

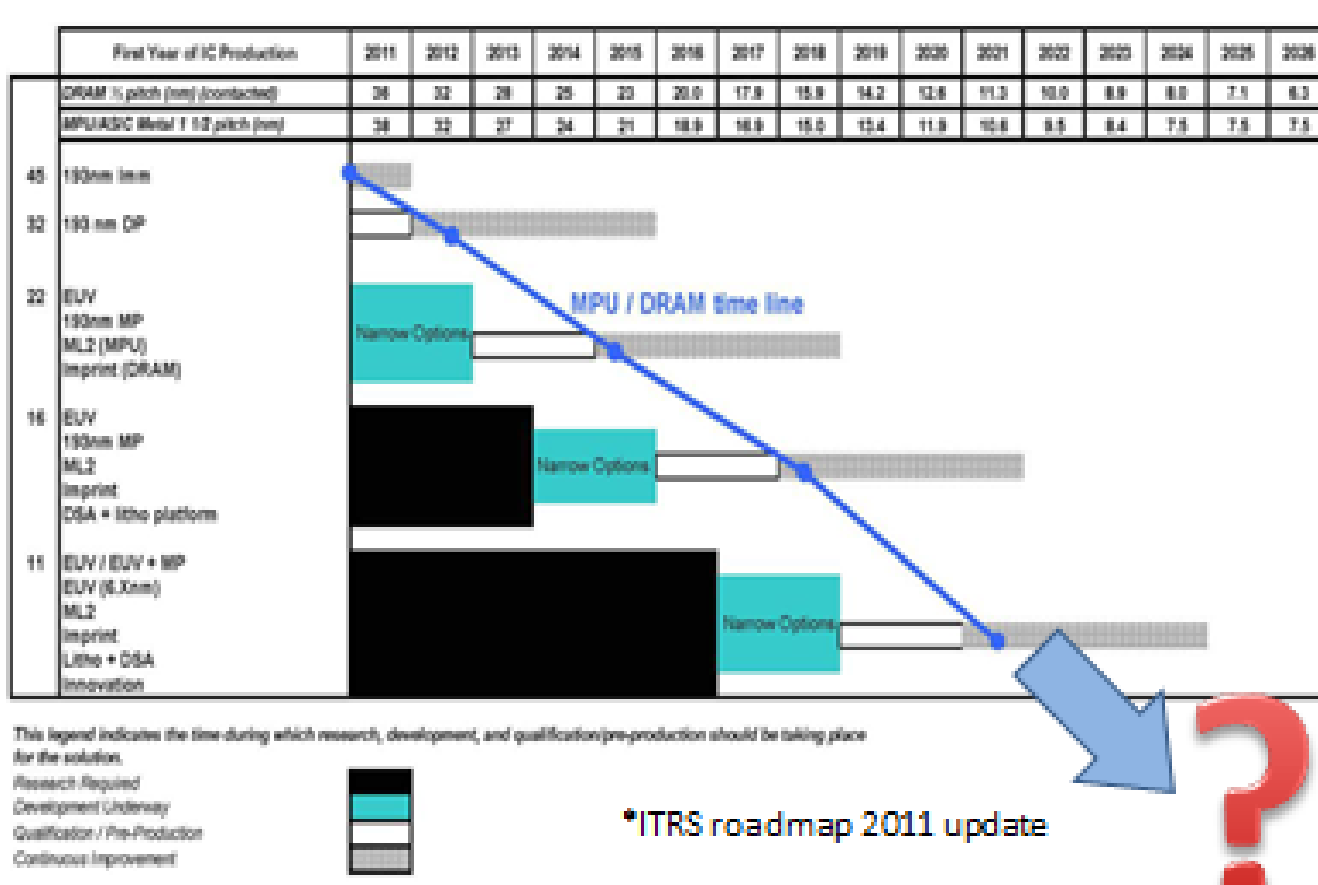
Sub-5 nm Patterning Using Helium Ion Beam Lithography and Nanoimprint Lithography

Yifei Wang¹, Ahmad N. Abbas¹, He Liu¹, Yuhan Yao¹, Wen-Di Li², Chongwu Zhou¹, R. Stanley Williams³ and Wei Wu^{1*}

¹University of Southern California, ²University of Hong Kong, ³HP labs, Hewlett-Packard Co.

