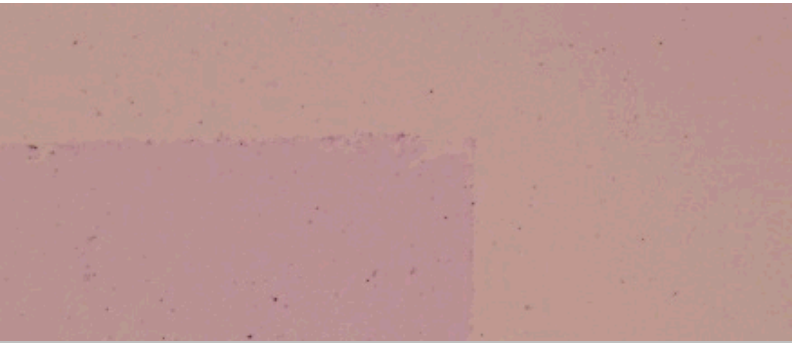
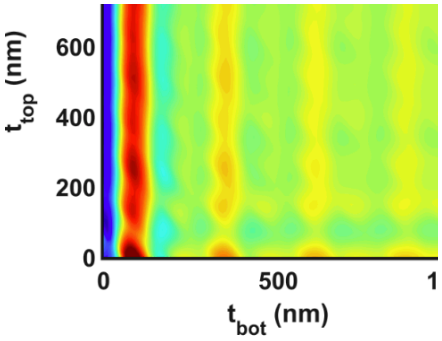
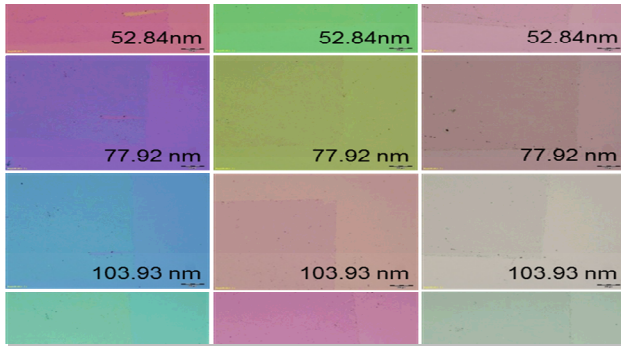
SAND2017-6845C






# Passivation of Graphene Films and Their Visibility

Isaac Ruiz, Michael D. Goldflam, Thomas E. Beechem, Anthony McDonald, Bruce L. Draper, Stephen W. Howell

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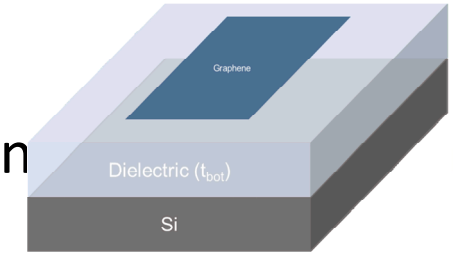
# Motivation to See the Graphene

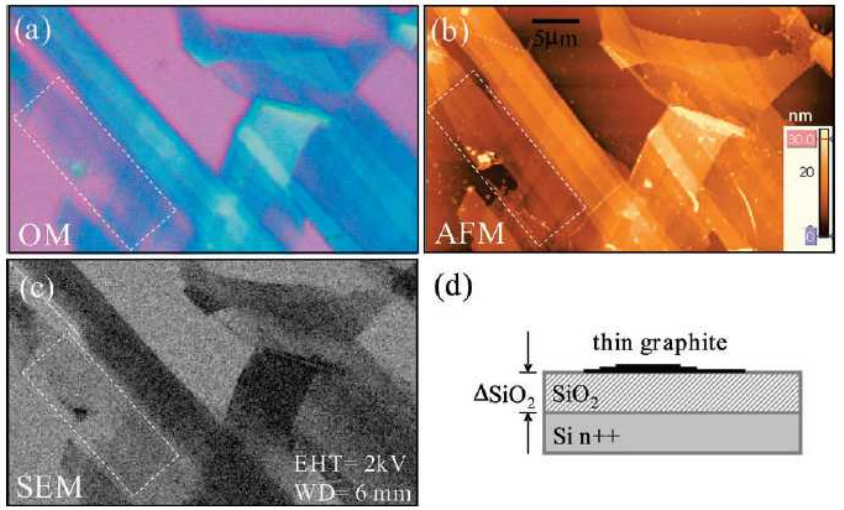
2D Materials are hard to see

Initial small flakes:
- Characterization
- Device Fabrication
- Layer Identification

Currently Large films:
- Morphology
- Uniformity
- Characterization




A lot of preliminary work on **unpassivated** graphene layers

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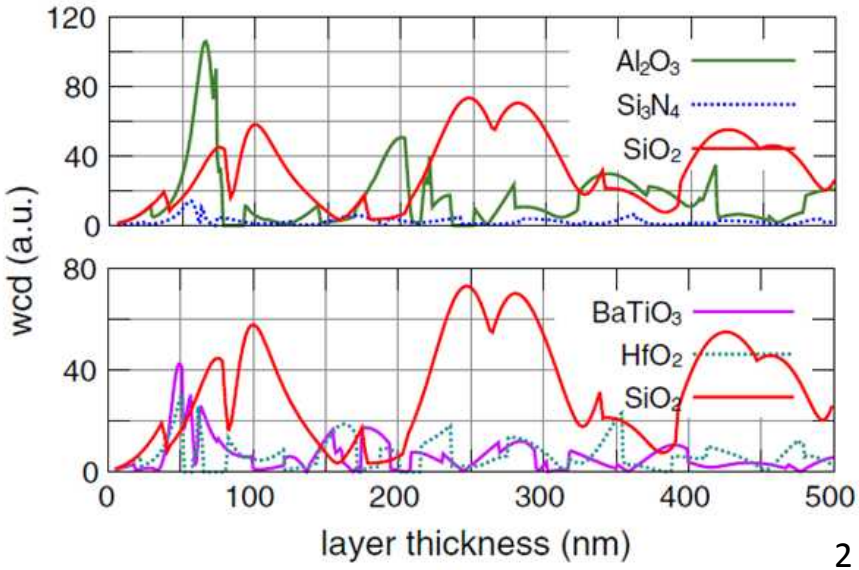
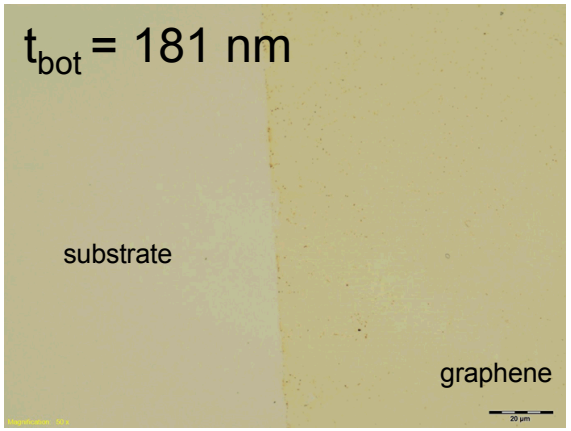
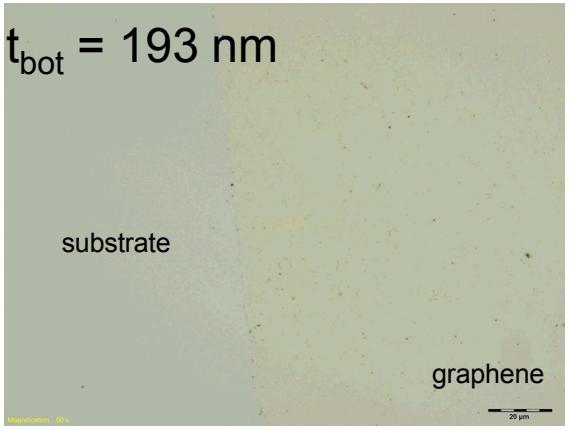
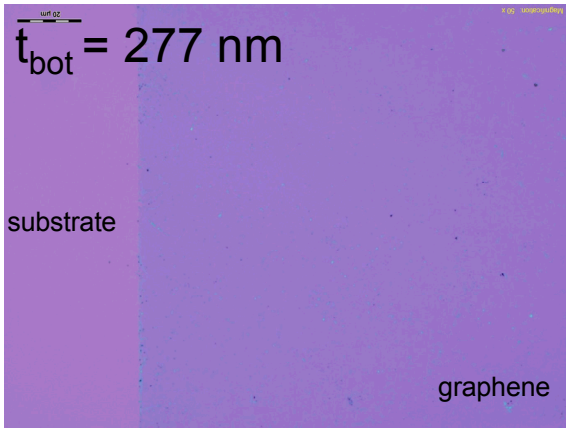


