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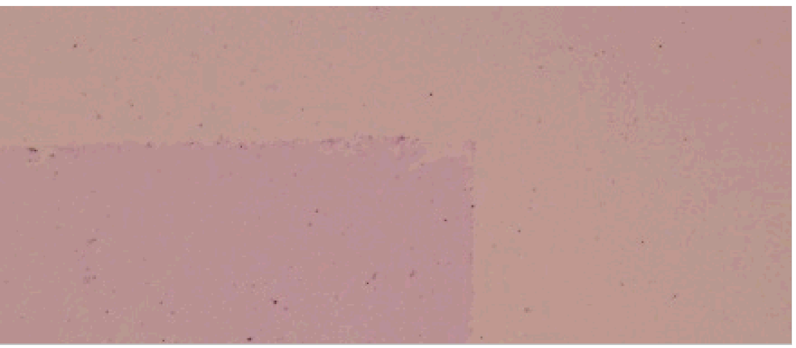

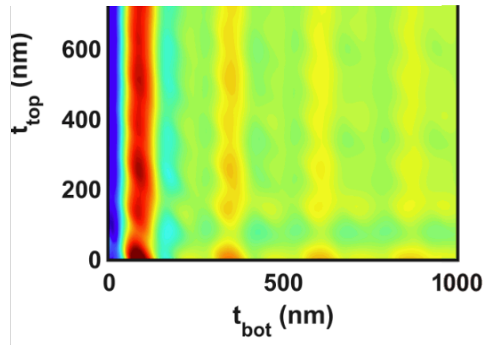

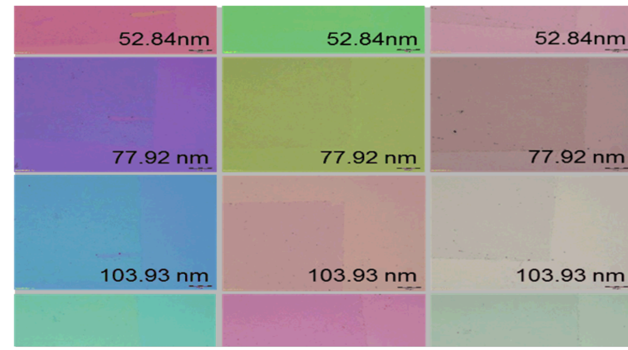

Optical Contrast of Passivated Graphene Films

Isaac Ruiz

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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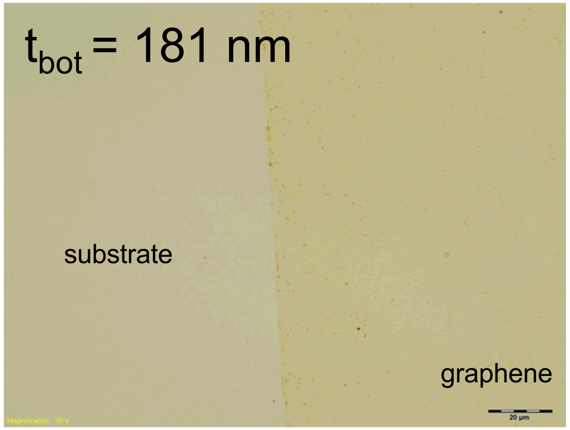
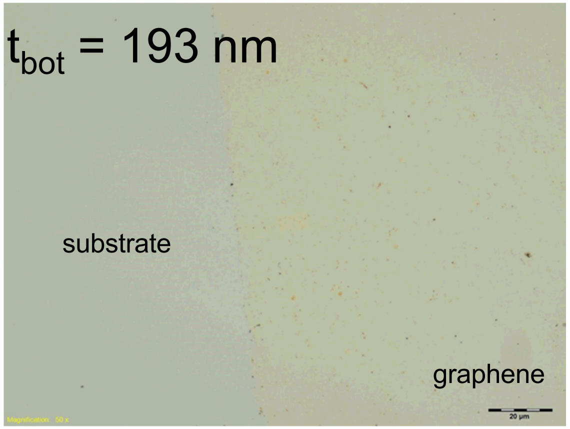
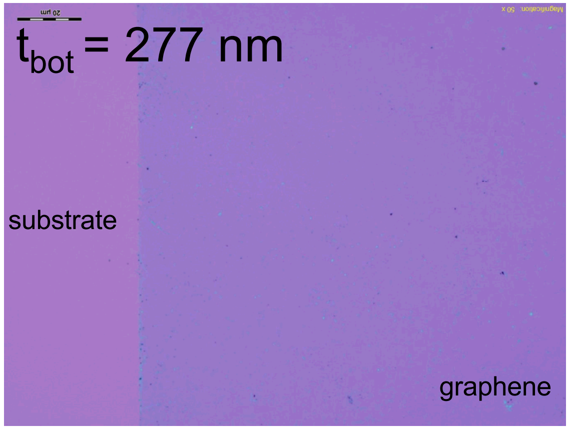
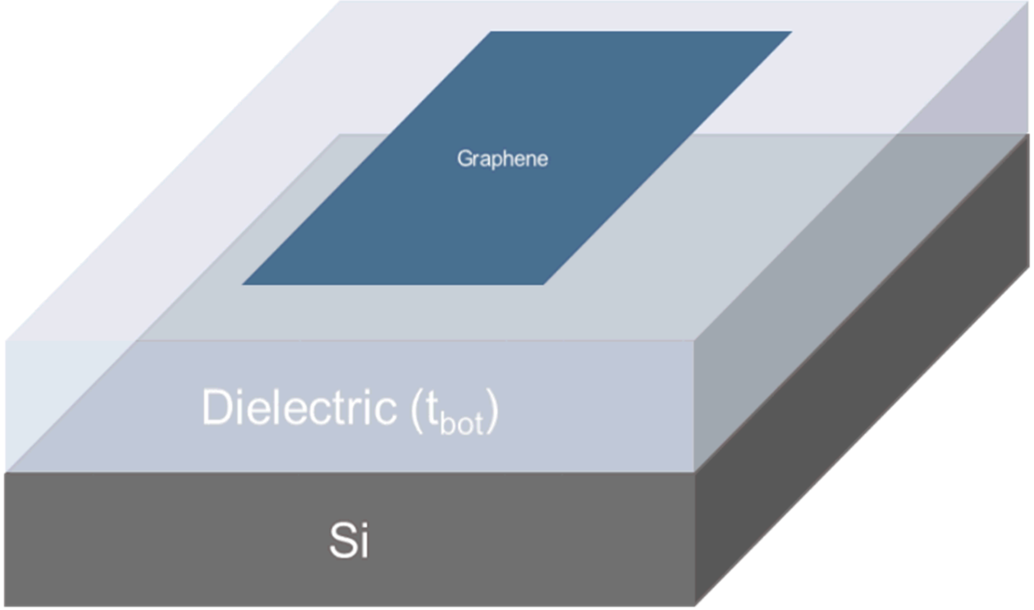
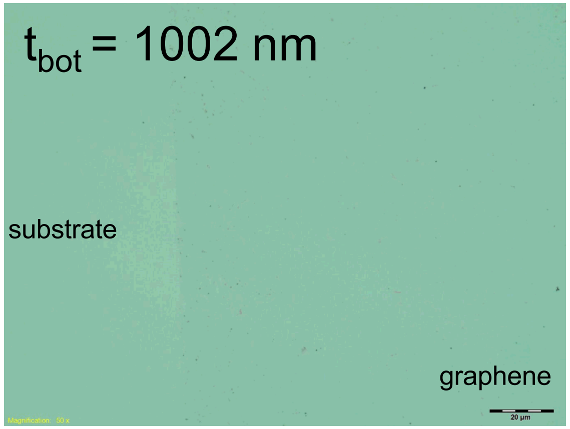
Optical Contrast of Graphene



