

- Three step curing process
  1. Thermal stepping process
     - 60°C - 10 minutes
     - 80°C - 15 minutes
     - 100°C - 10 minutes
     - 120°C - 20 minutes
  2. UV curing
     - 500W, 400nm, ~63mW/cm^2 - 30 minutes
  3. Thermal curing
     - 120°C - 30 minutes

1:14 | 1:20



Prior to Curing

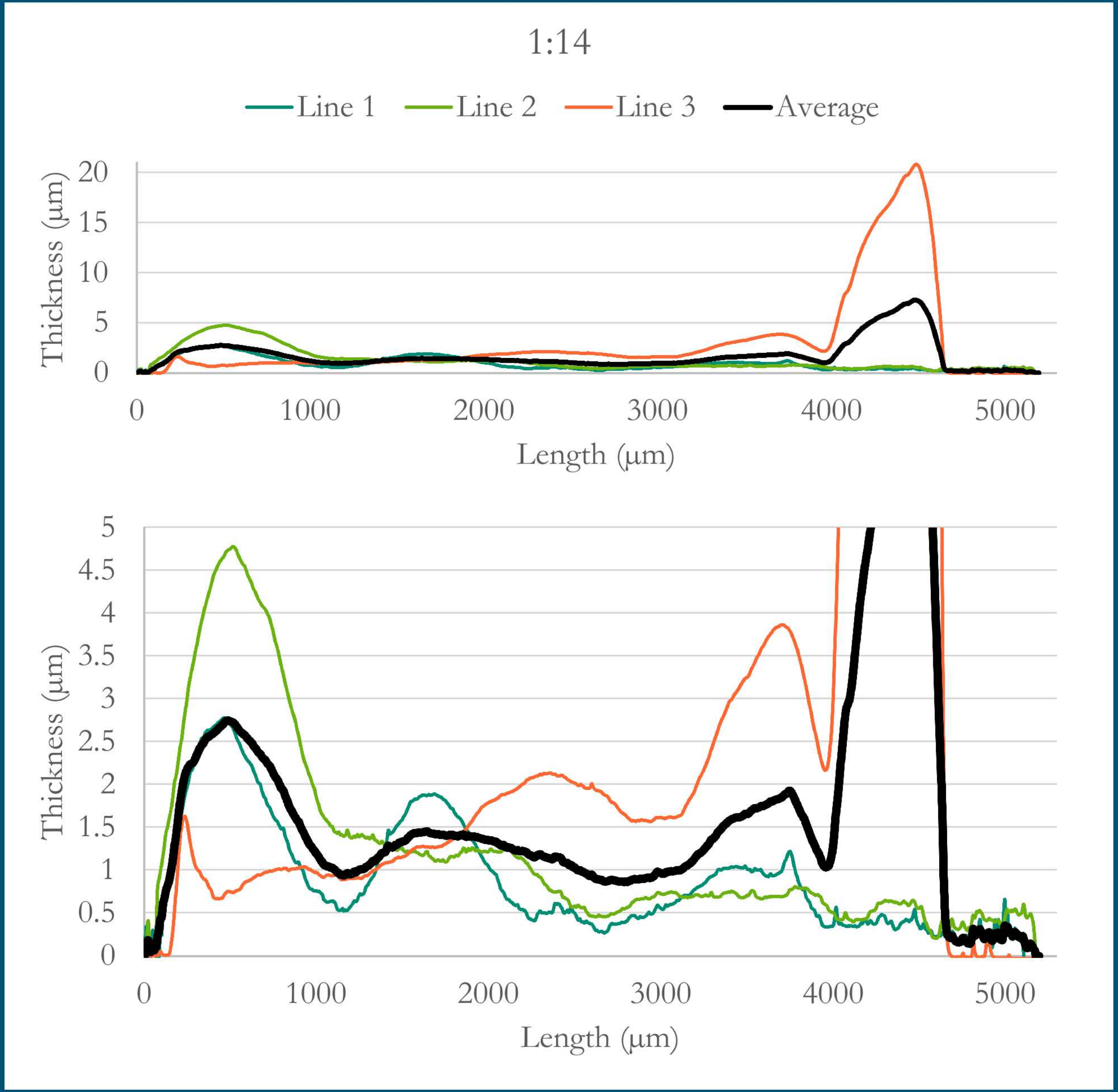
Following Thermal 1 and UV