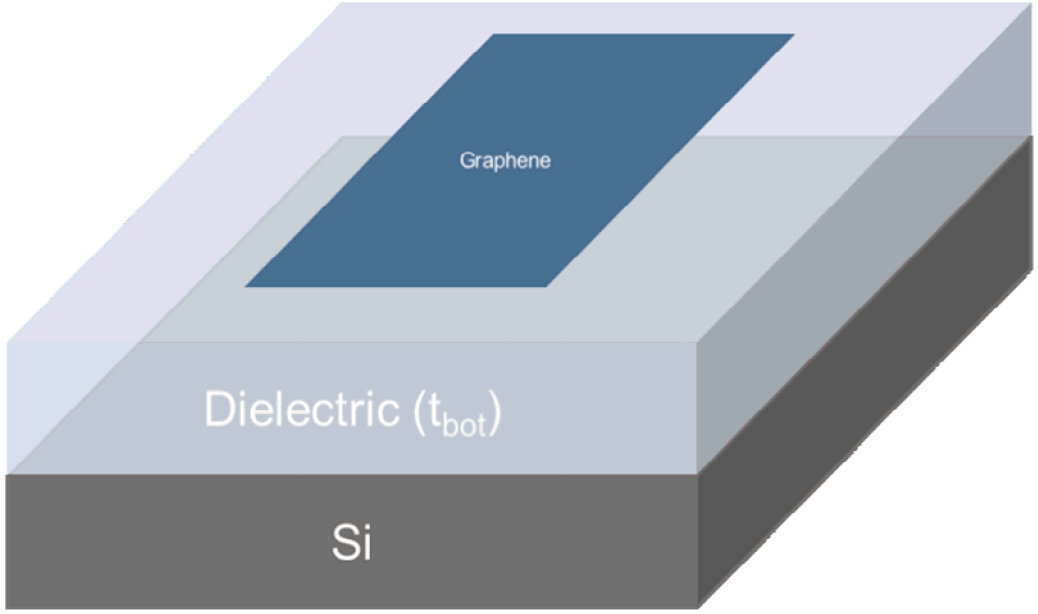

3

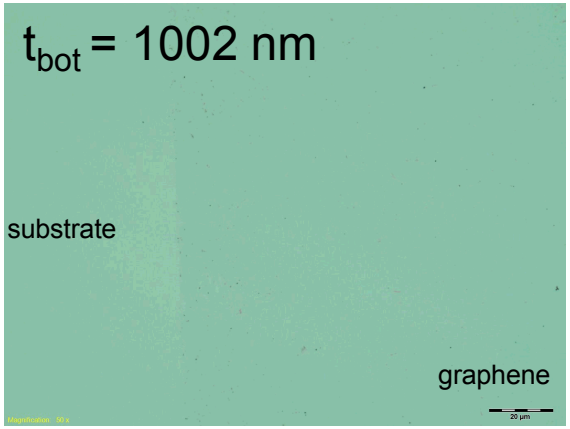
# Optical Contrast of Graphene



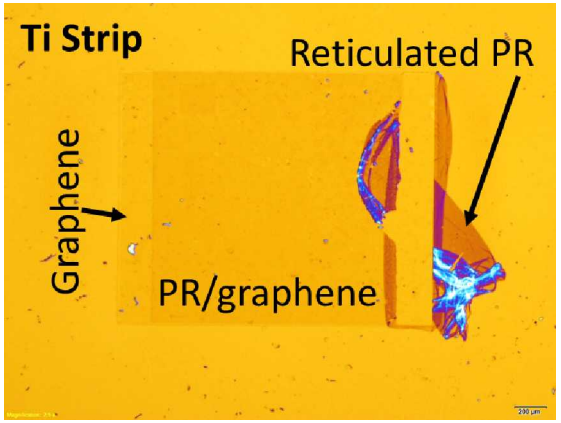



# Why Passivate Graphene?

- 2D materials are sensitive to atmosphere and fabrication processes.
  - Adsorption of water can electrically alter the electrical properties of the films.




- Future device applications will need to have the 2D material passivated in order to increase repeatability and reliability.

- Can designate dielectric thicknesses for both visibility and electrical performance.
  - Failure analysis
  - Characterization

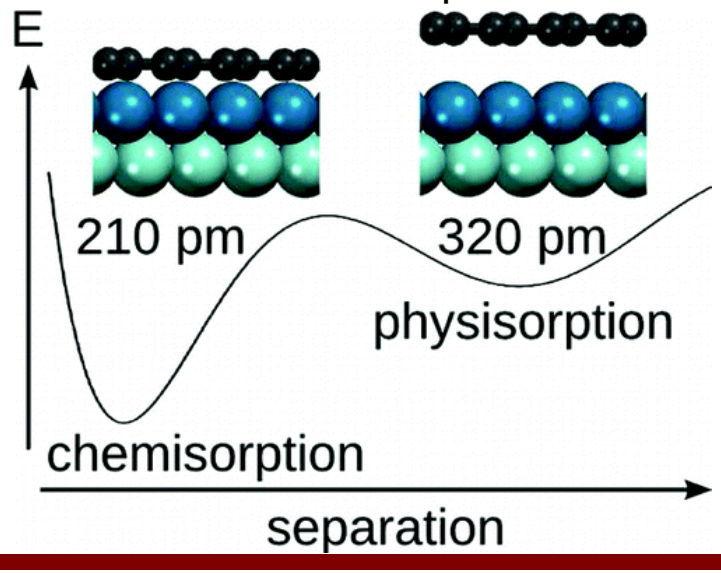
# Adhesion to Graphene

**Physisorption**

- Long range van der Wall force
- Electronic of graphene structure is maintained.

