Large Area Plasma-Enhanced Chemical Vapor Deposition of Nanocrystalline Graphite on Insulator for Electronic Device Application

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Outline

- Why PECVD for graphene deposition?
- PECVD system and deposition
- Nanocrystalline graphite (NCG)
- Device fabrication
- Conclusion

Why PECVD for graphene growth?

Comparison of methods for growth of graphene

Method		Advantage	Disadvantage
Exfoliation from graphite	Use adhesive tape to peel graphene from HOPG	Highest quality Simple	Random (shape, size, location) Does not scale
Epitaxial growth on SiC	Anneal SiC (1200 – 1500°C) → Si sublimation	Good Control over number of layers Large domains	Expensive substrates High temperature Surface steps
Catalytic growth on metal	Heat catalyst film and supply hydrocarbon (CVD: 530 – 1000°C; SWP-CVD: 300°C)	No limit of substrate size Low temperature	Requires graphene transfer for electronic application

- Research into growth methods not exhausted

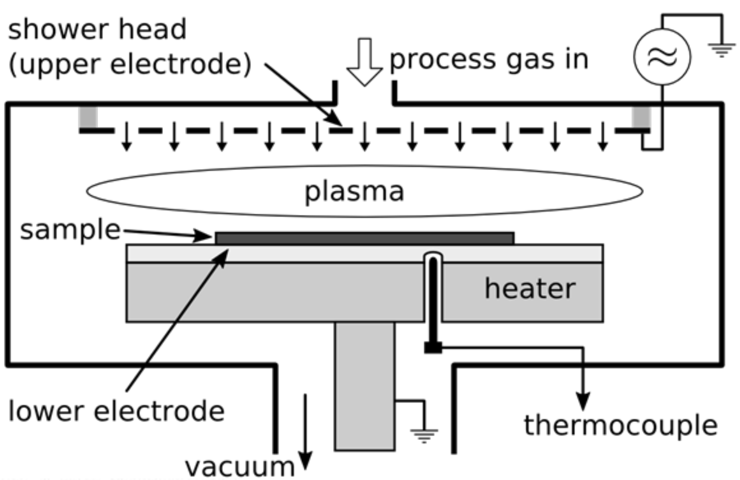
PECVD deposition

- PECVD in use for large-area uniform film deposition
- Different plasma-enhanced CVD methods for graphene or graphene-like film deposition reported
  - Remote PECVD [1]
    → Custom built/modified equipment
  - Surface wave PECVD [2]
    → On metal, requires transfer
- Evaluate the PECVD route further

[1] L. Zhang et al., *Nano Research*, vol. 4, no. 3, pp. 315–321, 2010.
[2] J. Kim et al., *Applied Physics Letters*, vol. 98, no. 9, p. 091502–091502–3, 2011

Chemistry and PECVD System

- Carbon source (CH_4) → CH_x, C_2H_y, C_3H_z, H
- Chemical binding followed by hydrogen desorption
- PECVD system used
  - Oxford Instruments Nanofab 1000 Agile
  - 200 mm substrates, parallel plate configuration



