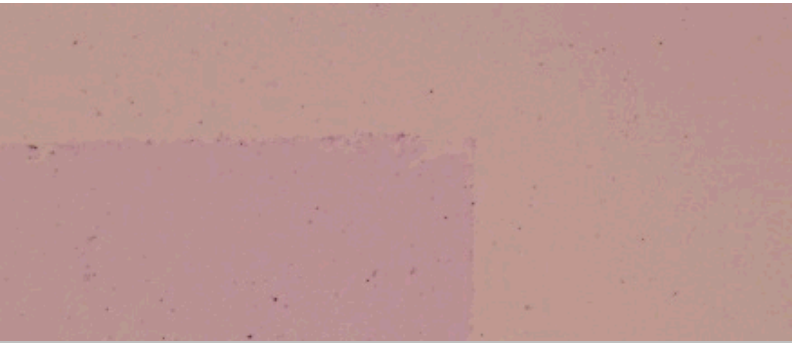
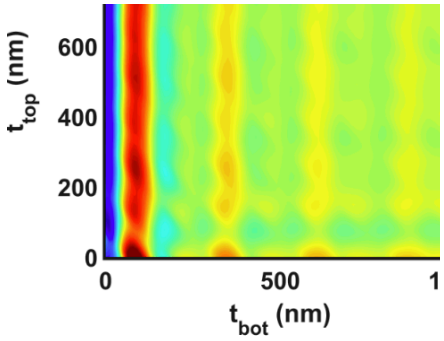
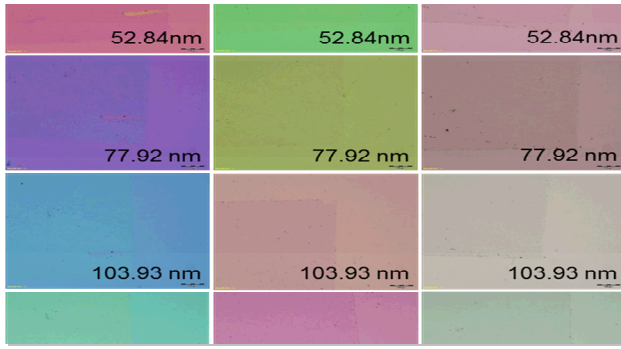
SAND2017-5176C







Finding Graphene: Observing Atomically Thin Materials Encapsulated in Dielectrics

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Postdoctoral Appointee

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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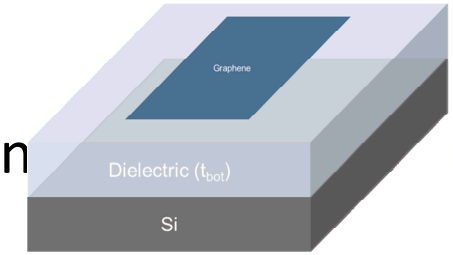
Motivation to See the Graphene

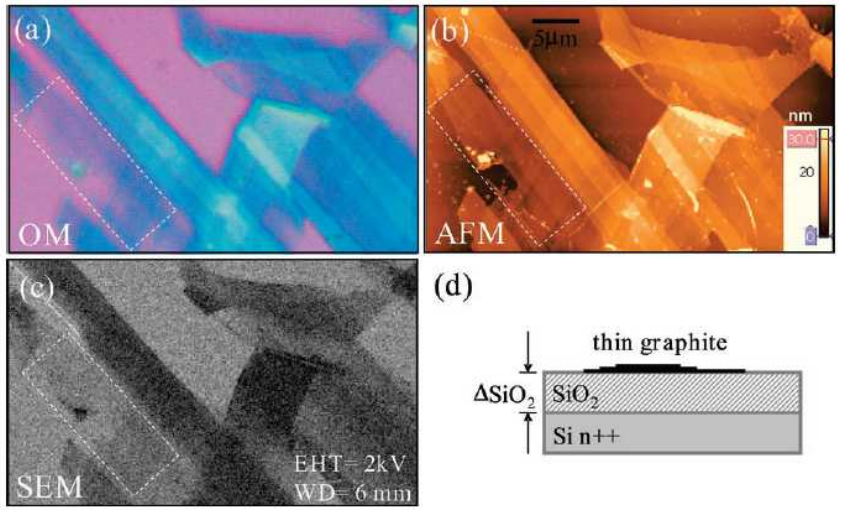
2D Materials are hard to see

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

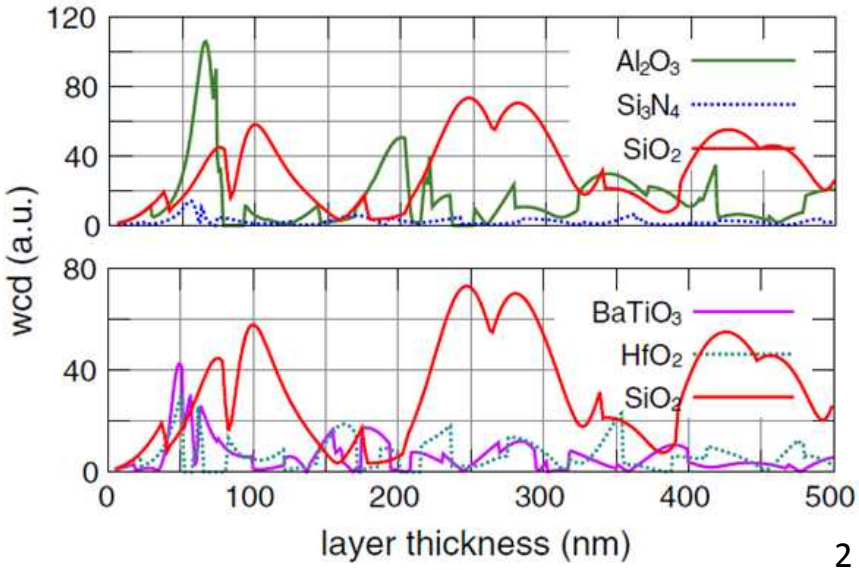
Currently Large films:
- Morphology
- Uniformity
- Characterization