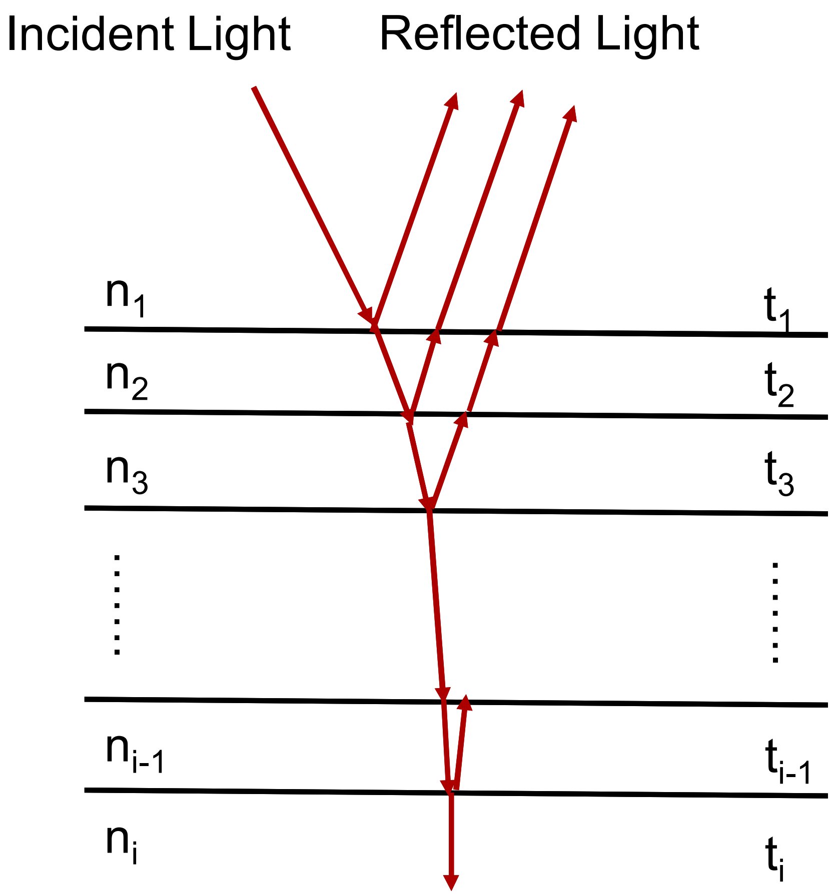








Optical Model



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

$$\mathrm{H}_{i,j} = \begin{pmatrix} 1 & \frac{Q_{i,j}}{\tau_{i,j}} \\ \frac{Q_{i,j}}{\tau_{i,j}} & 1 \end{pmatrix} \qquad L_j = \begin{pmatrix} e^{-i\beta_j} & 1 \\ 1 & e^{+i\beta_j} \end{pmatrix} \qquad \beta_j = \frac{2\pi}{\lambda} n_j t_j$$

$$Q_{i,j} = \frac{Q_\perp + Q_\parallel}{2} \qquad \tau_{i,j} = \frac{\tau_\perp + \tau_\parallel}{2}$$

$$Q_\perp = \frac{n_i \cos\Phi_i - n_j \cos\Phi_j}{n_i \cos\Phi_i + n_j \cos\Phi_j} \qquad \tau_\perp = \frac{2 n_j \cos\Phi_i}{n_i \cos\Phi_i + n_j \cos\Phi_j}$$