www.oxford-instruments.com

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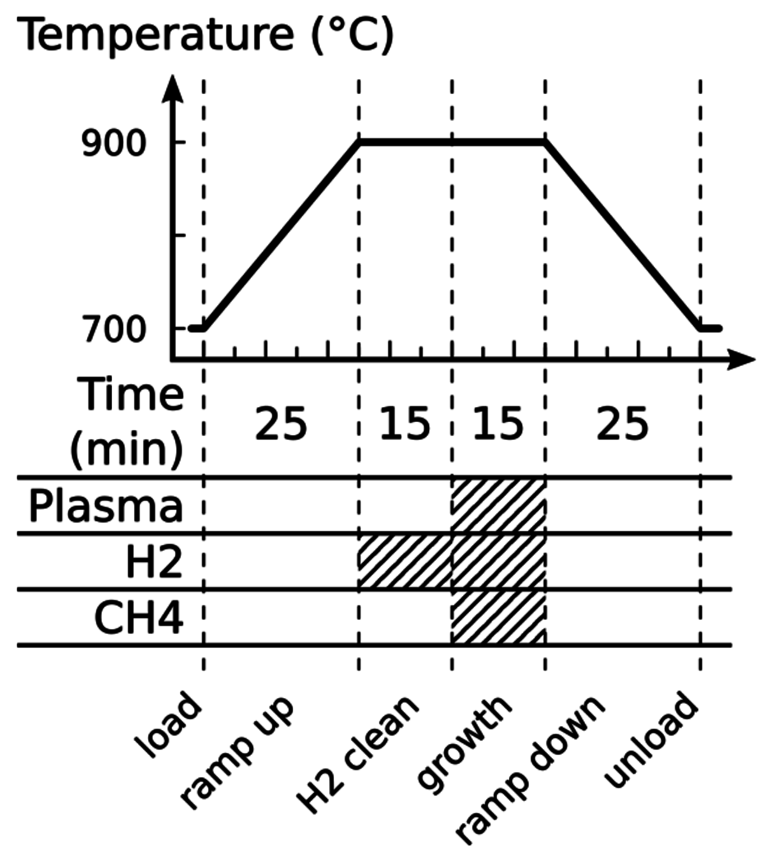
Deposition Process

- Si wafer with 240 nm thermal oxide

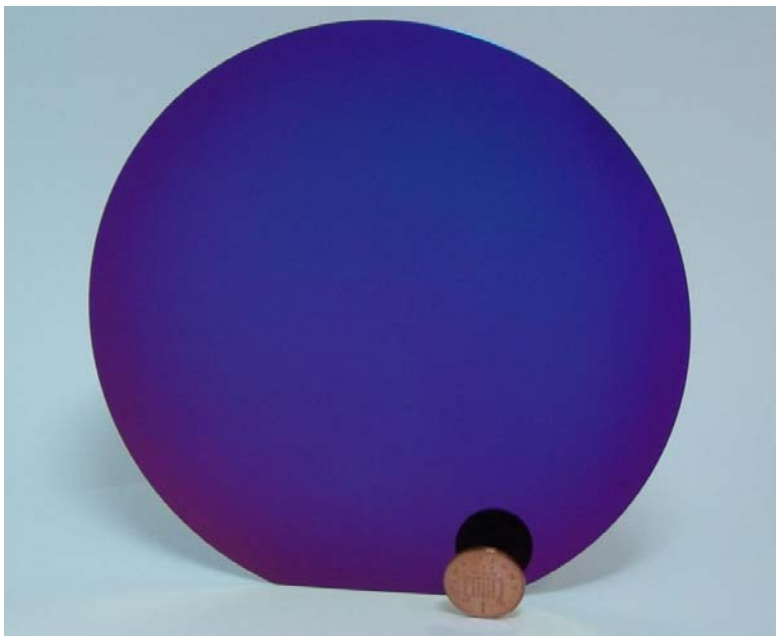
1. Heat-up from loading to processing temperature
2. Hydrogen pre-treatment
3. PECVD deposition
4. Cool-down and unload