**Chemisorption**

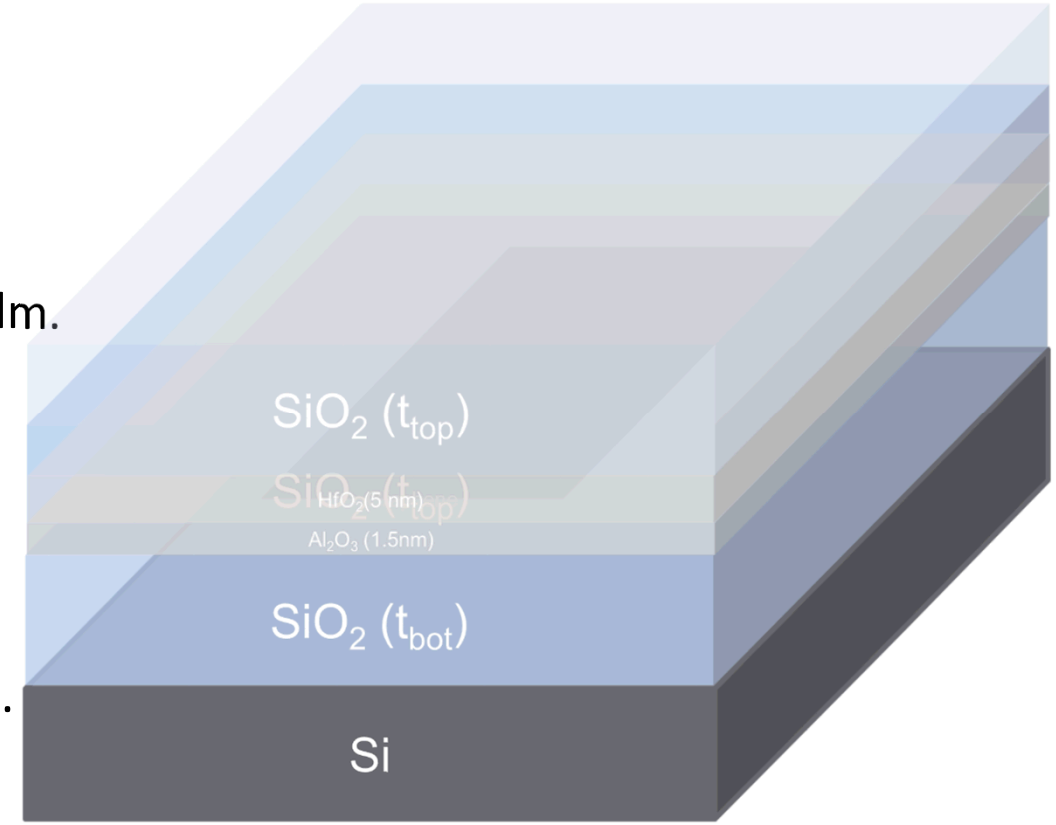
- Short range vdW force dominates
- Hybridization between metal D orbital and graphene's $\pi$ bond
- Electrical structure perturbed




- Metal-Graphene Adhesion
  - Physisorption
    - Ag, Al, Cu, Cd, Ir, Pt, and Au
  - Chemisorption
    - Ni, Co, Ru, Pd, and Ti
    - Hybridization between metal D orbital and graphene's $\pi$ bond
- Air/PMMA/Photoresist-Graphene Adhesion
  - Chemisorption
    - C-O, C=O, C-H out of plane bonds
    - Alter electrical properties
- Dielectric-Graphene Adhesion
  - Chemisorption
    - Requires out of plane bonds for nucleation

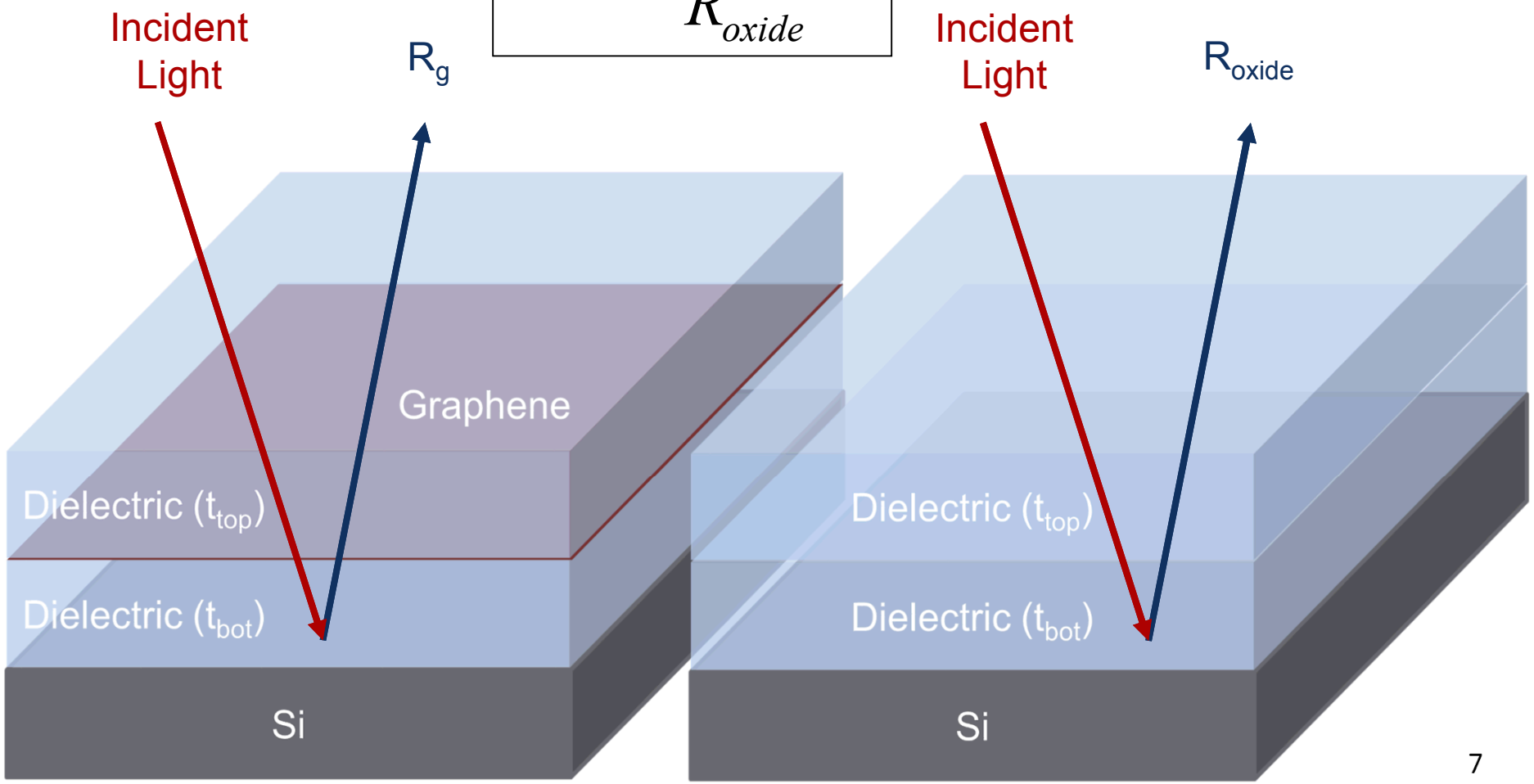
# $SiO_2$ Encapsulation

- Depositing dielectrics on graphene is difficult.
  - Poor adhesion (ALD).
    - No nucleation sites for precursors.
    - Perturbs graphene properties
  - Destructive for the graphene film.
    - ex: PECVD, Sputtering, PVD
- Solution
  - E-beam Al to wet graphene.
    - Oxidized to form $Al_2O_3$
  - Thin $HfO_2$ for added protection.
  - Then $SiO_2$ can be deposited by PECVD without damaging graphene.