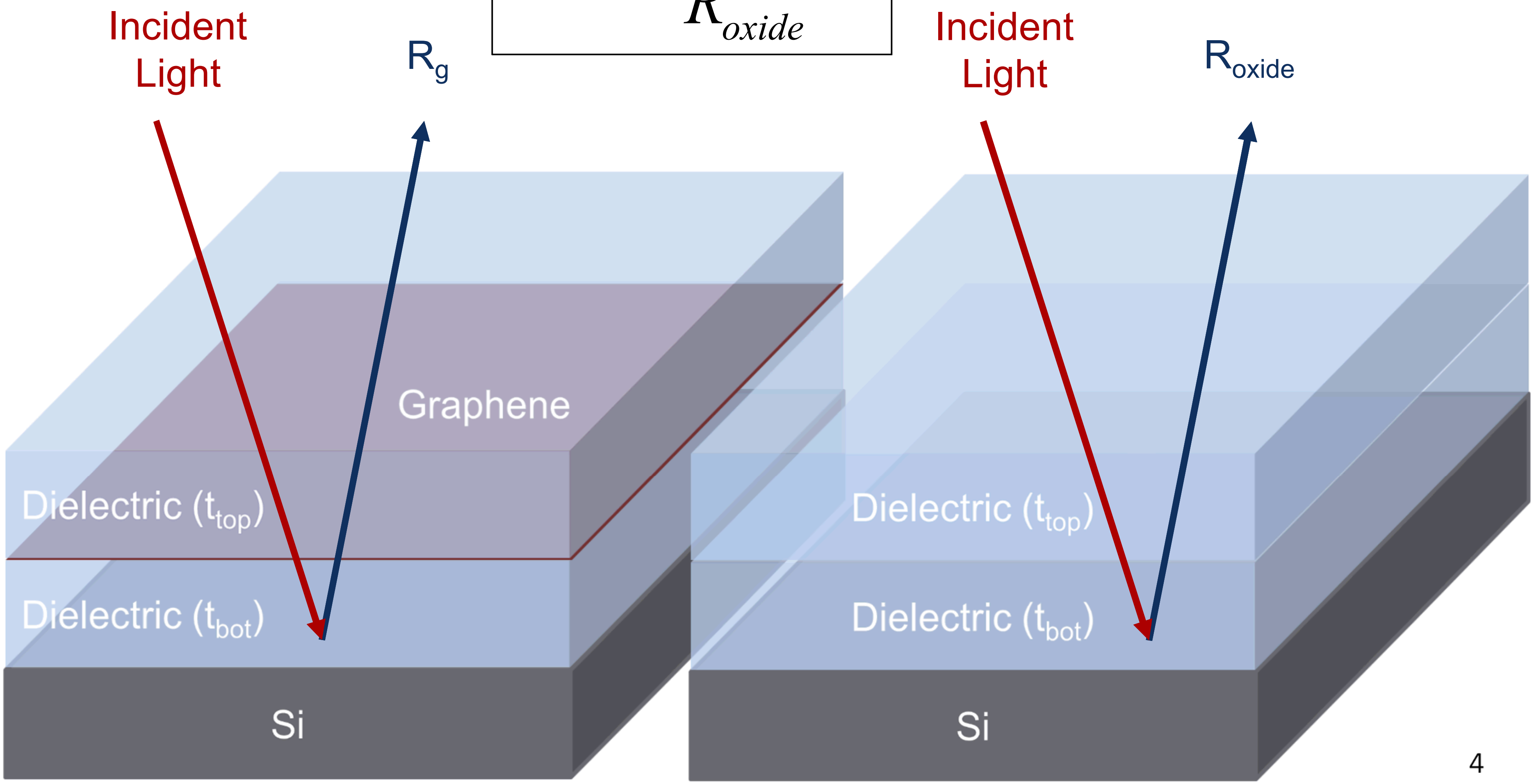
$$Q_\parallel = \frac{n_j \cos\Phi_i - n_i \cos\Phi_j}{n_i \cos\Phi_j + n_j \cos\Phi_i} \qquad \tau_\parallel = \frac{2 n_j \cos\Phi_j}{n_i \cos\Phi_i + n_j \cos\Phi_i}$$