Final Cured Sample

5 mm

Film Performance – Thickness and Surface Uniformity

- Profilometry performed on cured samples
- Both material concentrations exhibited nonuniform film thickness
  - Both featured at least one peak across the film, likely due to fluid migration during print
- 1:14 concentration demonstrated a thickness on the order of 1 µm, going as low as ~500 nm
- 1:20 concentration demonstrated severe slope across film, with thickness between 1 and 2 µm
- Surfaces likely too uneven to reliably serve as optical coatings as is



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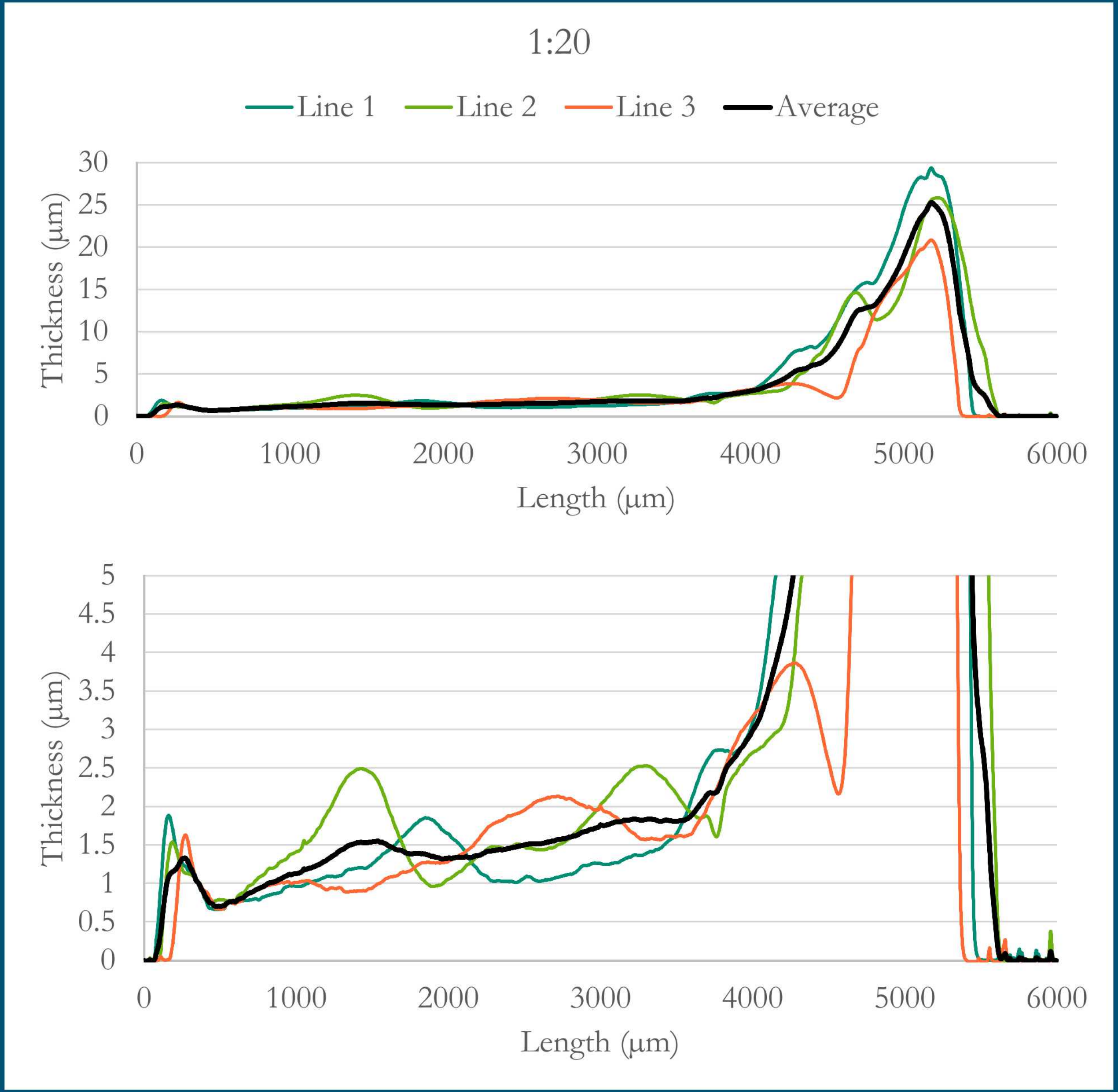
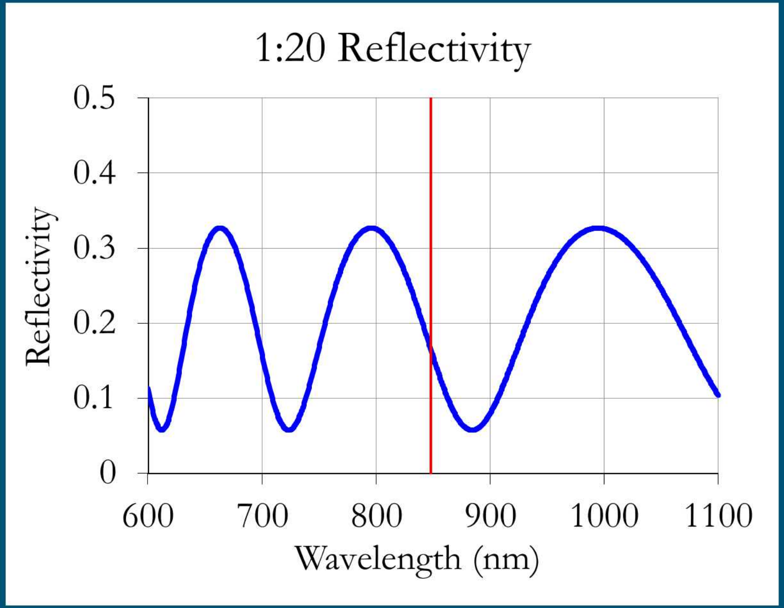
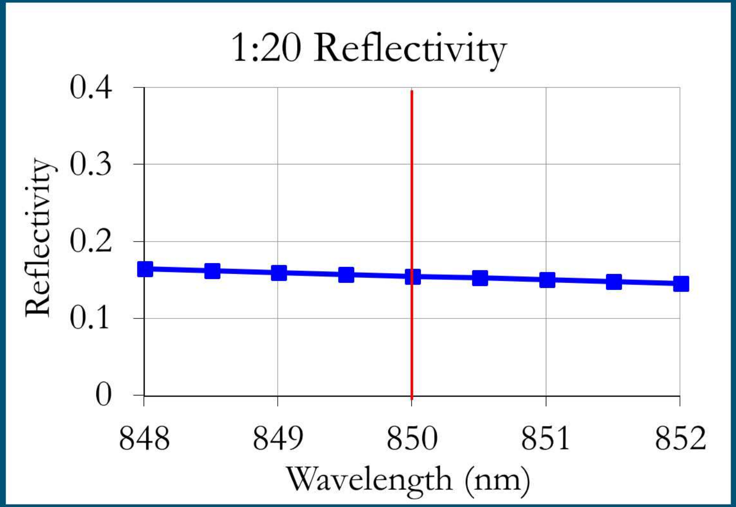