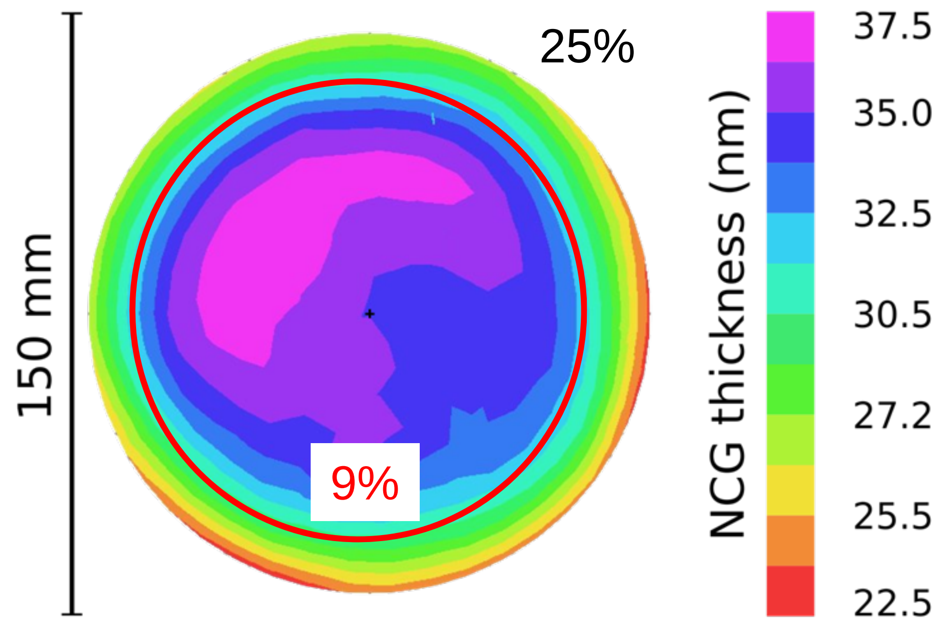
(step durations are typical values)

Deposition uniformity

- 15 minutes, 900°C, 100 W RF,
  90 sccm H_2, 72 sccm CH_4 → 30-37 nm thickness



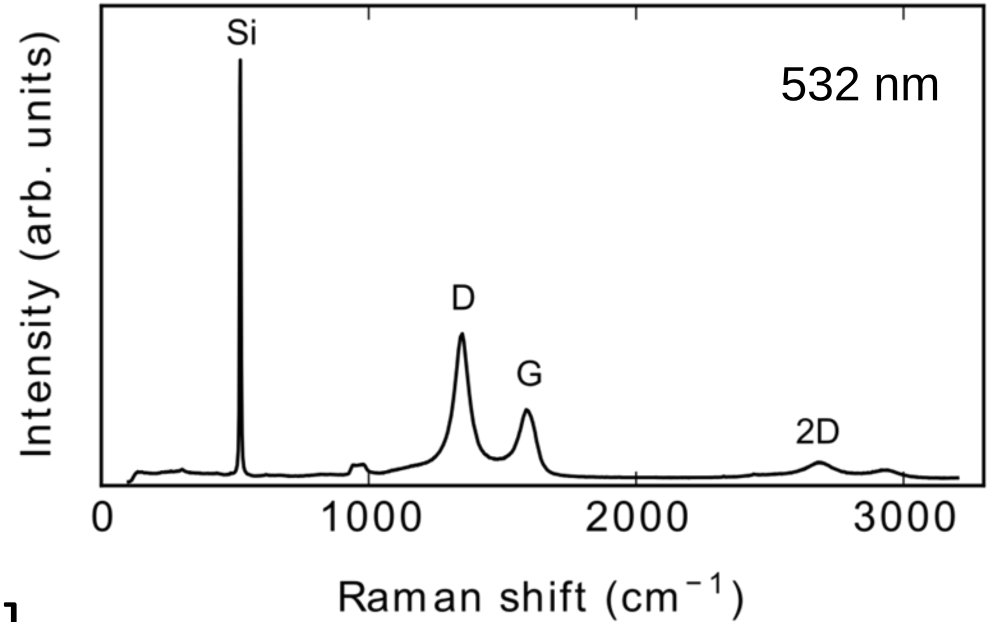
150 mm (6”) substrate



Ellipsometer thickness mapping

$$Max - Min = \frac{(Max\ - Min)}{(Max + Min)} \times 100\%$$

Raman



- Deposited films exhibit distinct D (1350 cm^{-1}), G (1600 cm^{-1}) and broad 2D (2700 cm^{-1}) peaks
- I(D)/I(G) = 2.06
- Film described before [3]
  1. G-peak position unaffected by λ (1600 cm^{-1})
  2. I(D)/I(G) ≈ 2