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

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

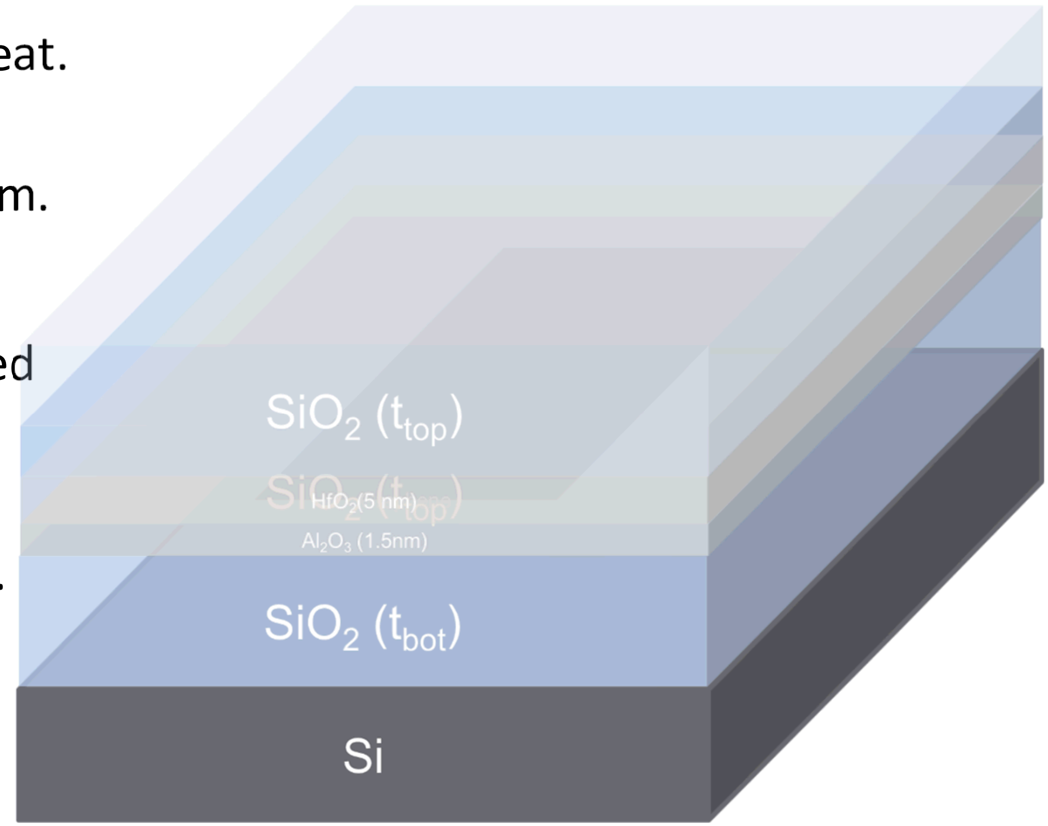
Reflectivity Calculation

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

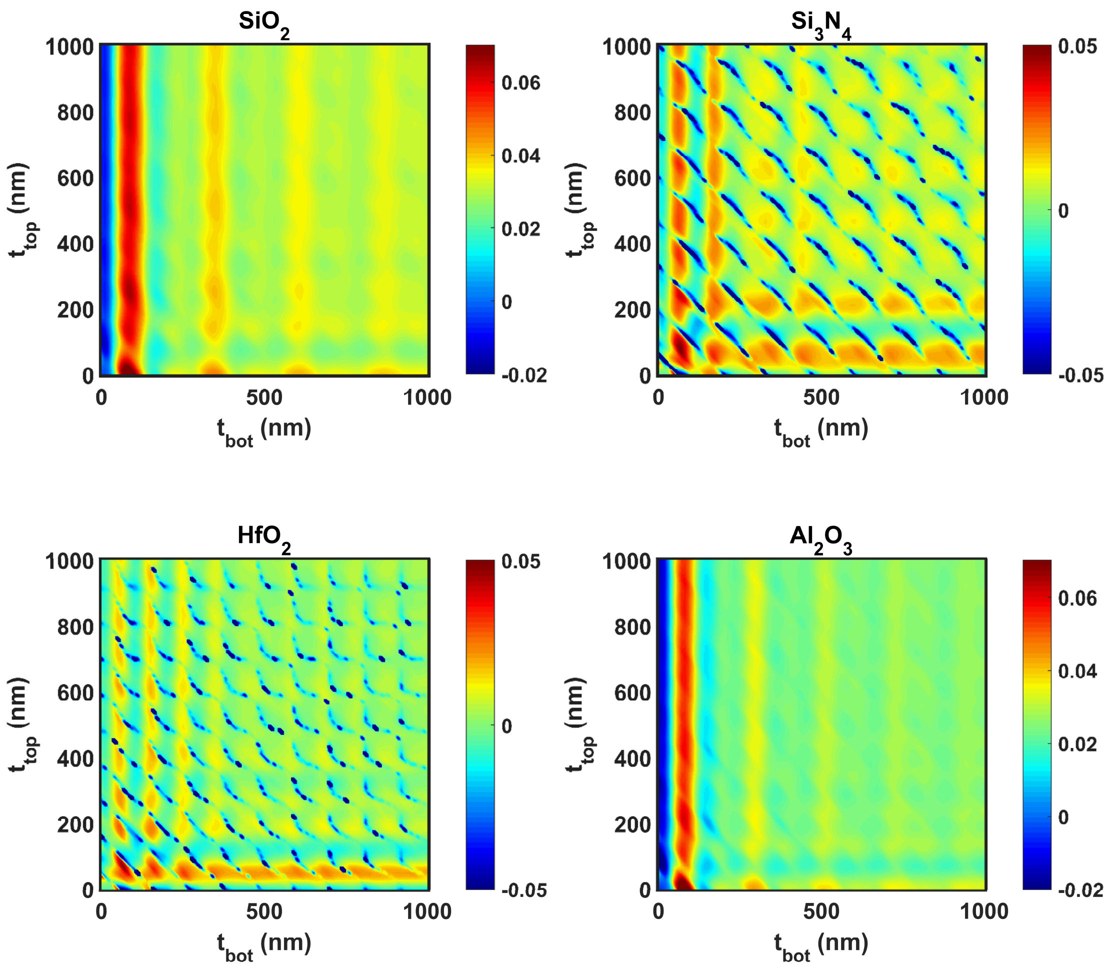


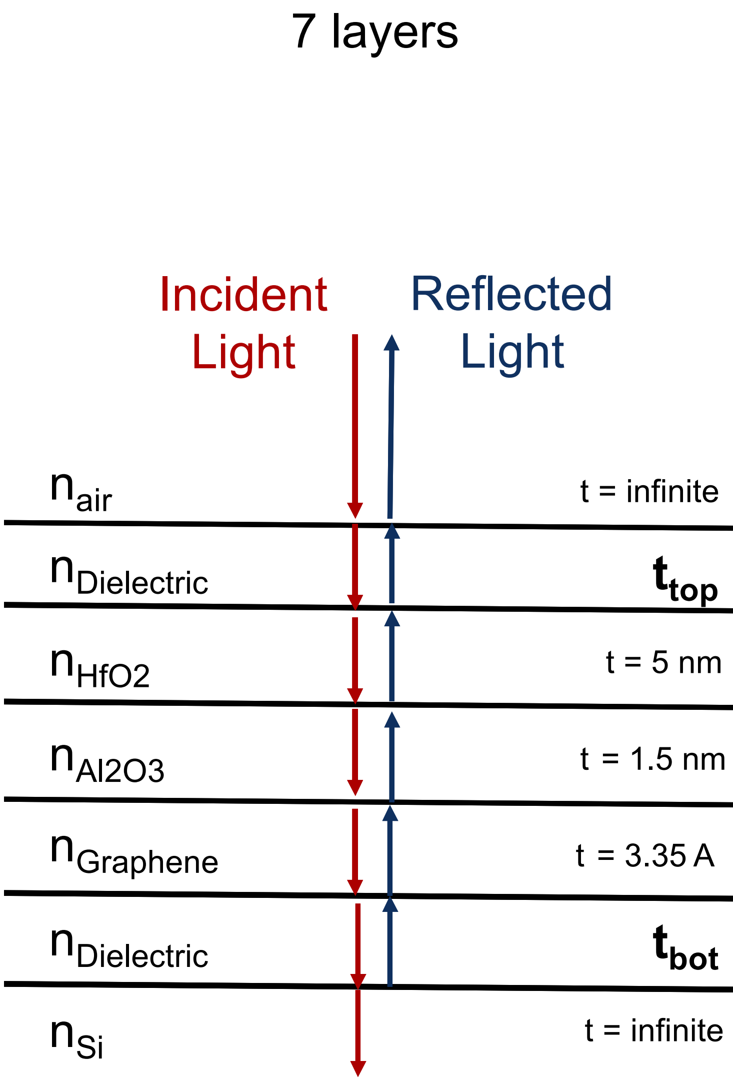
Experimental Stacking

- 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.