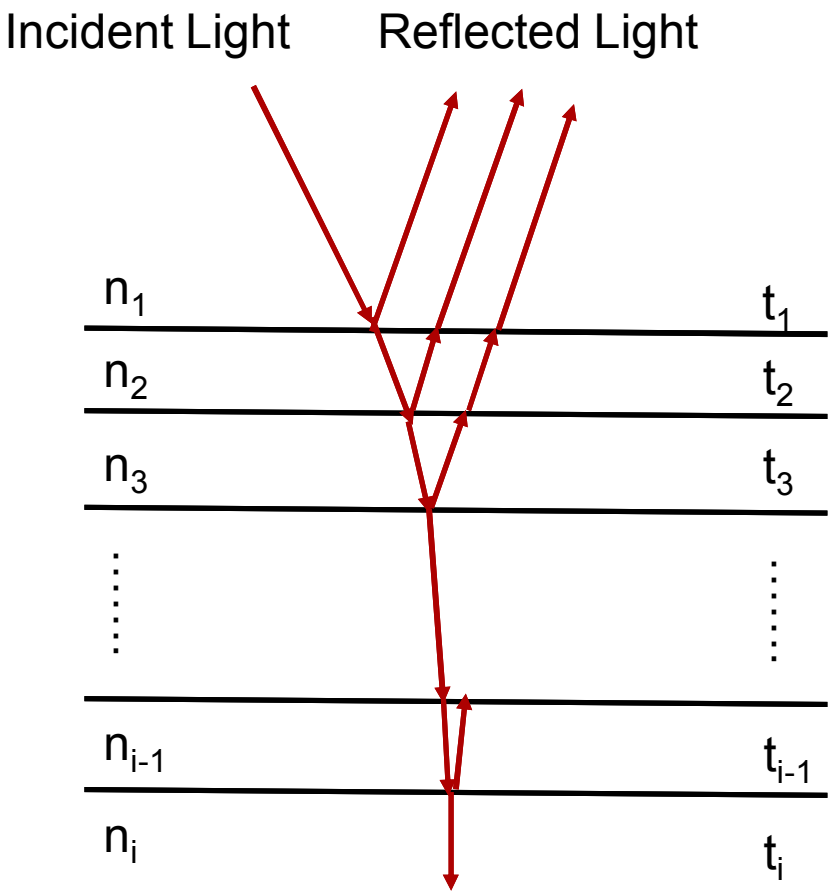
# Contrast Calculation

$$C = \frac{R_{oxide} - R_g}{R_{oxide}}$$



# Optical Model

$$S = \mathrm{H}_{1,2} L_2 \mathrm{H}_{2,3} L_3 \ldots L_{n-1} \mathrm{H}_{n-1,n} = \begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix}$$