A lot of preliminary work on unpassivated graphene layers

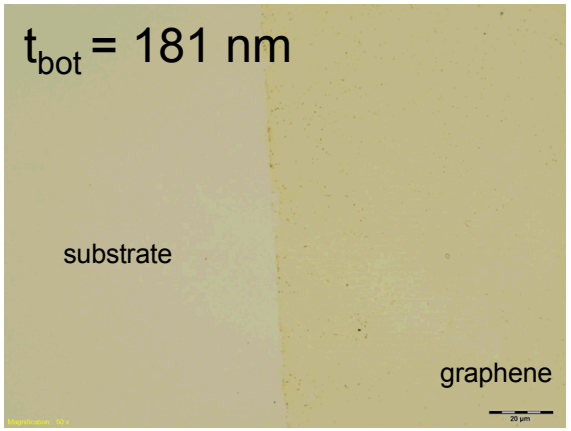


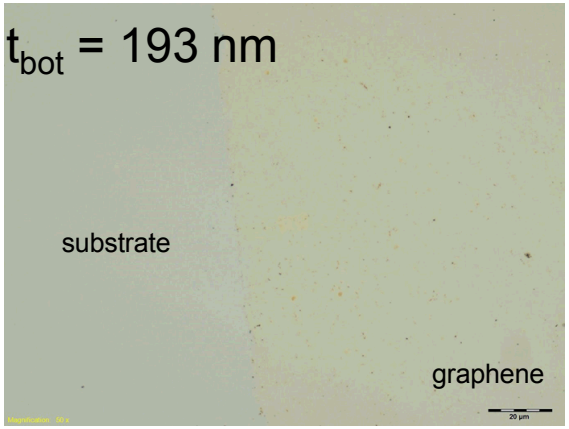
2

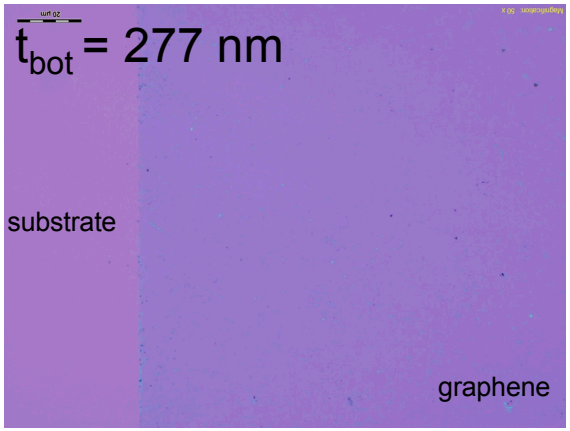


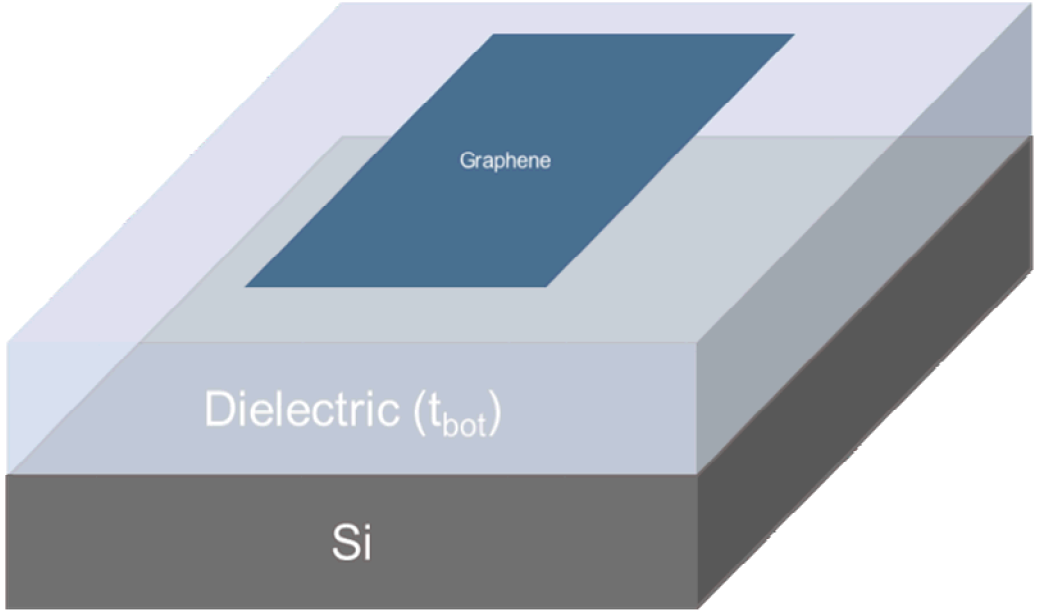
3

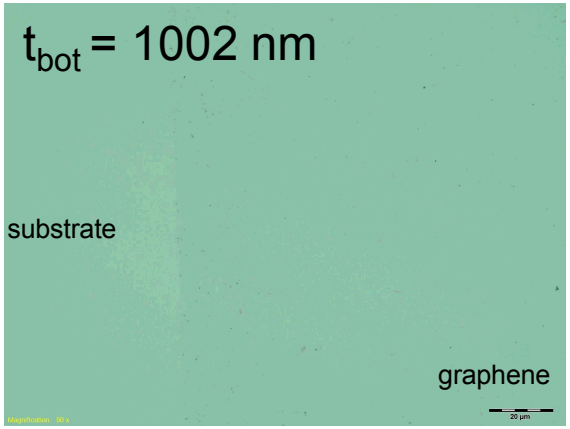
Optical Contrast of Graphene





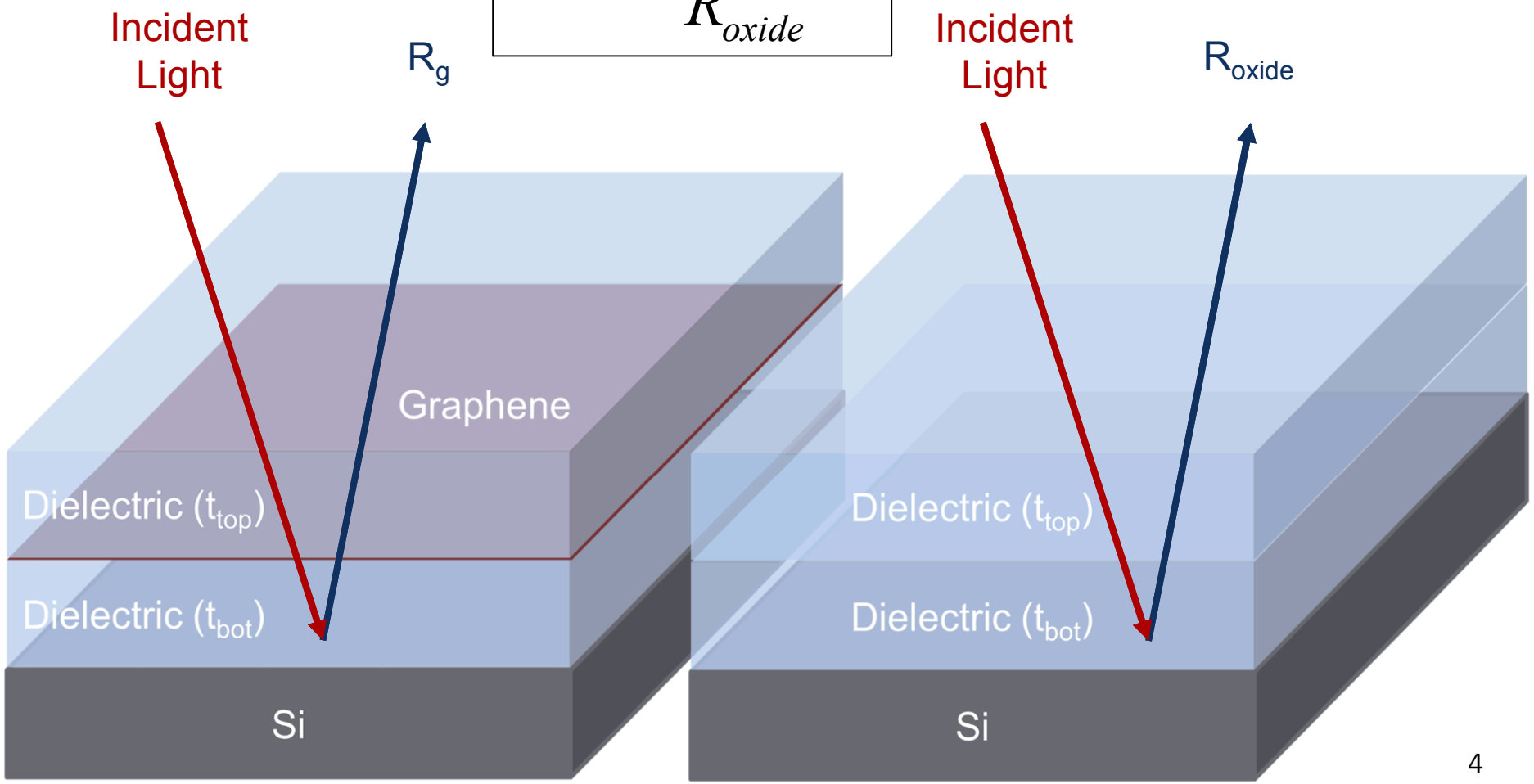