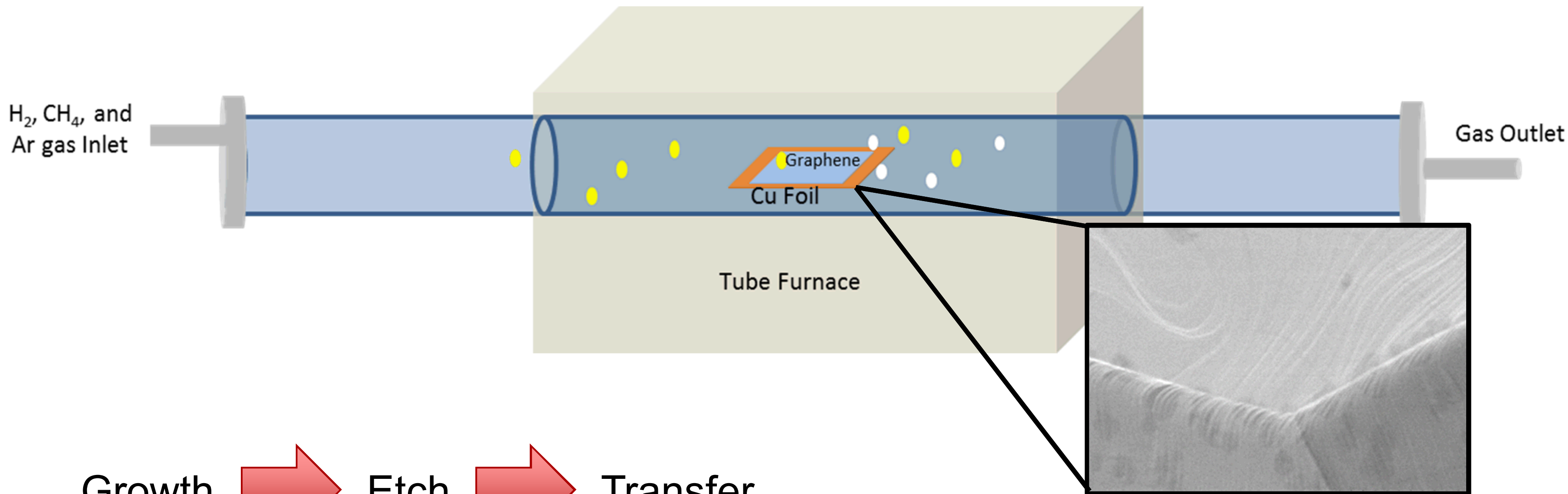


Optical Model Results

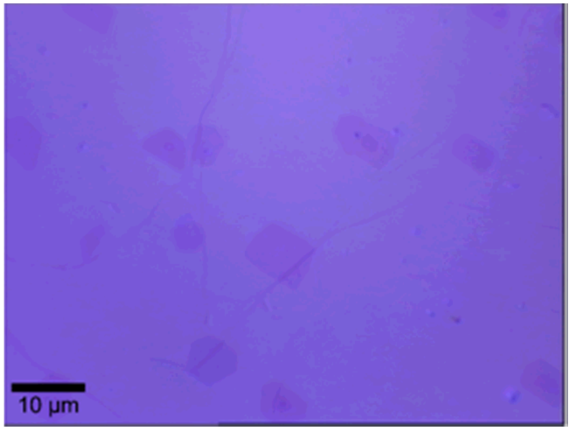


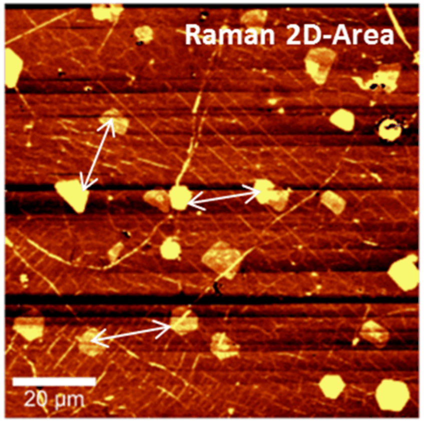


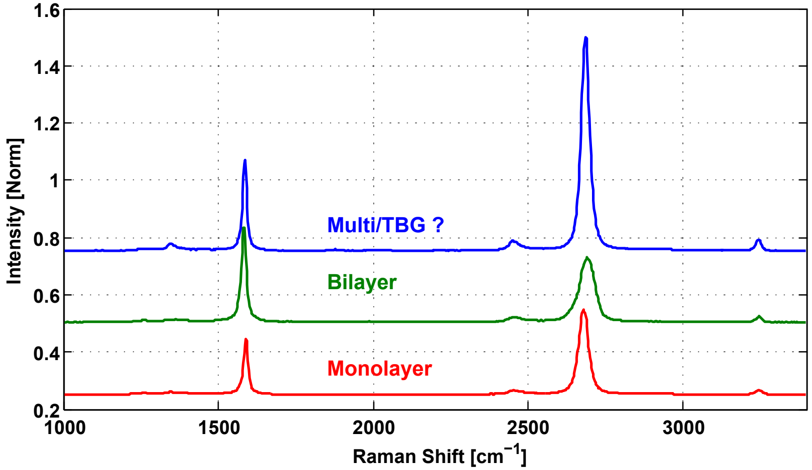
Graphene Synthesis



Growth → Etch → Transfer







RI1 RI2

Contrast Measurement

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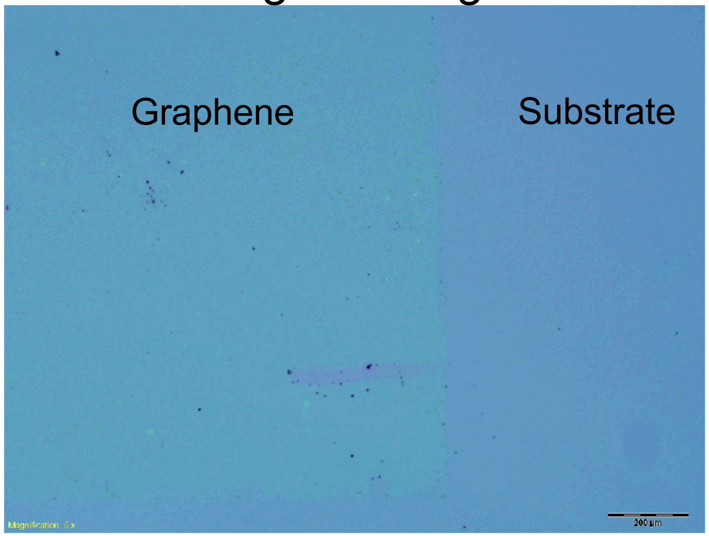
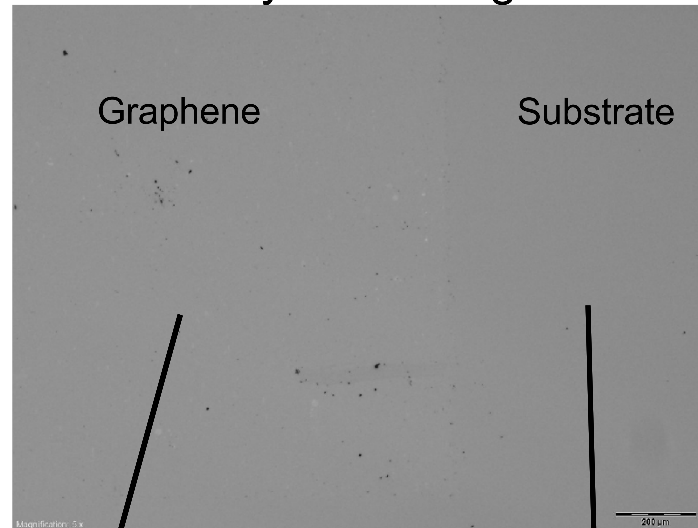
Original Image



Convert to greyscale

Greyscale Image



Measured with Olympus MX80
Objective lenses
    LMPlanFI 5X/0.13
    LMPlan 100X/0.80
Illuminated with 100W mercury apo lamp
    Model U-LH100HGAPO