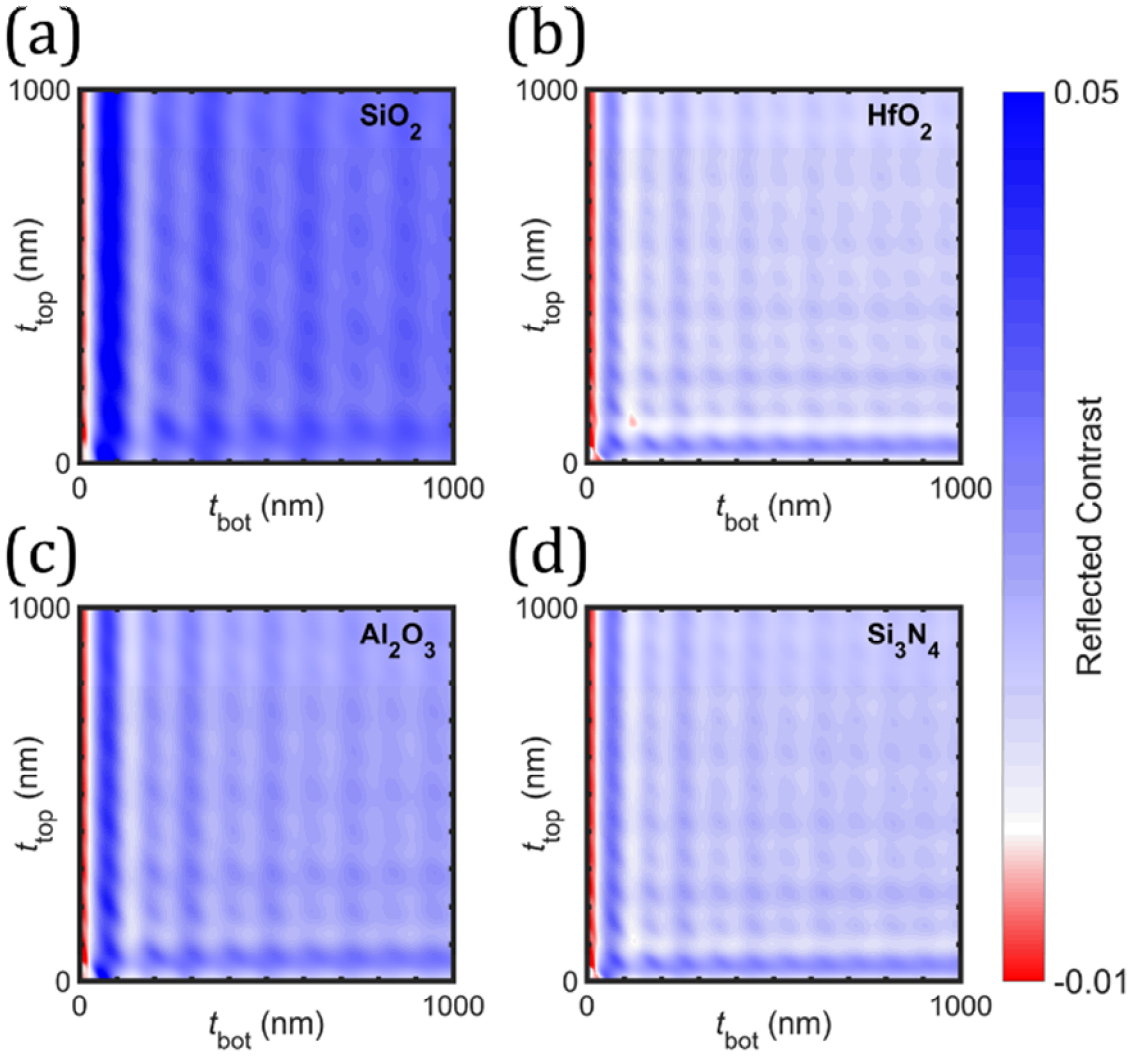

$$R_k = \left| \frac{s_{12}}{s_{22}} \right|^2$$

$$C = \frac{R_{oxide} - R_g}{R_{oxide}}$$

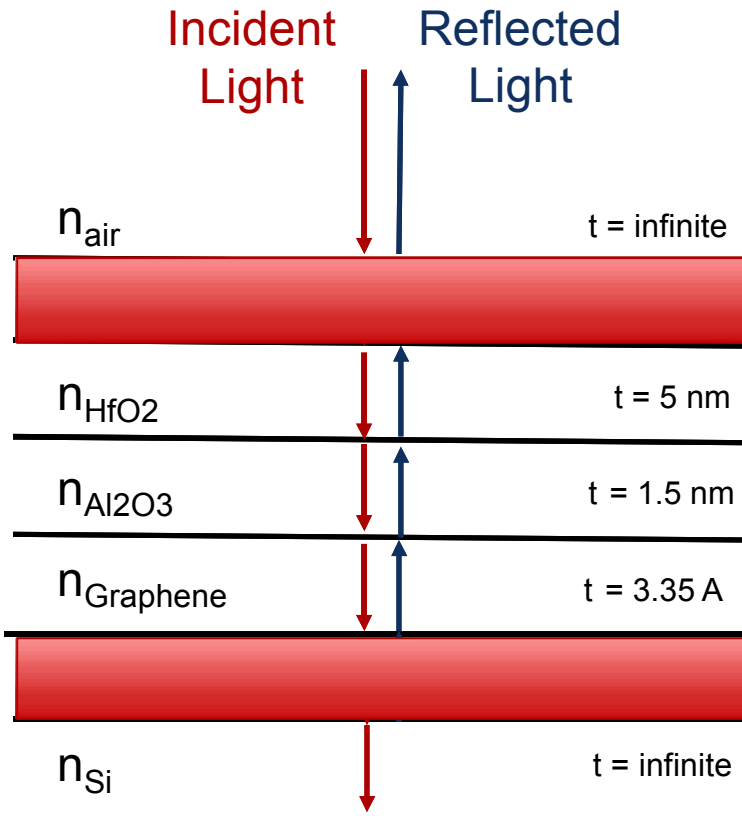
Variables:
Film thickness
Materials Index of Refection
Incident Light
- Wavelengths
- Angle