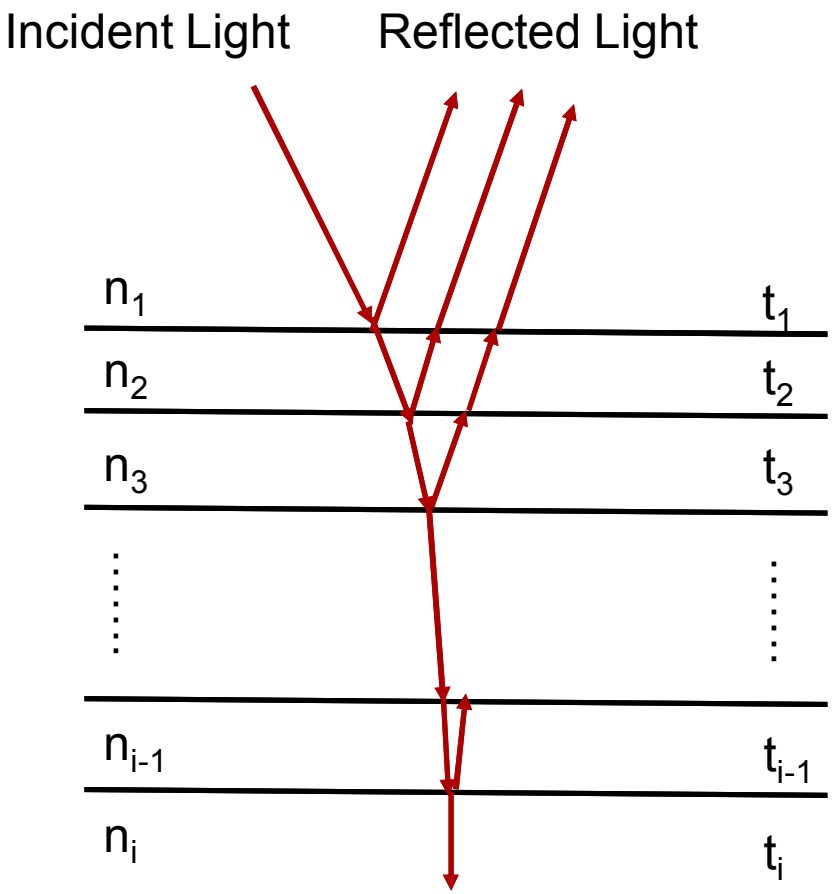
Reflectivity Calculation

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



Optical Model

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



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

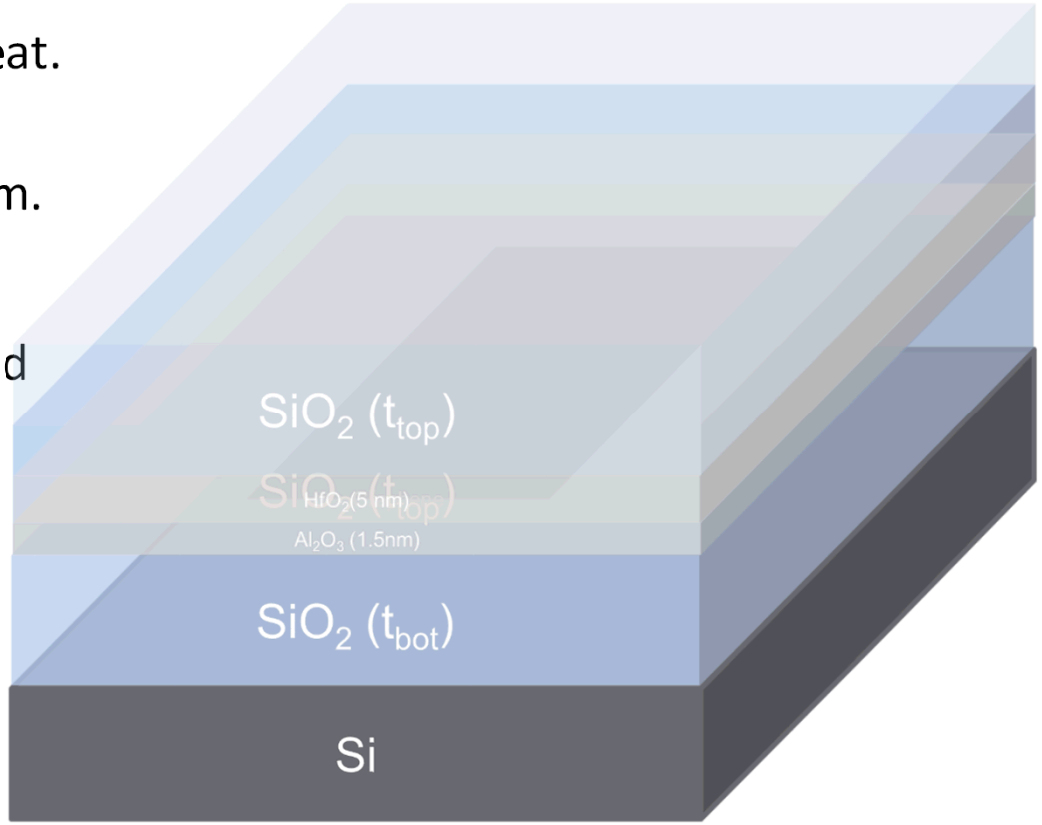
$$C = \frac{R_{oxide} - R_g}{R_{oxide}}$$