Film Performance – Reflectivity and Optical Thickness

- 1:14 samples too nonuniform to produce reliable data
- 1:20 sample was tested to measure reflectivity
  - ~20% reflectivity at 850 nm operational wavelength
  - ~7% reflectivity at ~875 nm
- Optical thickness (RI*thickness) measured to be 1989 nm
  - RI of film estimated to be slightly less than that of bulk NOA 89 (1.51 → 1.50)
  - Thickness of film calculated to be 1326 nm, roughly matching profilometry





Future Work

- Identify methods of improving surface uniformity
  - Changes in material composition
  - Changes in deposition procedure
- Evaluate methods of improving in-situ curing to prevent material flows during deposition
- Experiment with producing films of different thicknesses for operation at different wavelengths
- Identify alternative materials for film composition
  - Easily tunable refractive index via altering mixing ratios
- Explore feasibility of producing waveguides using current material set

Conclusion

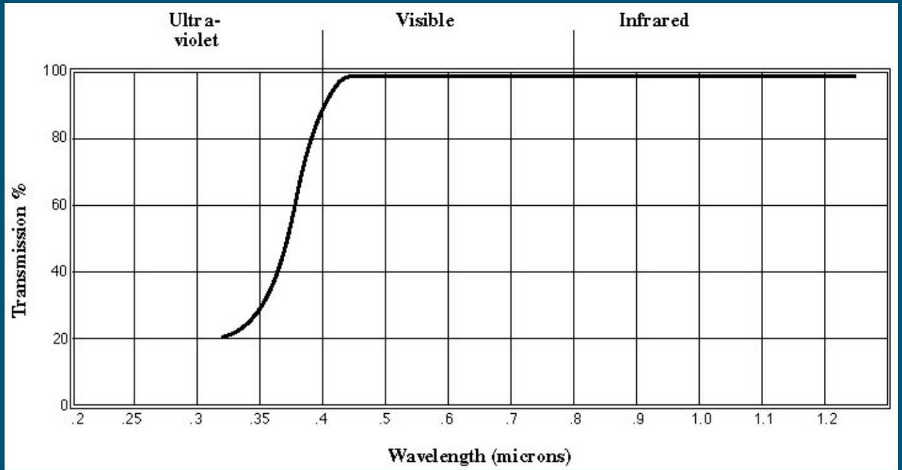
- Demonstrated aerosol jet printing of optical thin films using commercial materials
- Established a multi-stage curing process to simultaneously drive off solvents and harden remaining film material
- Films produced using 1:20 dilution capable of reducing reflectivity to ~20%, could be decreased to <10% if thickness is properly adjusted
- Ongoing work to print optical coatings using additive manufacturing methods

Questions?