→ Nanocrystalline graphite

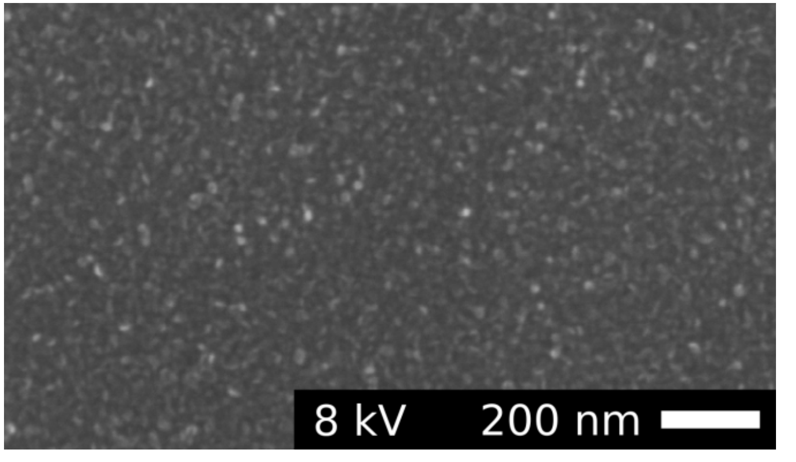
[3] A. C. Ferrari and J. Robertson, Phil. Trans. R. Soc. A 362 (2004), pp 2477–2512

Nanocrystalline graphite

- NCG is a film with crystalline ("graphene") domains in random orientation
- Size of crystalline domains L_a can be estimated from I(D)/I(G) ratio [4]