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

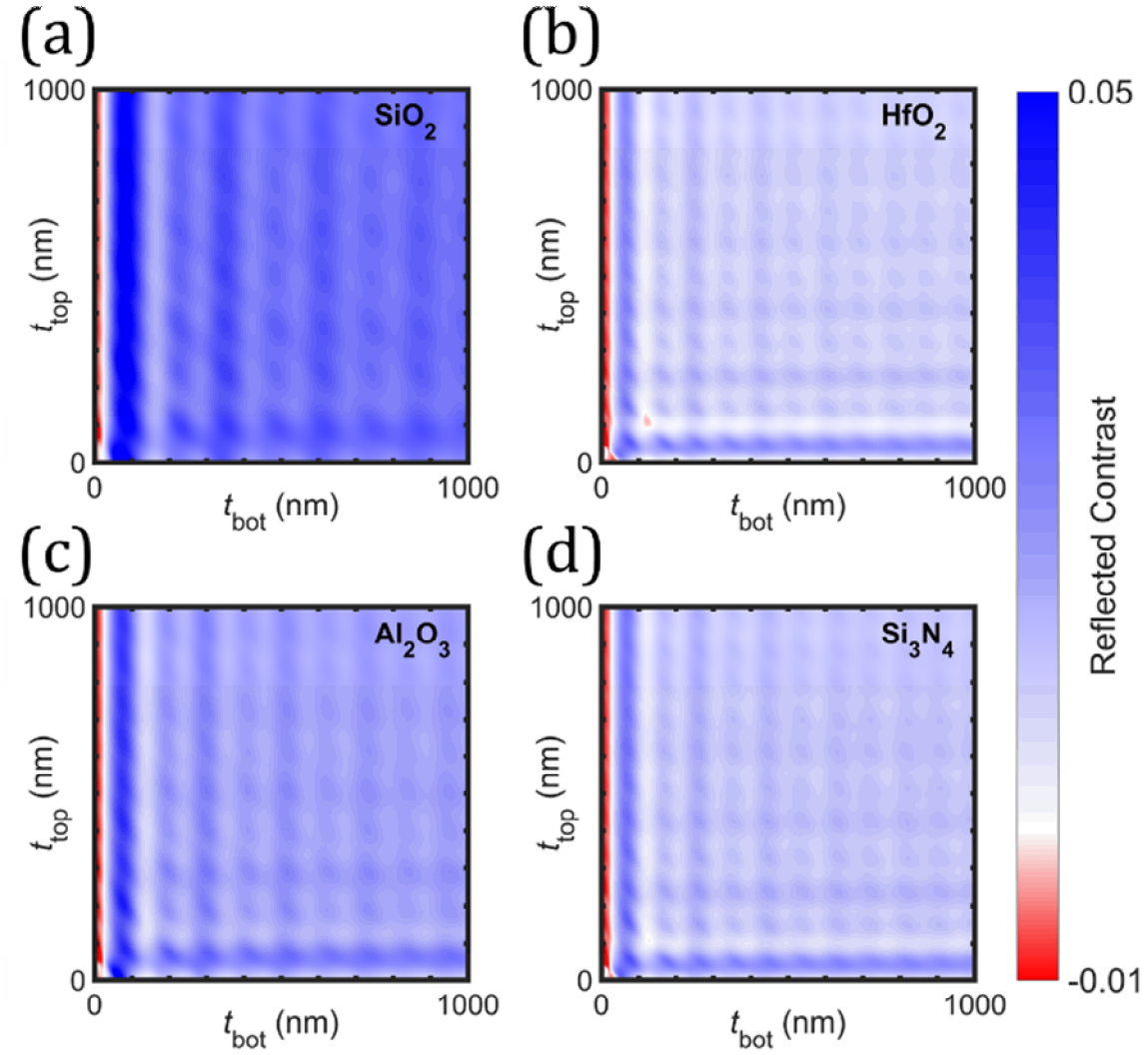
Potential Errors:
- Film contamination
- Dielectric Constants

SiO_2 Encapsulation

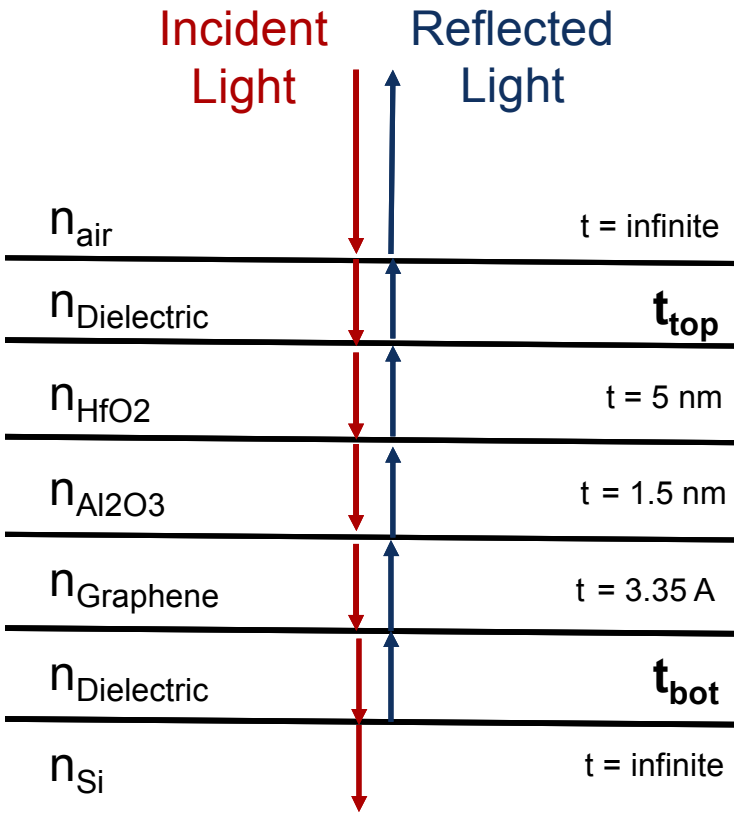
- Depositing dielectrics on graphene is difficult.
  - Adhesion to graphene is not great.
  - Many deposition processes are destructive for the graphene film.
- Solution
  - Protective Al layer, is evaporated by e-beam.
    - Oxidized to form Al_2O_3
  - Thin HfO_2 for added protection.
  - Then SiO_2 can be deposited by PECVD without damaging graphene.