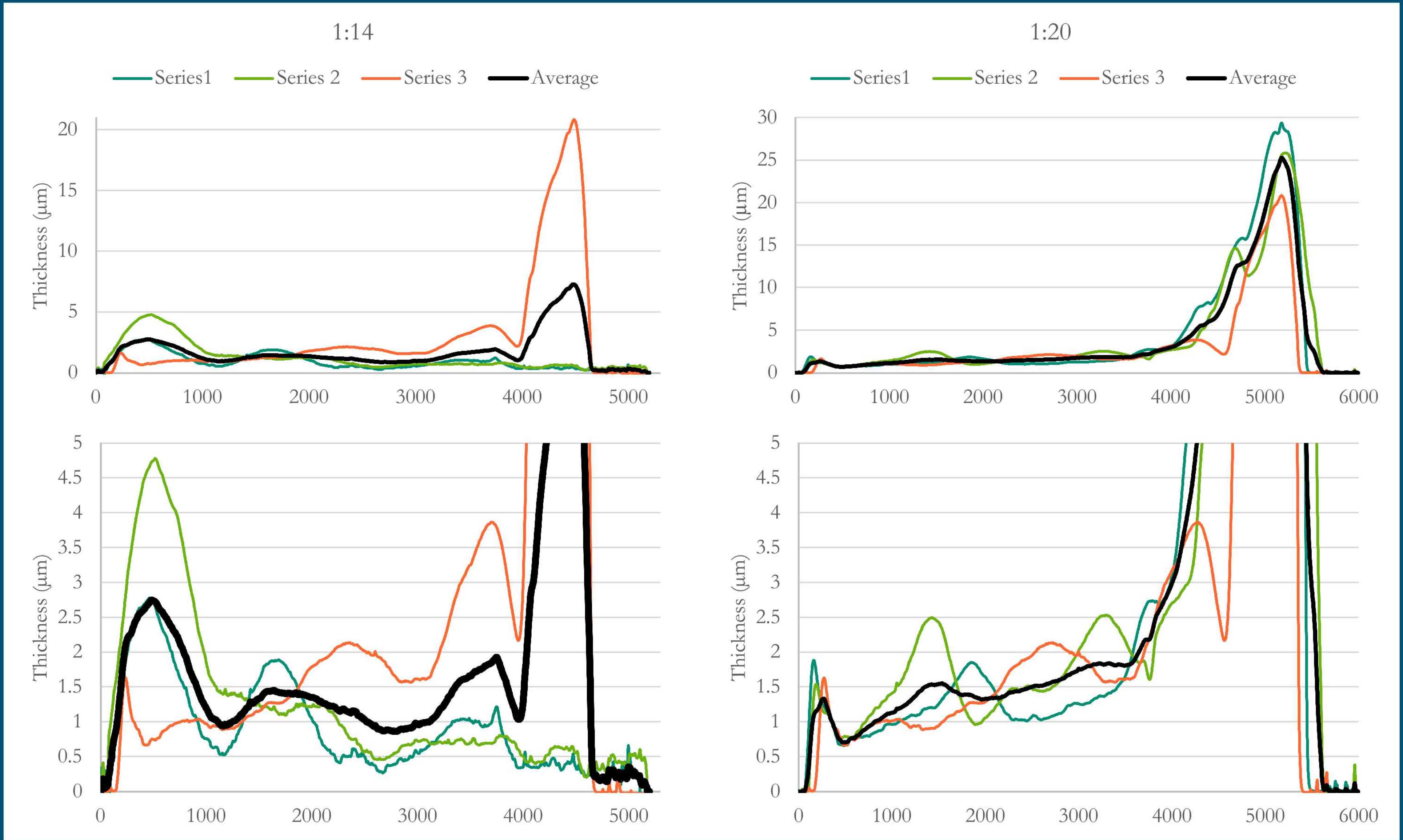
NOA 89 Pocket Slide

- Reflective Index: 1.51
- Temperature Range: -30℃ to 80℃
- Viscosity: 15-20 cps
- Modulus (psi): 4300
- Tensile Strength (psi): 194.5

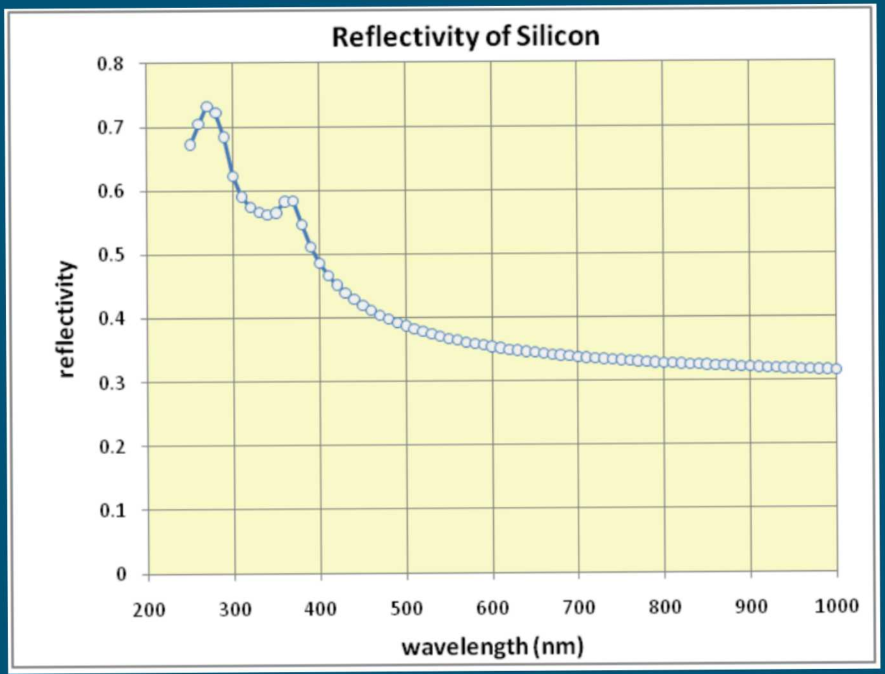
- Manufacture Recommended Curing Procedure (310-395nm):
  - Precure: 15 seconds under 100 W mercury lamp
  - Final Cure: 5-10 minutes under 100 W mercury lamp



Film Performance – Thickness and Surface Uniformity



Film Performance – Reflectivity and Optical Thickness



https://www.pveducation.org/pvcdrom/materials/optical-properties-of-silicon