$$\frac{I(D)}{I(G)} = \frac{C(\lambda)}{L_a}$$

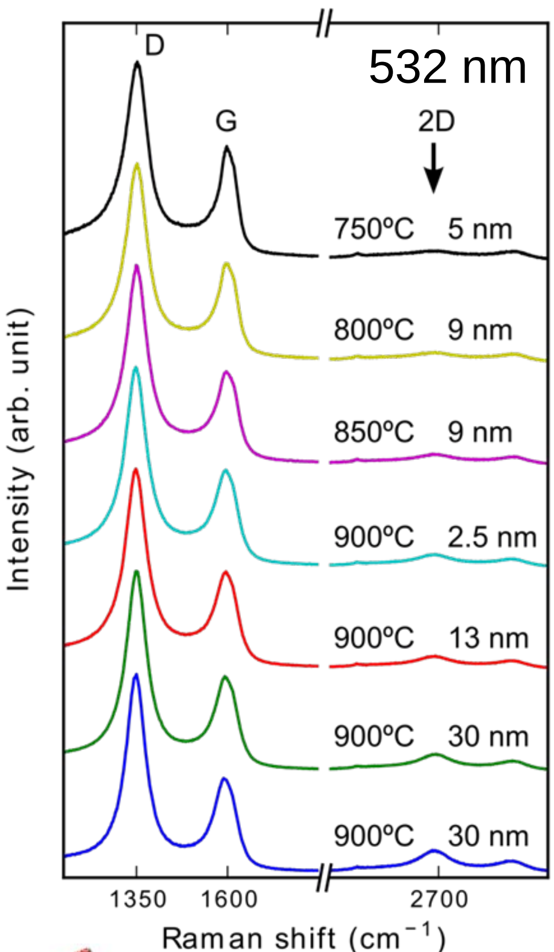
- Our films
  L_a = 2.2 to 2.7 nm

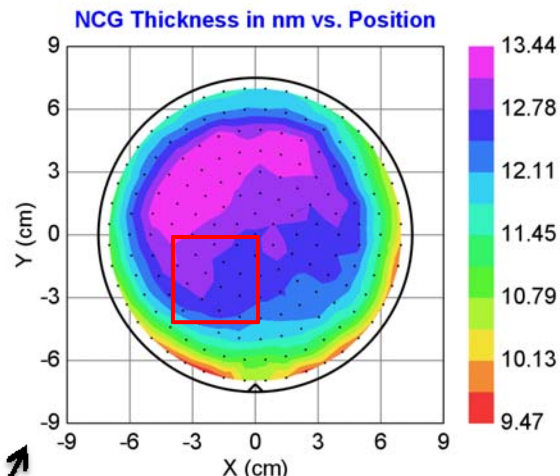


SEM of NCG surface

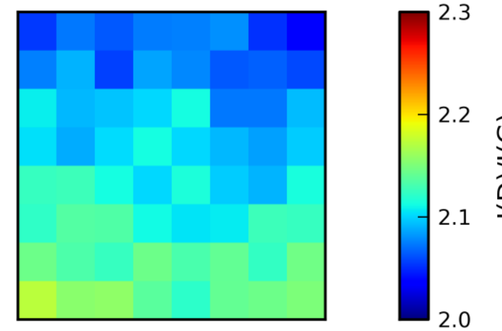
[4] A. C. Ferrari and J. Robertson, Physical Review B, 61(20) (2000), 14095