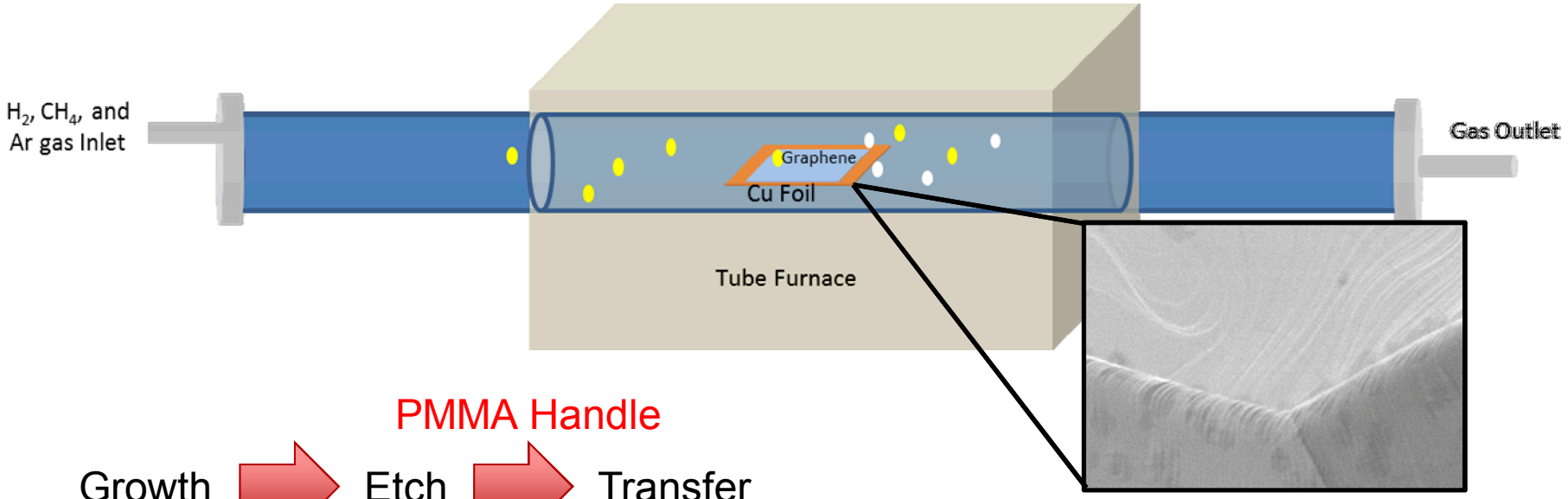
Reflectance Contrast



7 layers

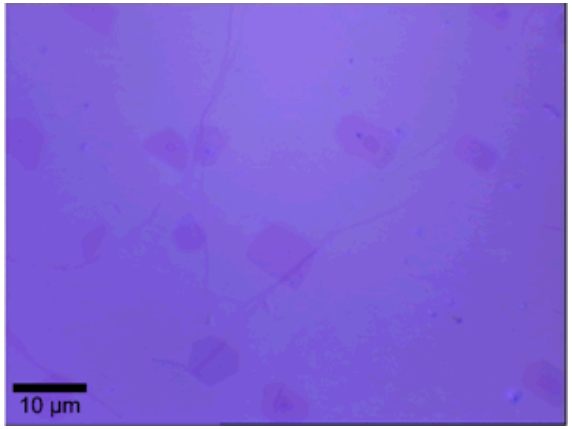


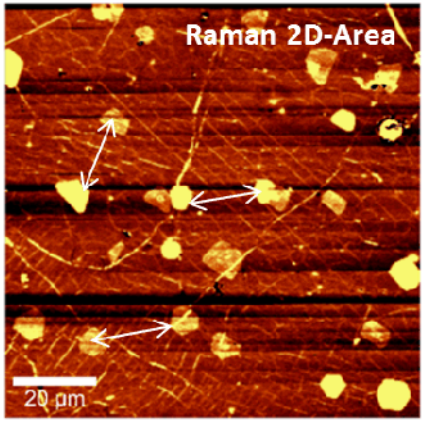
Graphene Synthesis

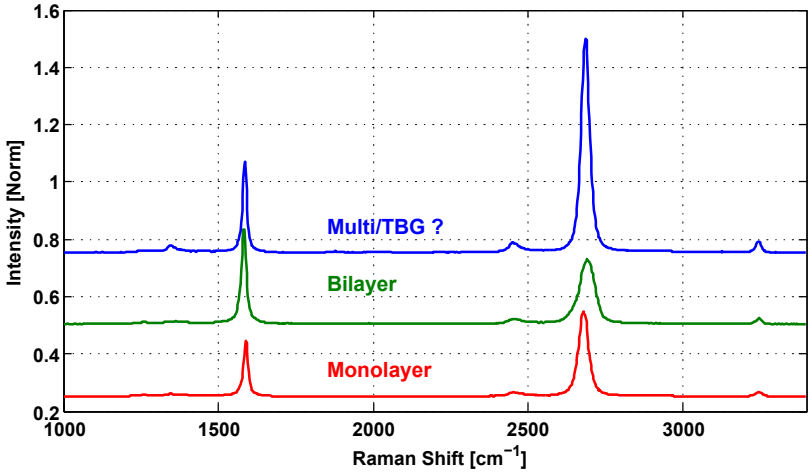


PMMA Handle

Growth → Etch → Transfer

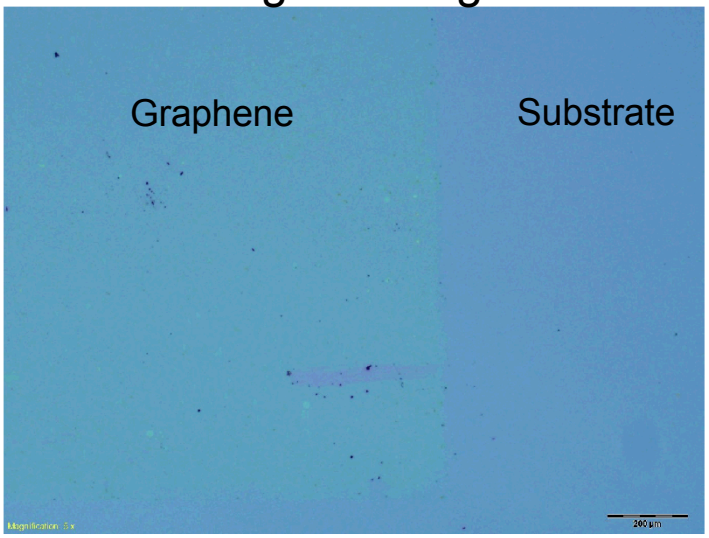






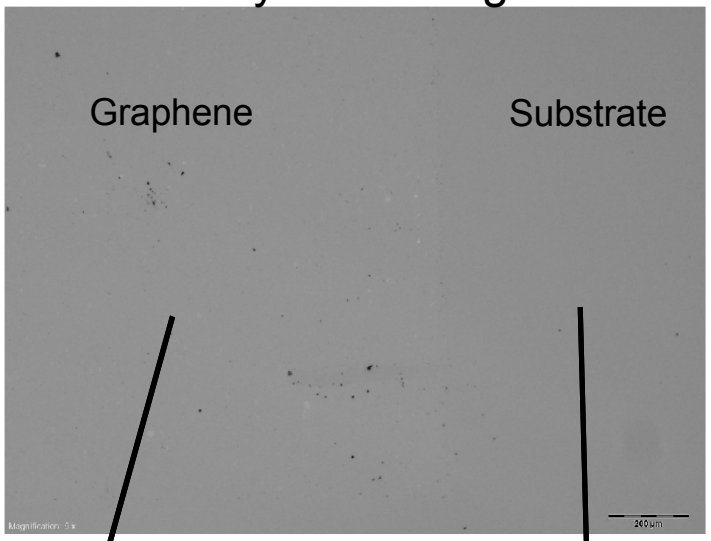
Contrast Measurement