*Email: wu.w@usc.edu Web: <http://www.usc.edu/dept/ee/wugroup/>

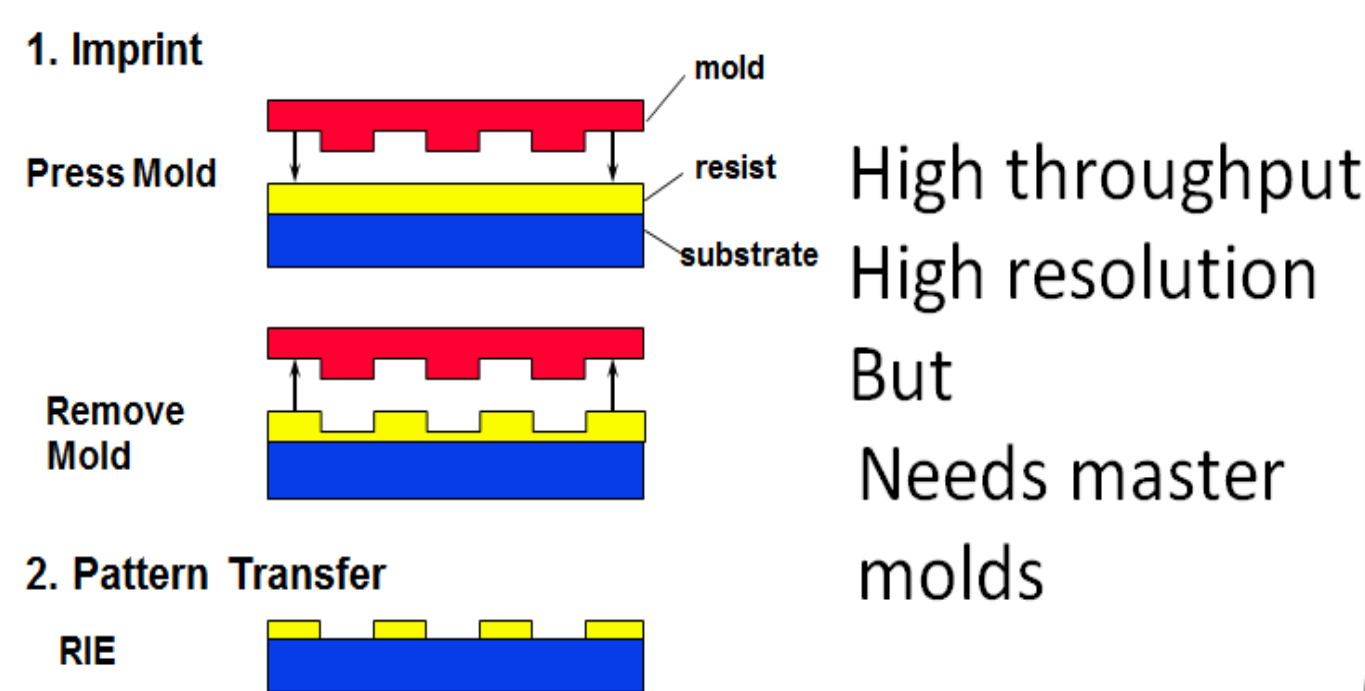
Where is the end of roadmap?



Goal: Deterministic patterning with sub-5 nm resolution.

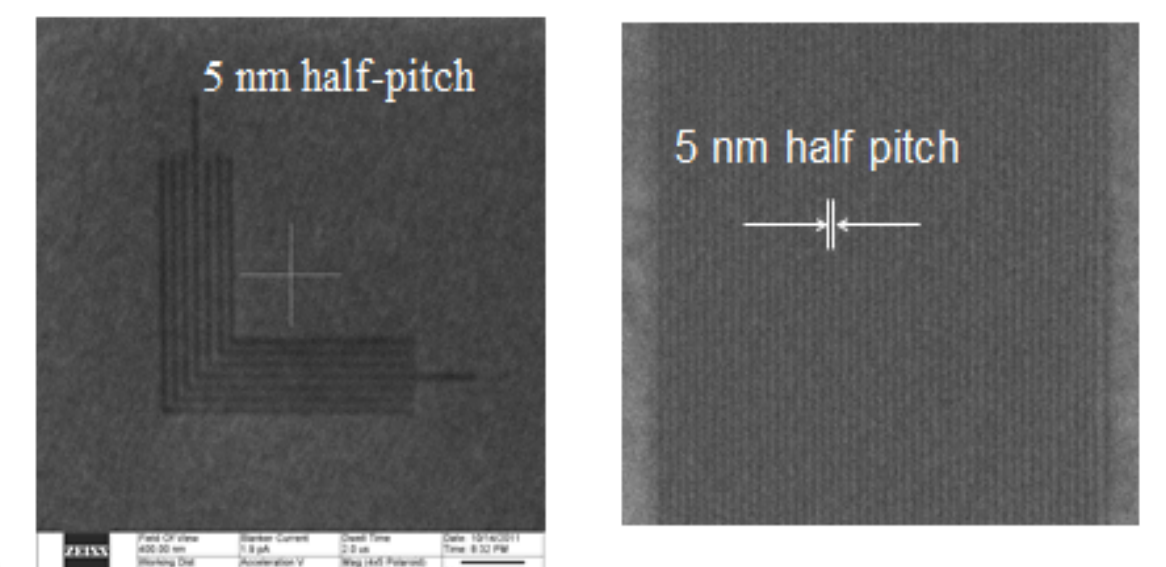
- Enabling technology for nanodevices.
- Reach the end of roadmap.
- Electron-beam lithography doesn't have enough resolution.