Potential Errors:
- Film contamination
- Dielectric Constants

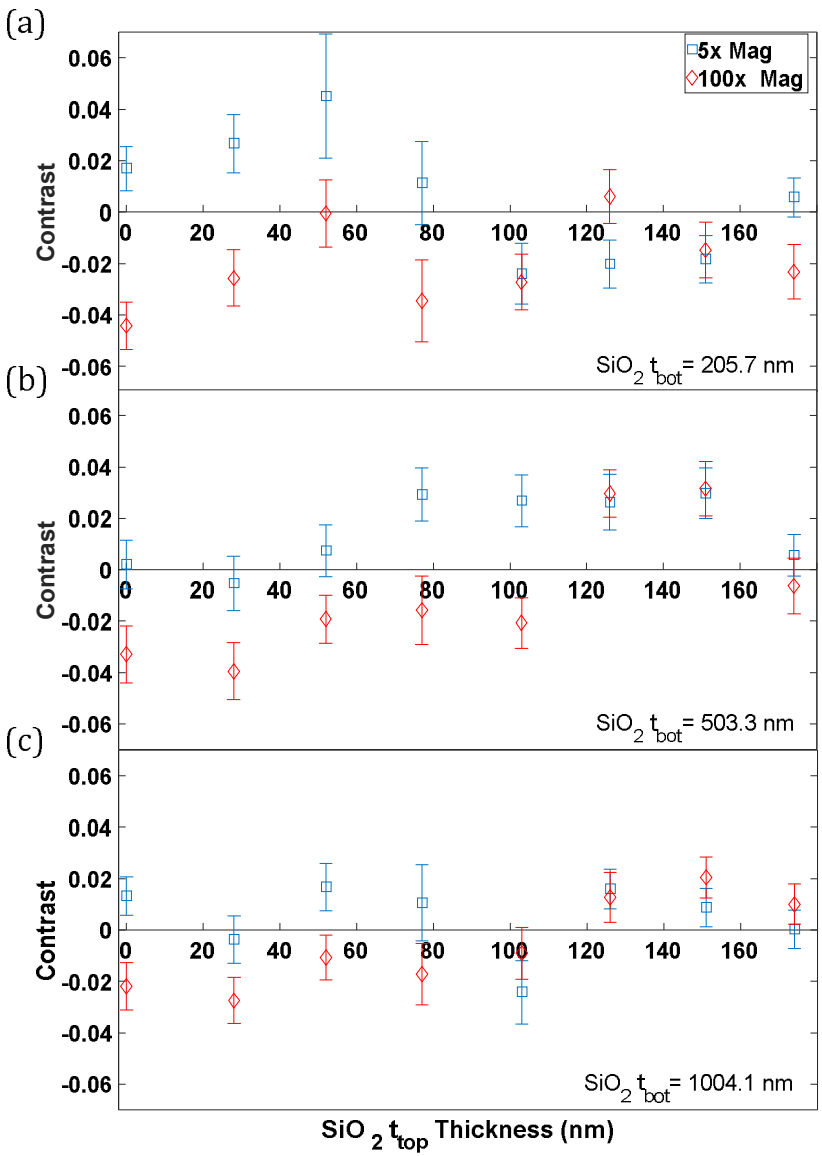
# Reflectance Contrast

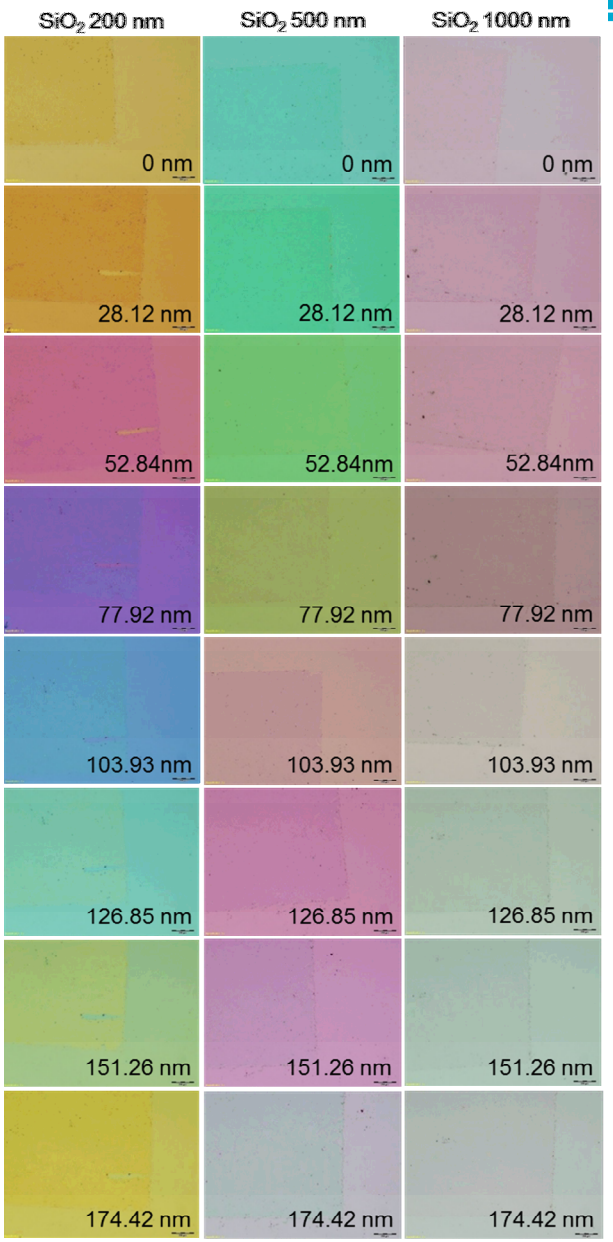



7 layers
Over Visible Range

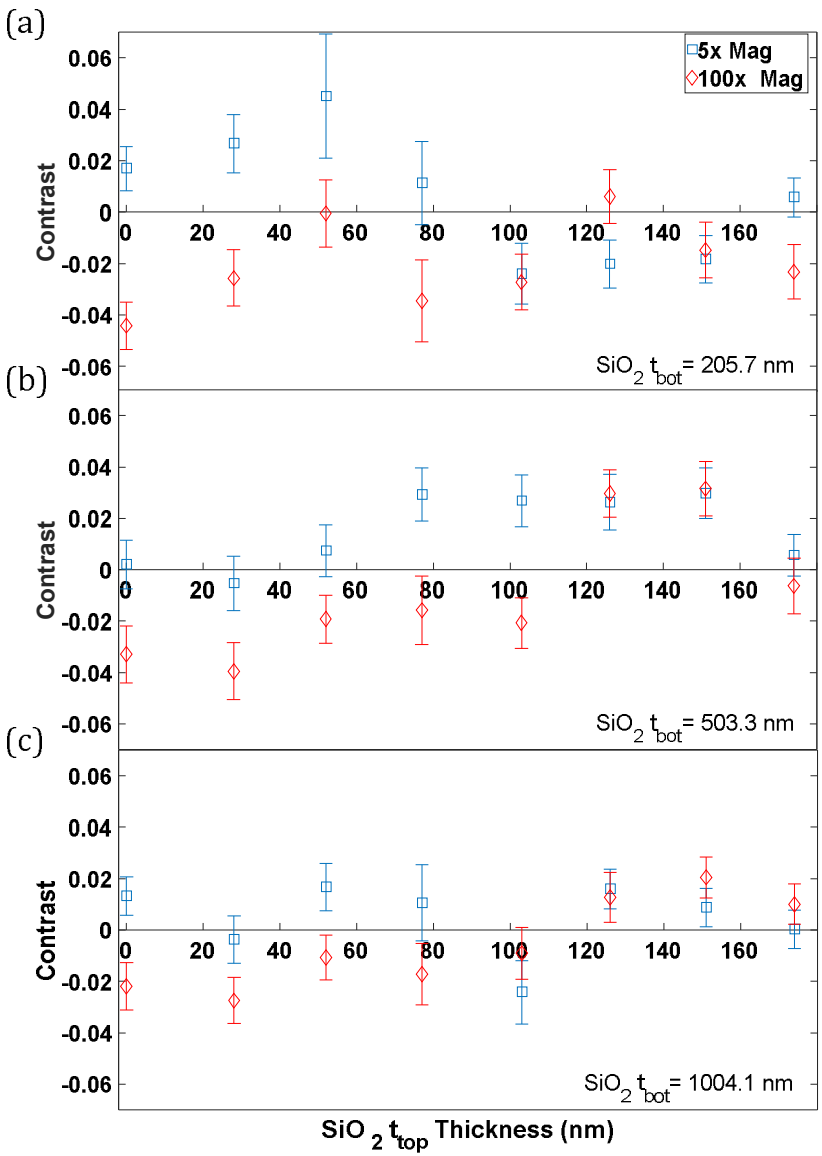


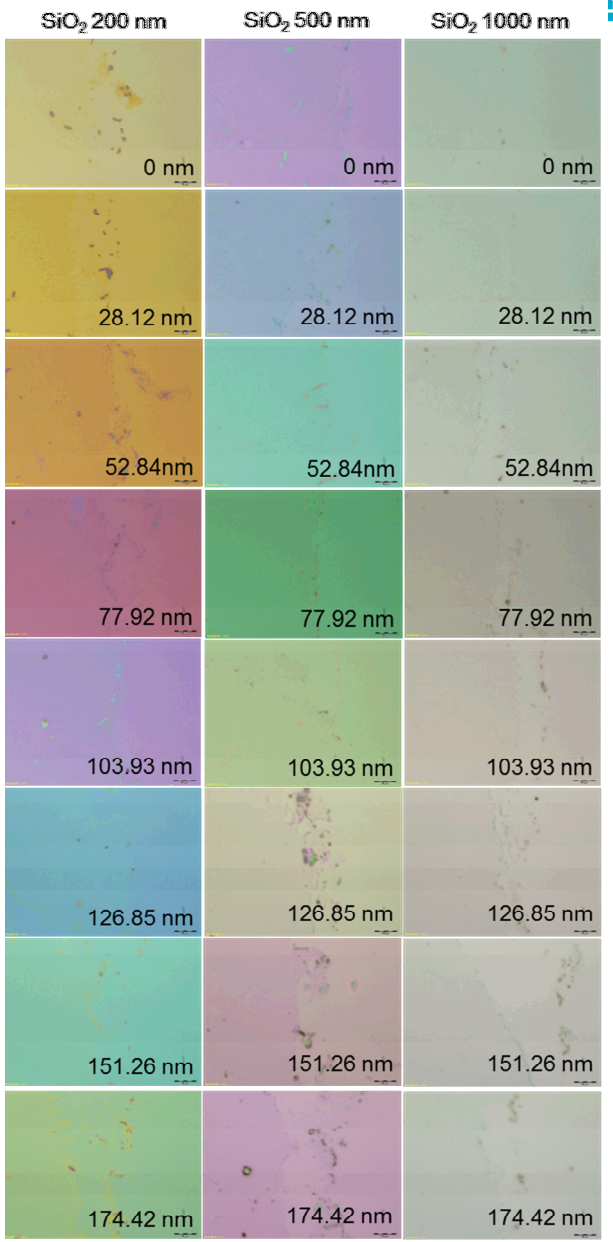
# Experimental Results



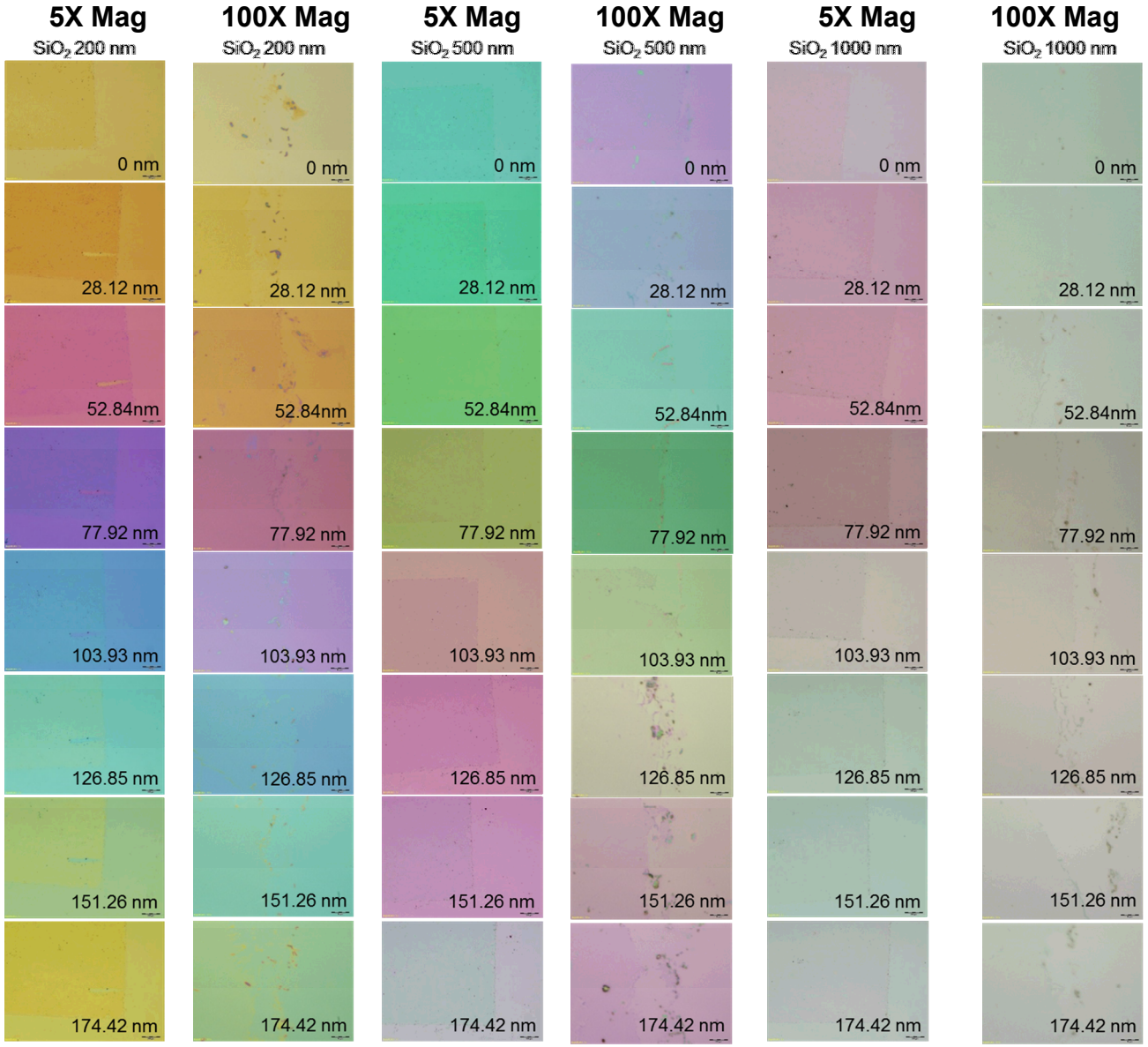



# High Optical Mag



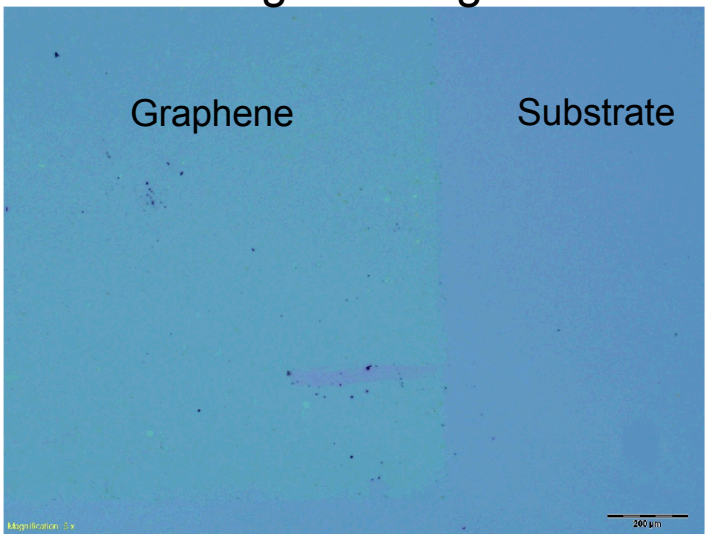
# High Mag vs Low Mag




- Large difference between 5X vs 100X