Original Image



Convert to greyscale

Greyscale Image



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

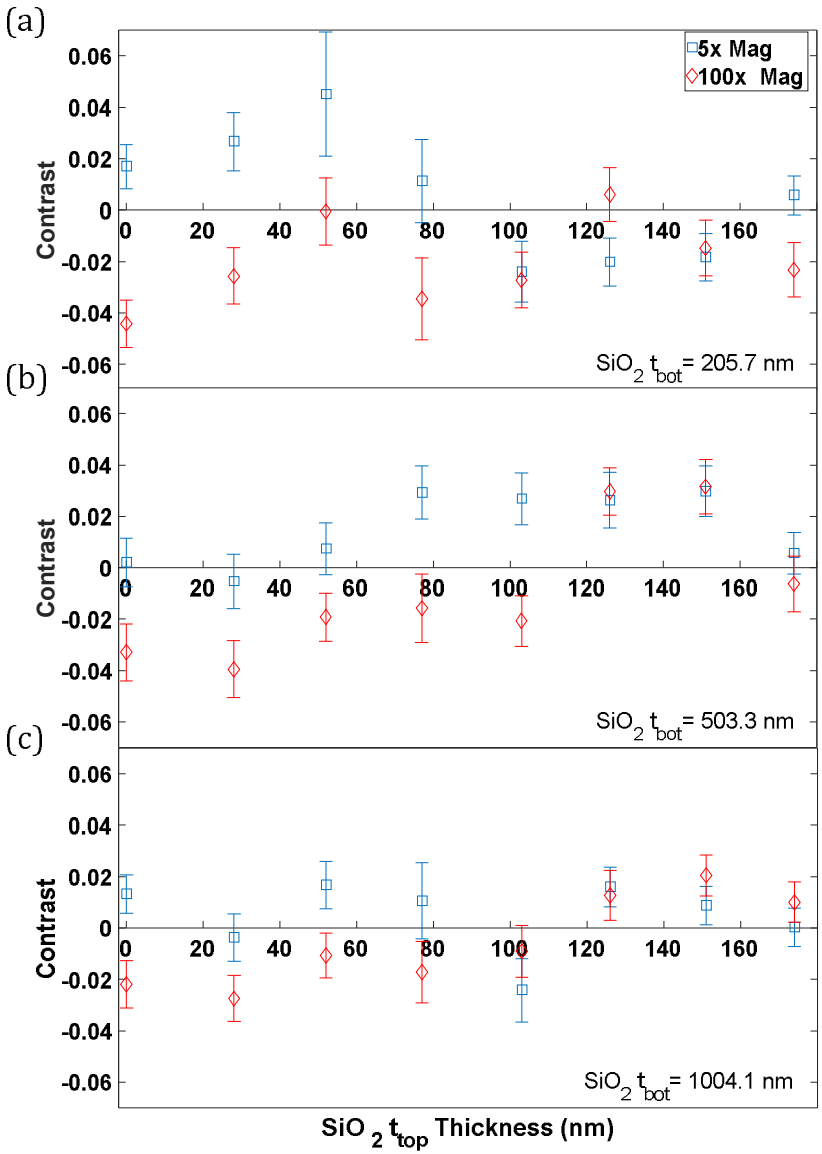
Measure Grey Index
Average for a clean region
SiO_2 substrate (R_{oxide})

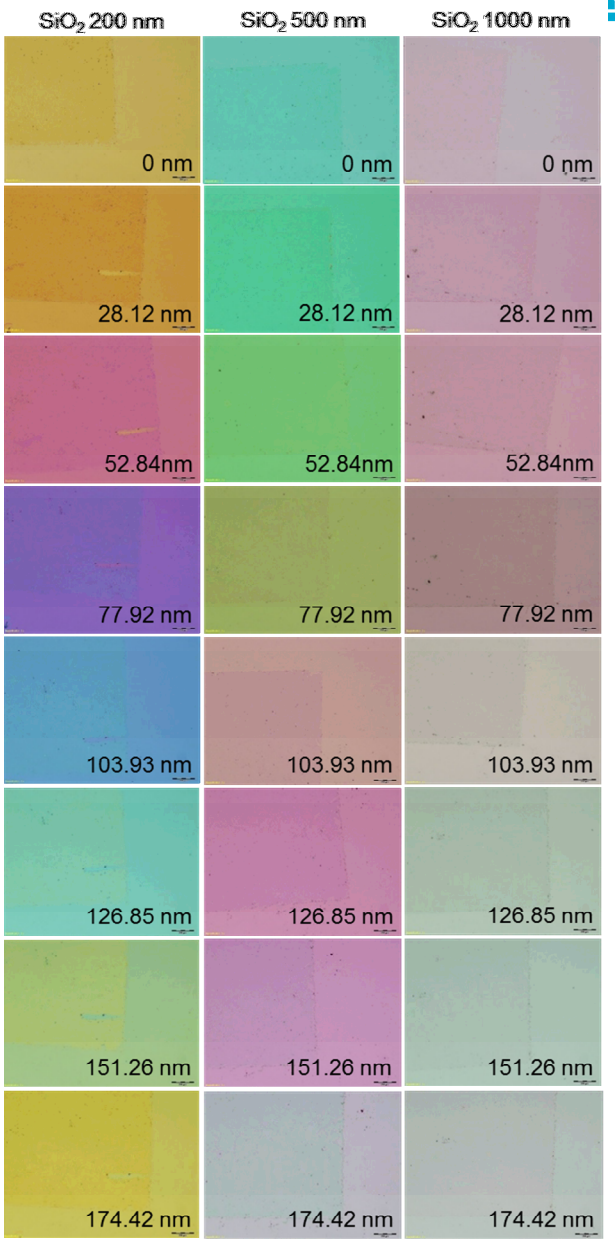
Measured with Olympus MX80
Objective lenses
- LMPlanFI 5X/0.13
- LMPlan 100X/0.80