Nanoimprint lithography



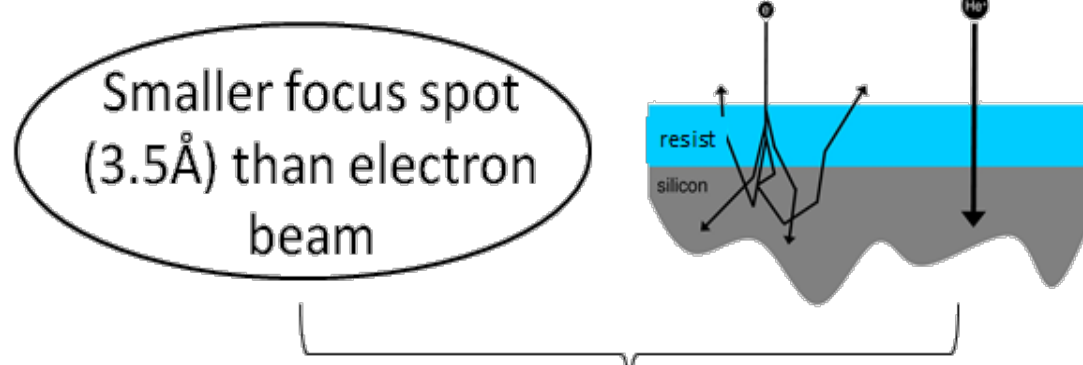
Direct Mill using He Ion Beam

Cr film Graphene Nanoribbons



He Ion Beam Lithography

Less proximity effects than EBL

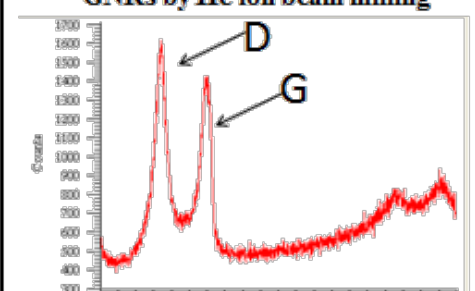


Better beam for lithography!

- But
- Slow
 - Damage certain substrate

Raman Spectra Show better Line-edge Smoothness

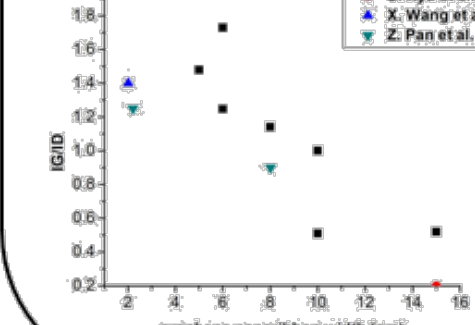
Raman Spectrum of 10 nm half-pitch GNRs by He ion beam milling



Using Raman spectra as the benchmark for line-edge roughness

- G: breathing mode
- D: defect mode (edge)
- Rougher edges, higher D peak
- Our GNRs have smoother line-edges based on IG/ID ratio