- $SiO_2$ thickness has large effect on contrast.
- Apparent dampening of contrast as $t_{bot}$ increases.
- Tuning of contrast possible:
  - Positive
  - Negative
  - 0

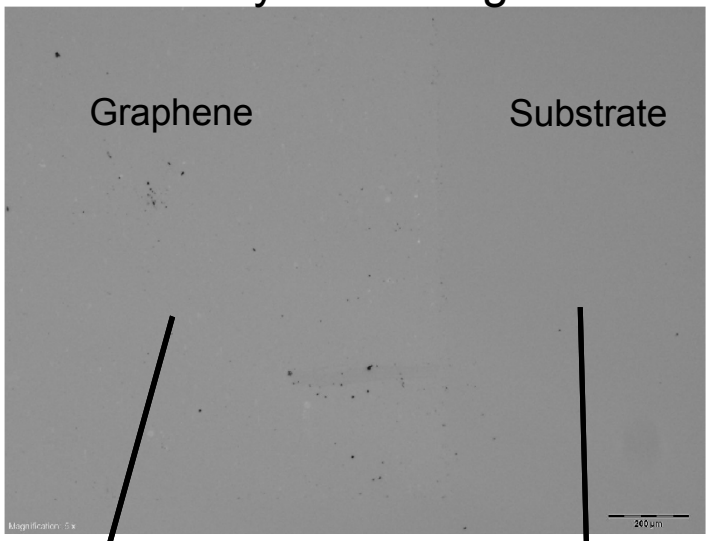
# Contrast Measurement

Original Image




Convert to greyscale

Greyscale Image




Measure Grey Index Average for a clean region of graphene ($R_g$)

Measure Grey Index Average for a clean region $SiO_2$ substrate ($R_{oxide}$)