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

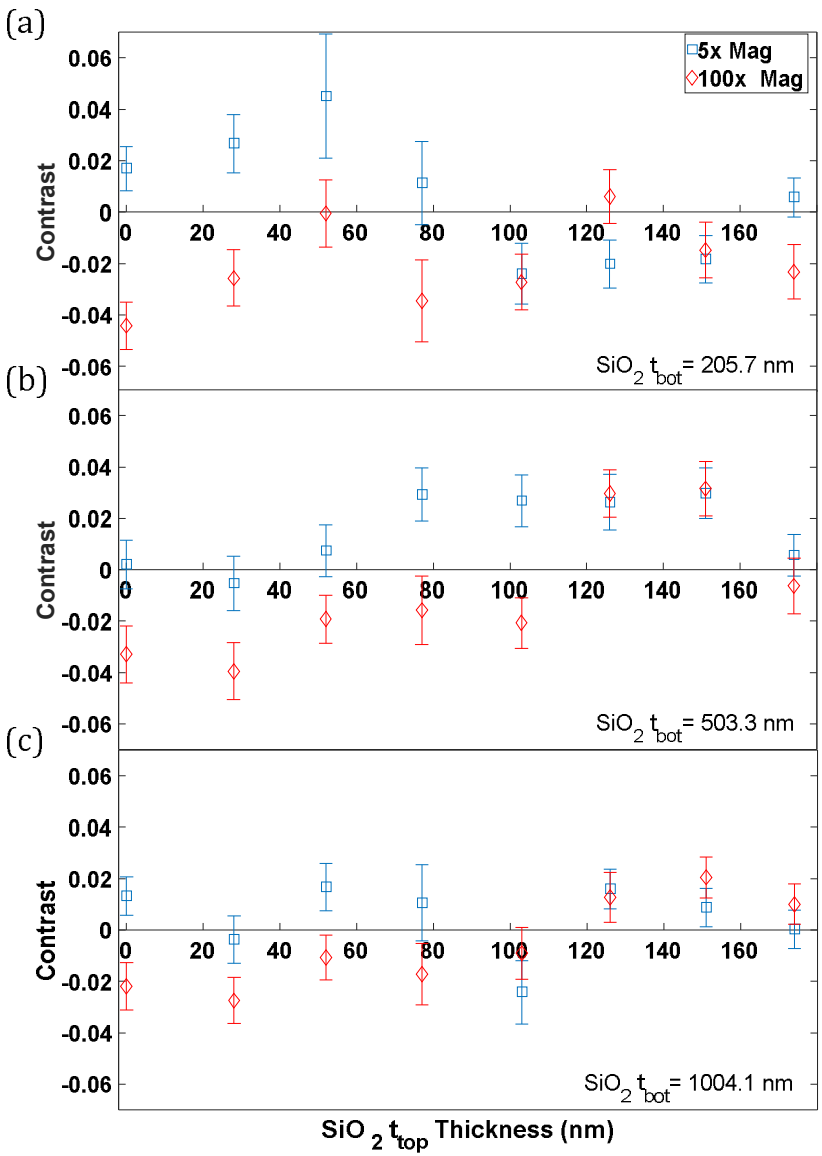
$$C = \frac{R_{oxide} - R_g}{R_{oxide}}$$