Other deposition conditions

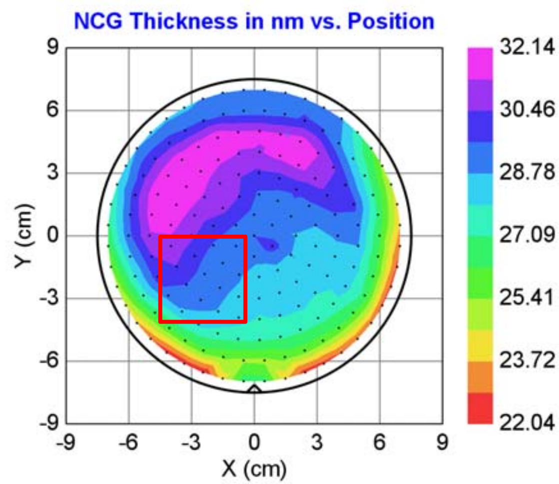




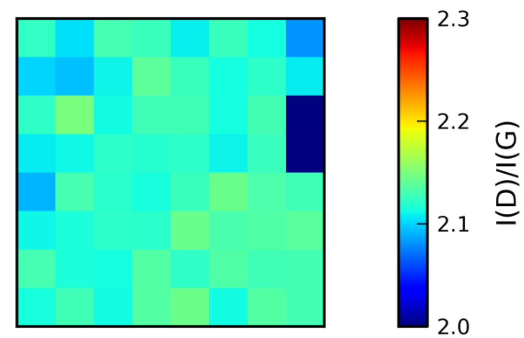
17% 8%



Raman map



19% 9%



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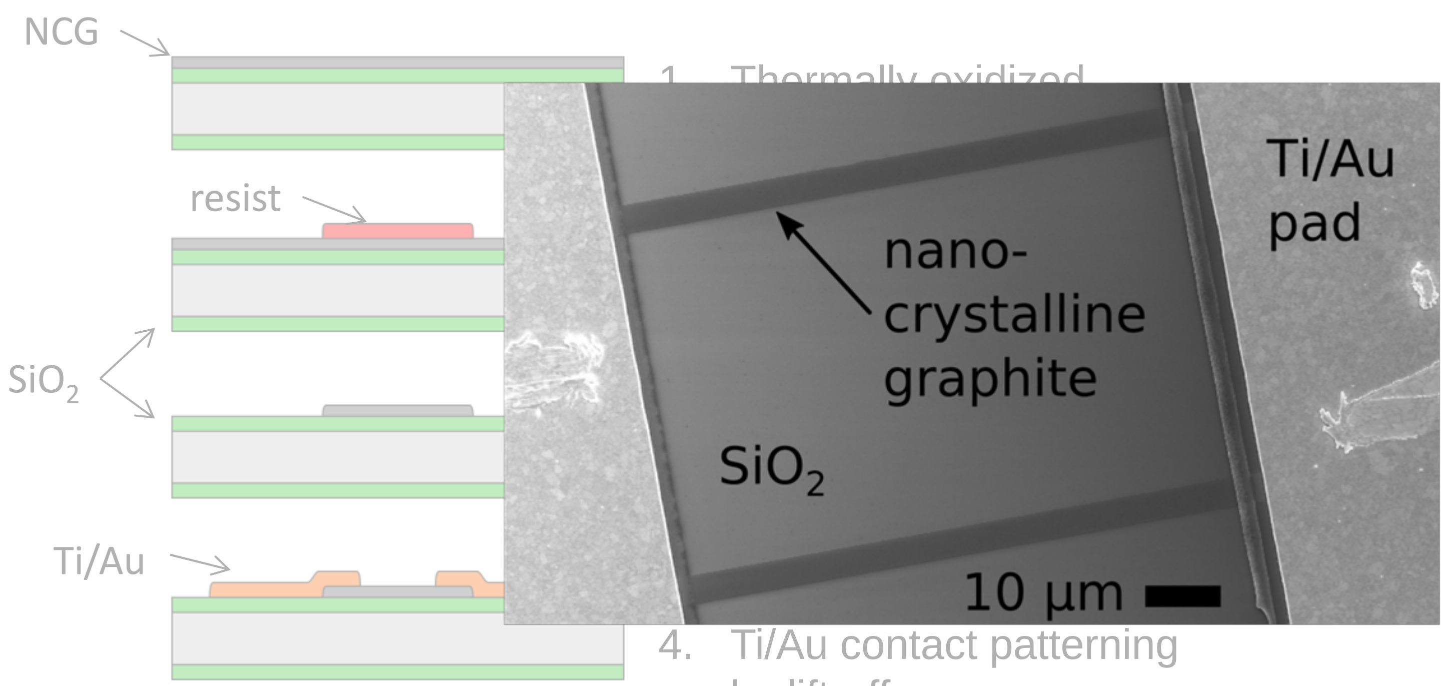
Device fabrication