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})

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

Slide 8

RI1 Ruiz, Isaac, 9/29/2016

RI2 Ruiz, Isaac, 9/29/2016

Experimental Results

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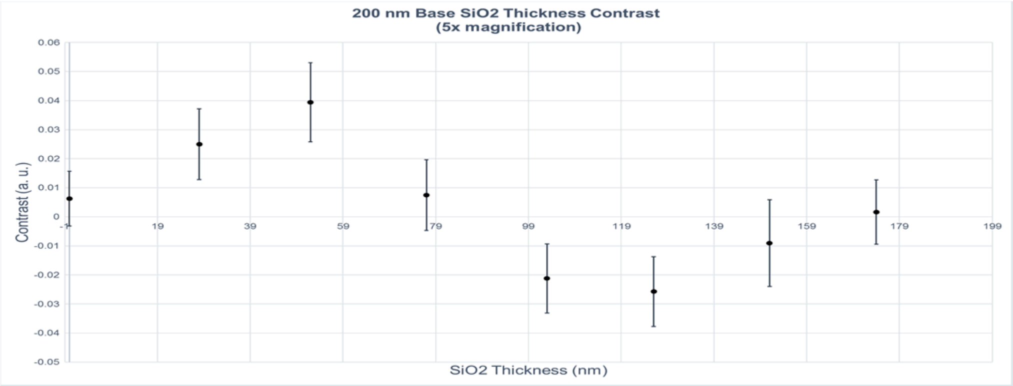
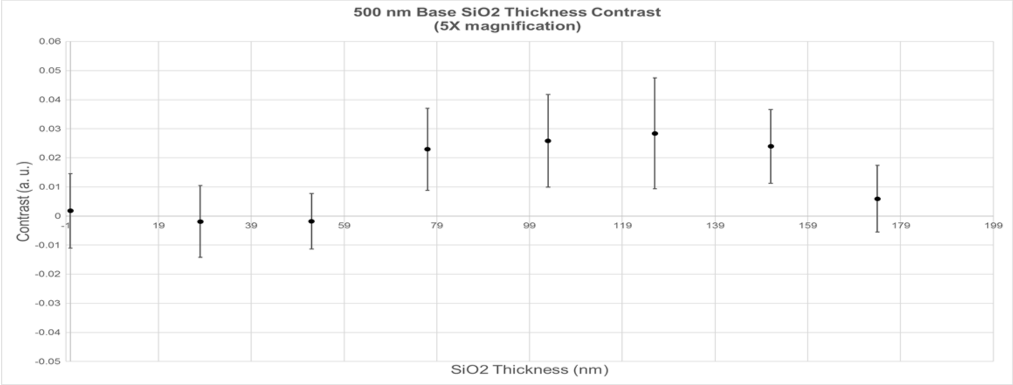
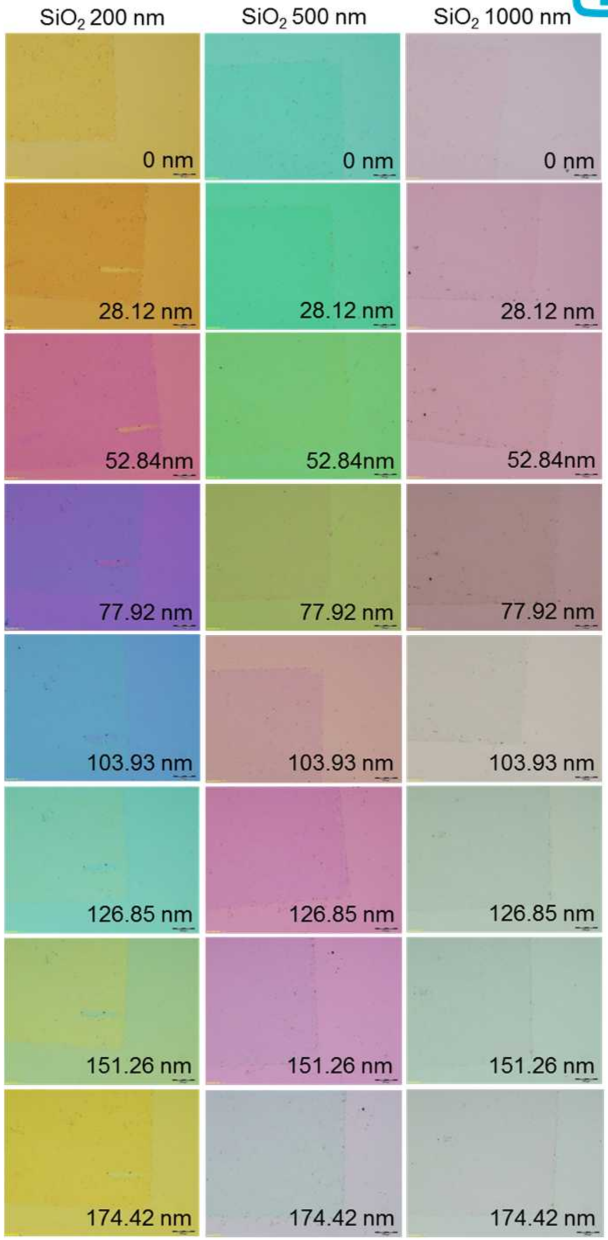
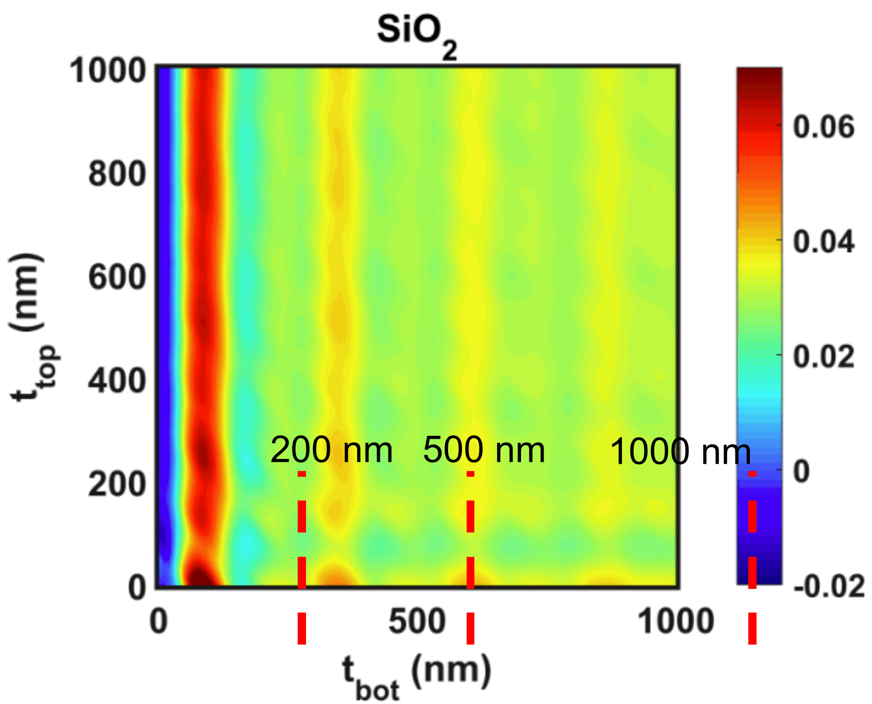