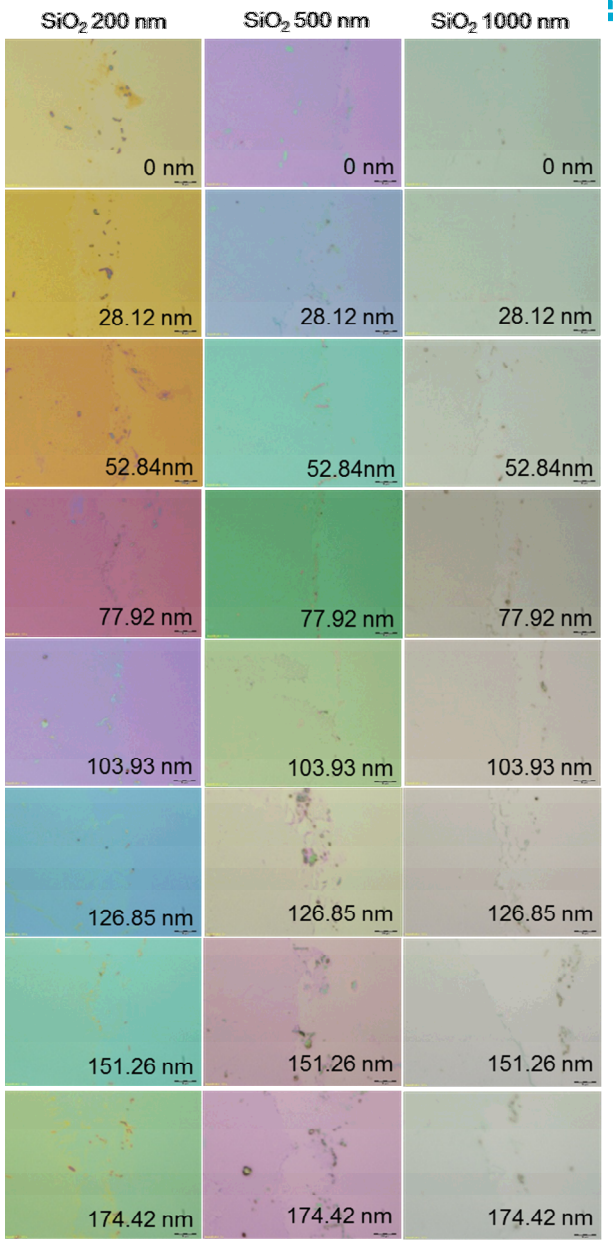
Experimental Results



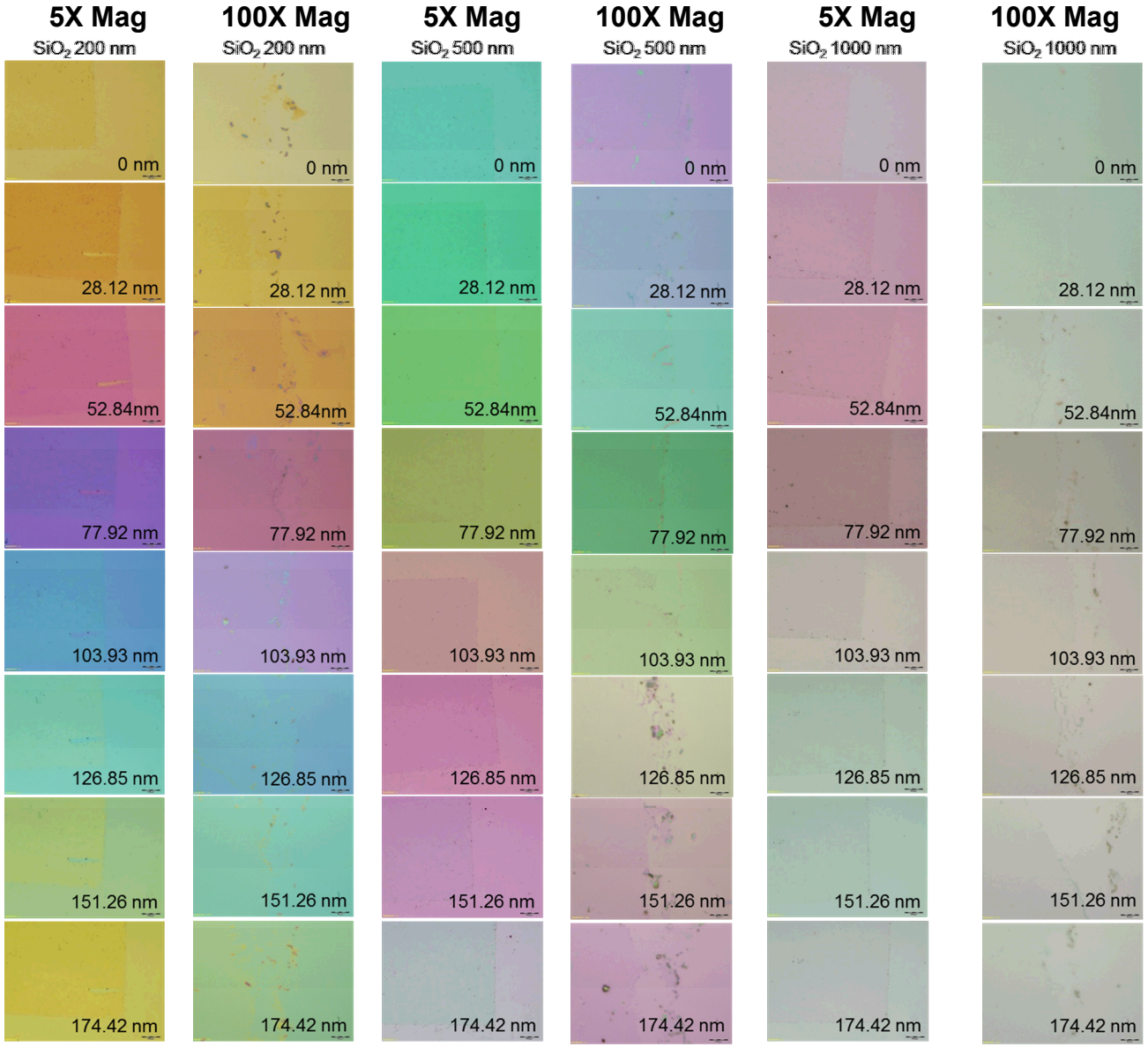


High Optical Mag



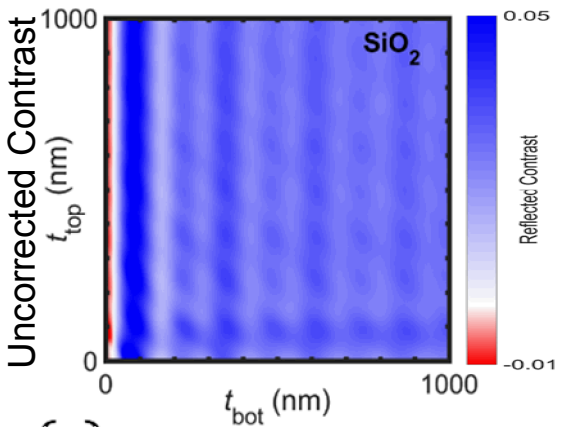


High Mag vs Low Mag



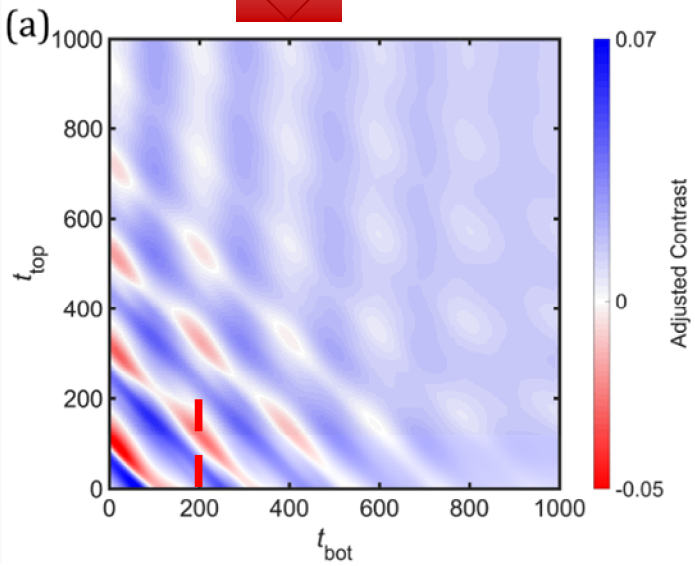
- Large difference between 5X vs 100X
- SiO_2 thickness has large effect on contrast.
- Apparent dampening of contrast as t_{bot} increases.
- Tuning of contrast possible:
  - Positive
  - Negative
  - 0

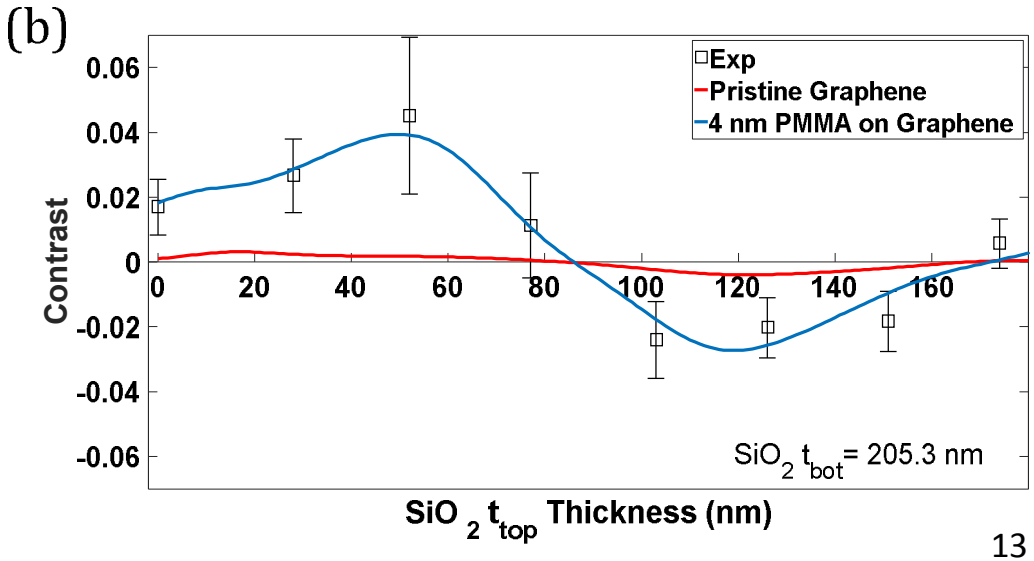
Comparison to Model



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.
- Set fourth a plan to make the model more robust and match experimental data.

Thank You

Sandia National Laboratories

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Anthony Mcdonald

Bruce L. Draper

Sandia National Laboratories

Questions?