- Contacted NCG strips fabricated



1. Thermally oxidized

4. Ti/Au contact patterning by lift-off

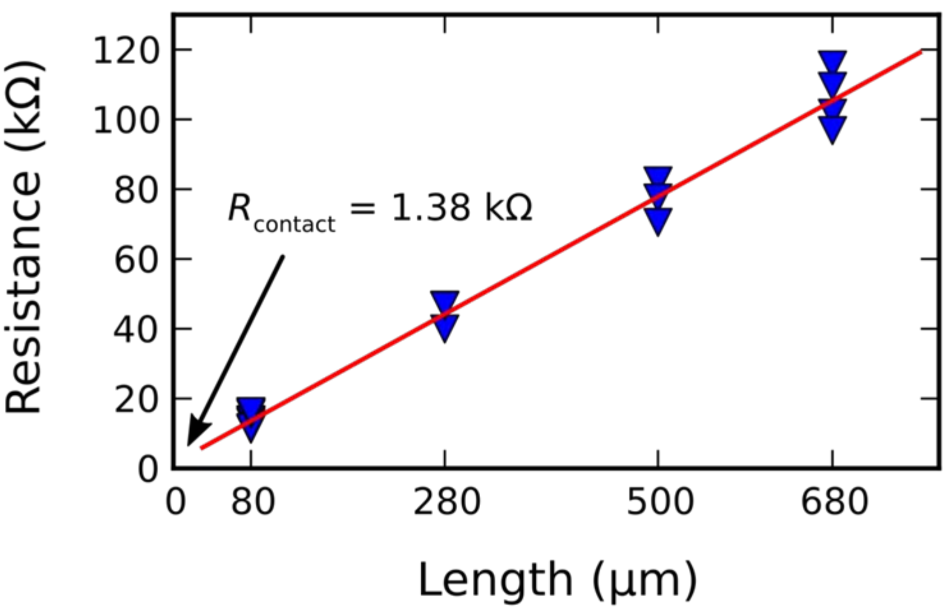
Resistivity

- Fabricated devices

ρ = 0.029 Ω cm

- Van der Pauw

ρ = 0.012 Ω cm



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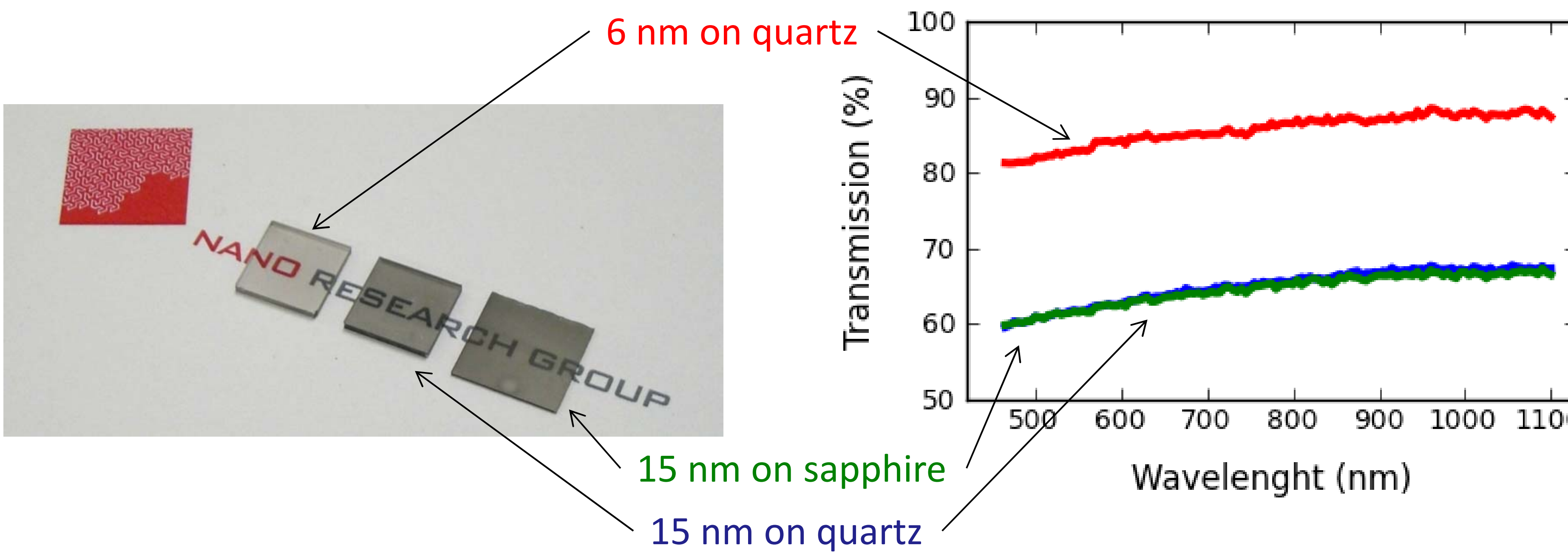
Film transparency

- NCG deposited on quartz and sapphire
- Optical transmission measured



- 85% transparency @ 13 kΩ/sq for 6 nm film on quartz glass

Conclusion

- Demonstrated large-area, meta-free PECVD of nanocrystalline graphite
- Uniform NCG coverage over 150 mm substrates
- Substrate size not limited
- Sheet resistance in kΩ/sq range
- NCG optical transparency > 85%
- NCG can be easily patterned and contacted
- Potentially usable for transparent electrodes

Growth comparison

Lets look at the comparison again

Method		Advantage	Disadvantage
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Plasma assisted deposition on insulator (including this work)	**Substrate exposed to carbon plasma**	**Metal-free** **Large-area** **Directly on insulator**	**?**

Acknowledgements

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Thank you for your attention