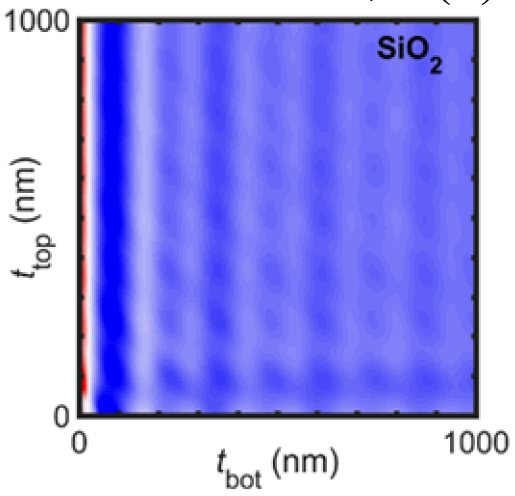
Measured with Olympus MX80
Objective lenses
- LMPlanFI 5X/0.13
- LMPlan 100X/0.80

Illuminated with 100W mercury apo lamp
- Model U-LH100HGAPO

$$C = \frac{R_{oxide} - R_g}{R_{oxide}}$$

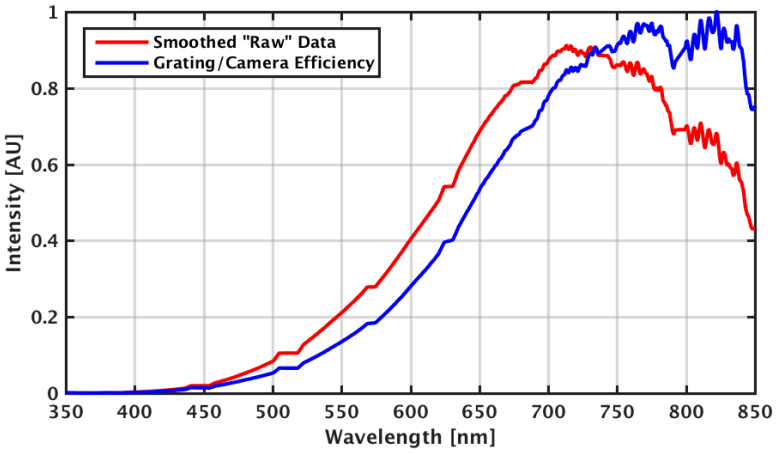
# Reflectance to Greyscale Value

Reflectance, R(λ)




X

Incident Spectrum, $P_i$ (λ)



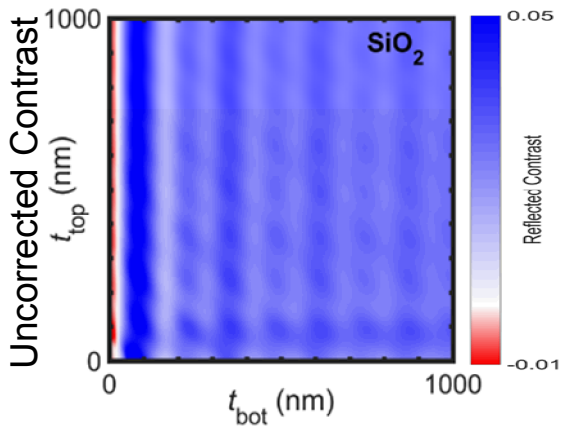

=

Reflected Spectrum

$P_r$ (λ)

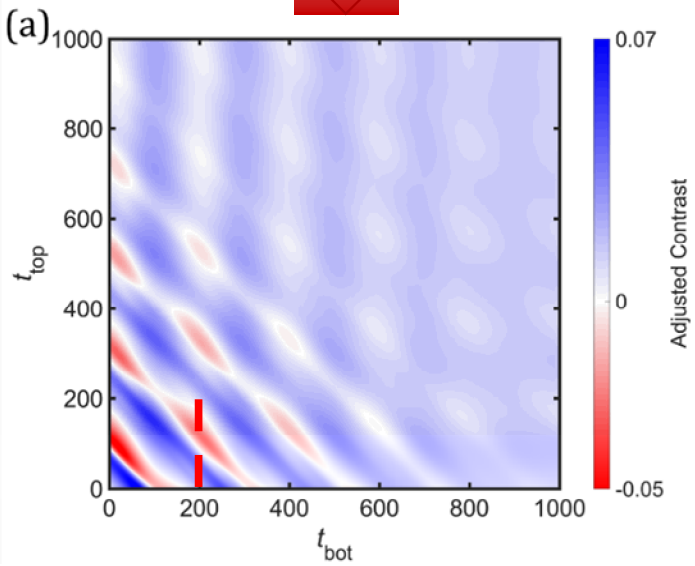
CIE XYZ Parameters → sRGB Values → Grey Scale Values

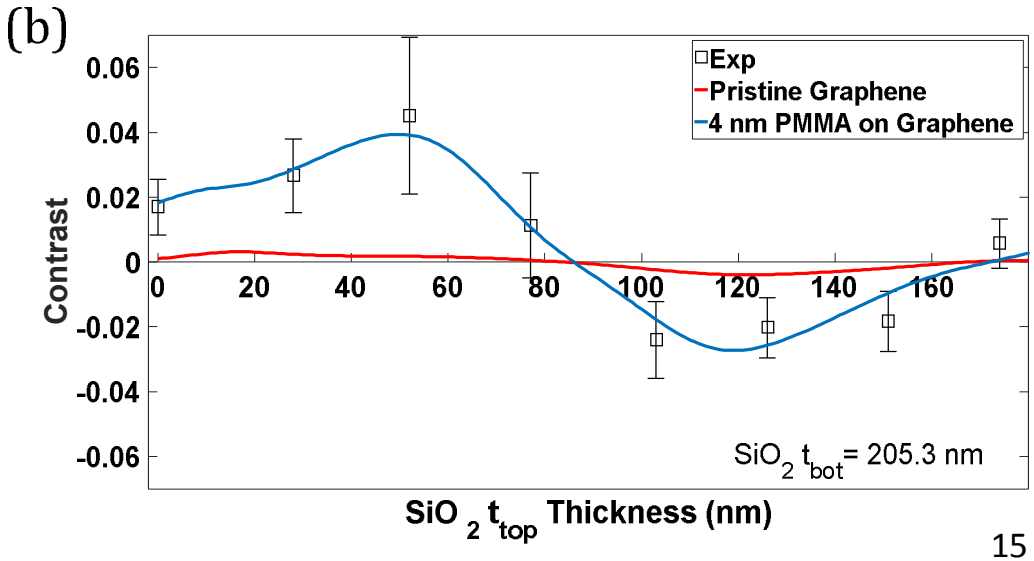
# Comparison to Model




**Adjusted contrast takes into account:**

- Incident light spectrum
- Incident light angle
- PMMA Contamination (extra layer)
- Monitor settings
- RGB to Grey scale conversion



# Conclusion

- Developed model to calculate reflectivity of multilayer stacks.
  - Calculated contrast of passivated graphene films in 8 layer stack.
- Experimentally fabricated buried graphene stacks within $SiO_2$.
- Found that the contrast varies greatly depending on the oxide thickness and the angle of the incident light.

# Thank You

Sandia National Laboratories


SNL Researchers

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Anthony Mcdonald

Bruce L. Draper

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# Questions?