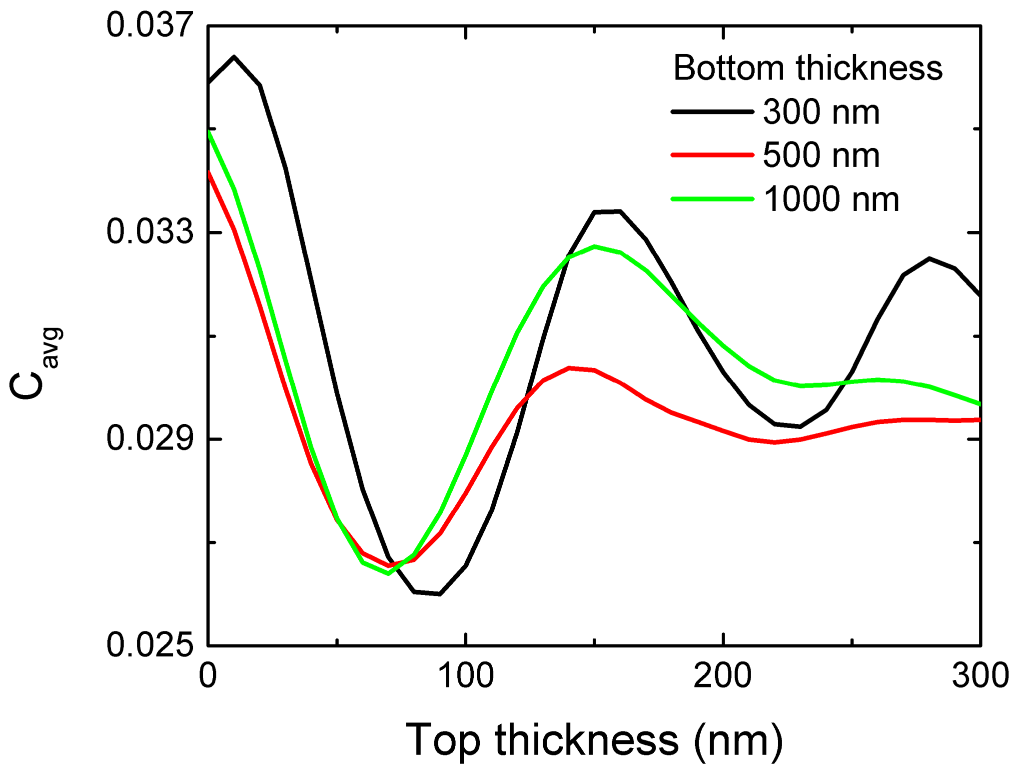




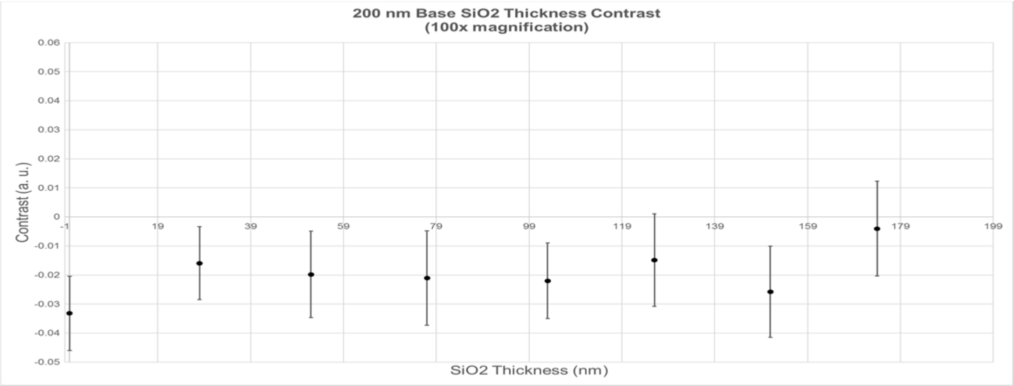
Low Magnification
LMPlanFI 5X/0.13

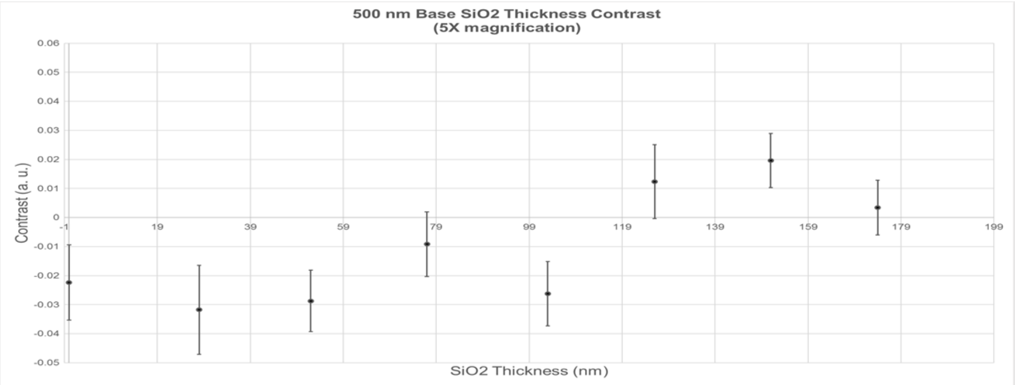
Comparison to Model

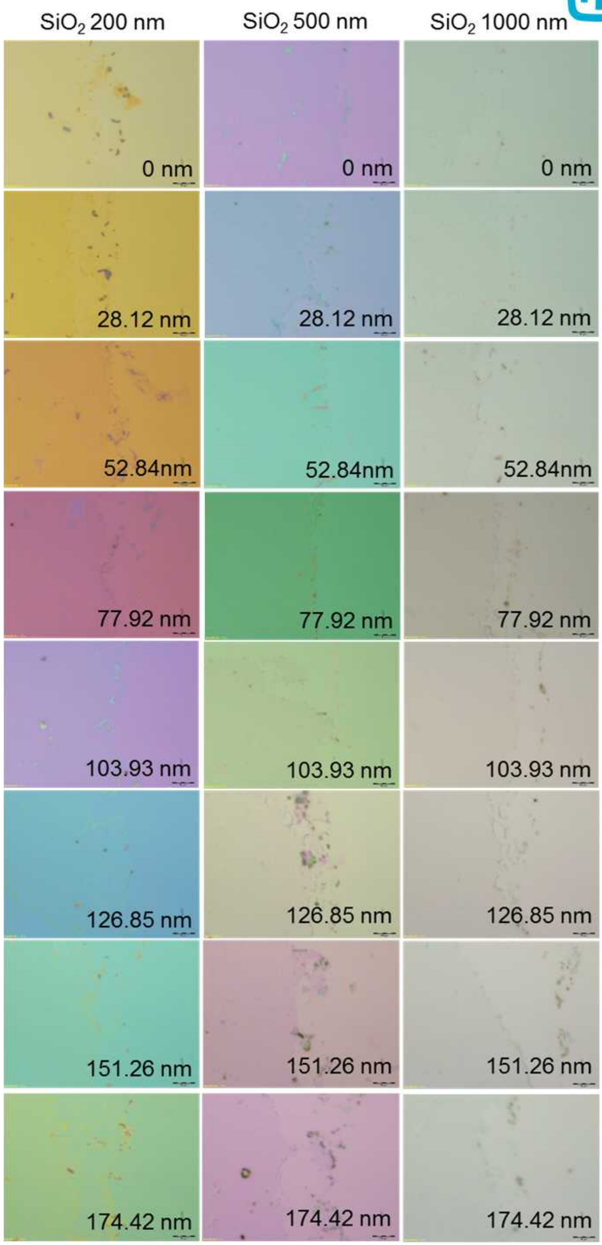




High Optical Mag

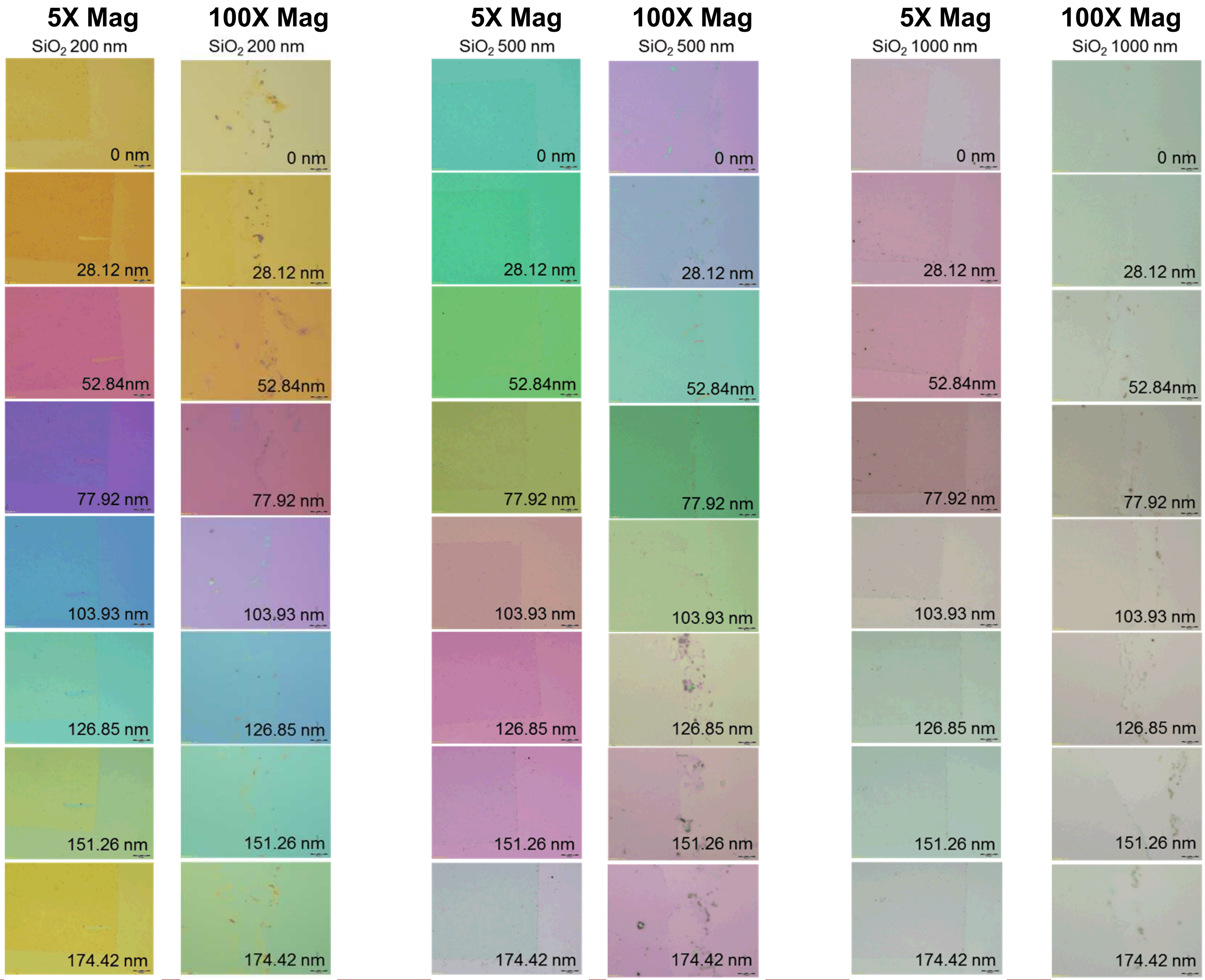






Low Magnification
LMPlanFI 100X/0.80

High Mag vs Low Mag



Future Work

- Angle of incidence is an important factor making graphene visible.
  - Must be taken into account in model
- Measure accurate optical constants
  - Dielectrics
  - Graphene

- Experimentally check the interesting variability in contrast predicted for HfO_2 and Si_3N_4

Conclusion

- Developed model to calculate reflectivity of multilayer stacks.
  - Calculated contrast of passivated graphene films in 7 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

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SNL Researchers

Stephen W. Howell

Michael Goldflam

Bruce L. Draper