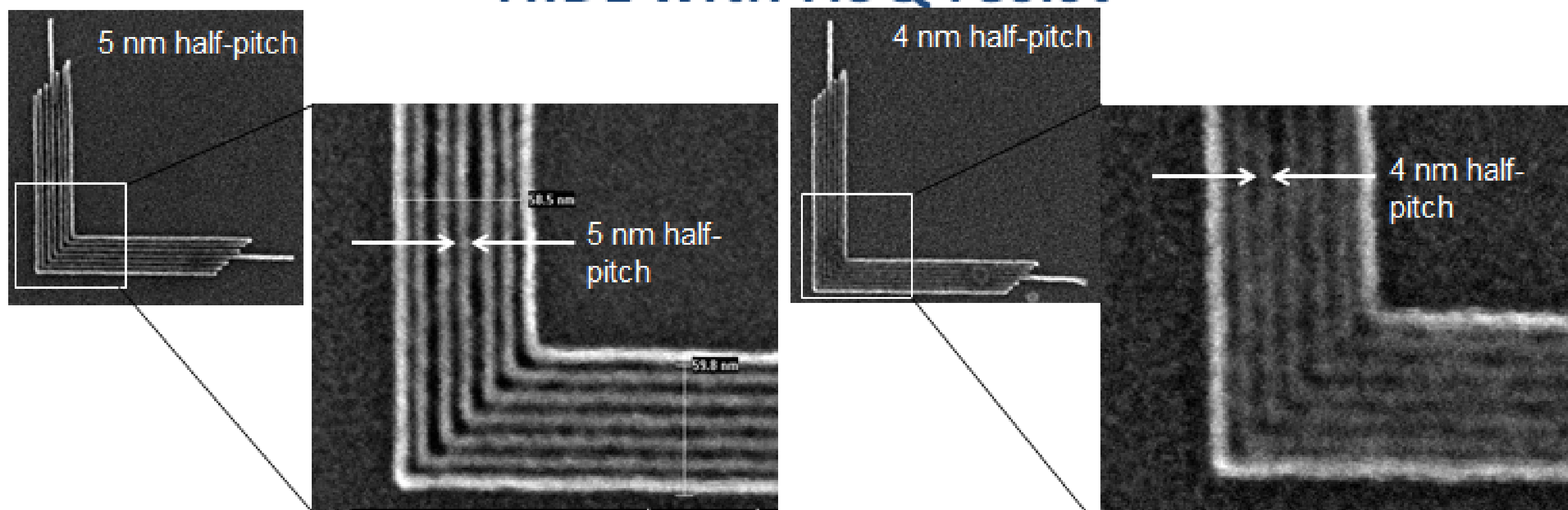
Comparison of IG/ID



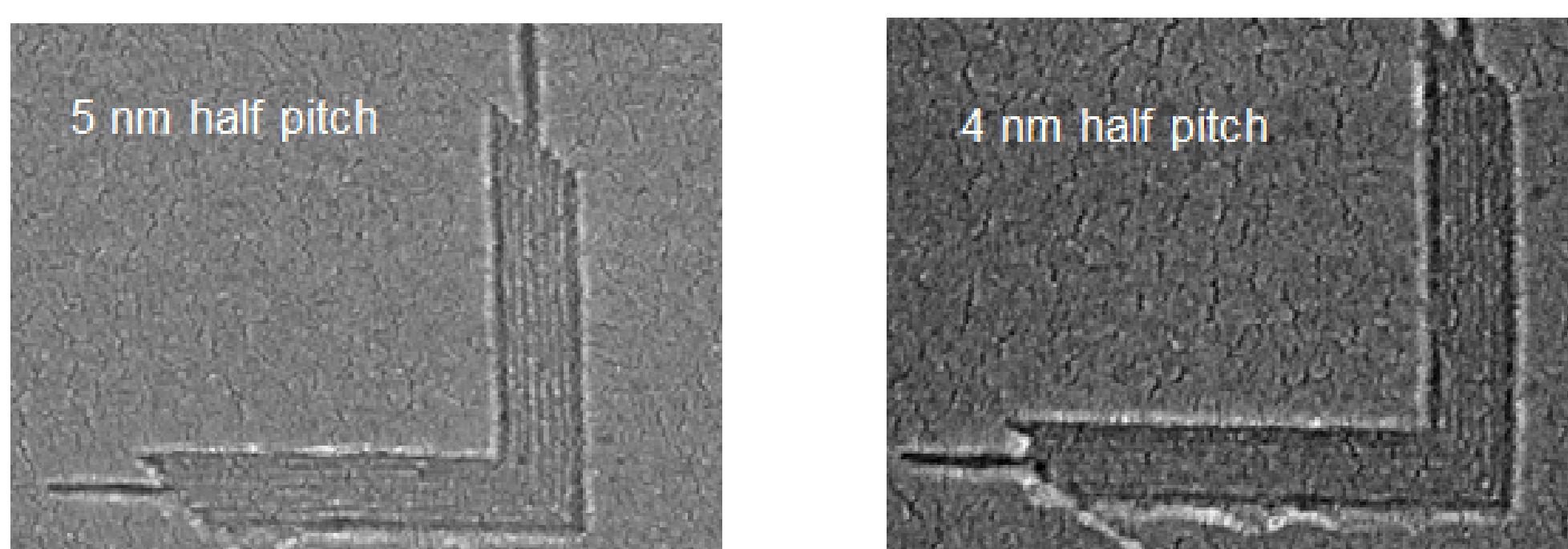
He ion milling is a promising tool for Graphene nanoribbons patterning

- Graphene has zero bandgap, so GNRs are needed.
- He ion milling has high resolution.
- He is inert, so there is no contamination.
- We showed smoother line edges than other top-down approaches.

Combination of He Ion Beam Lithography and Nanoimprint Lithography HIBL with HSQ resist

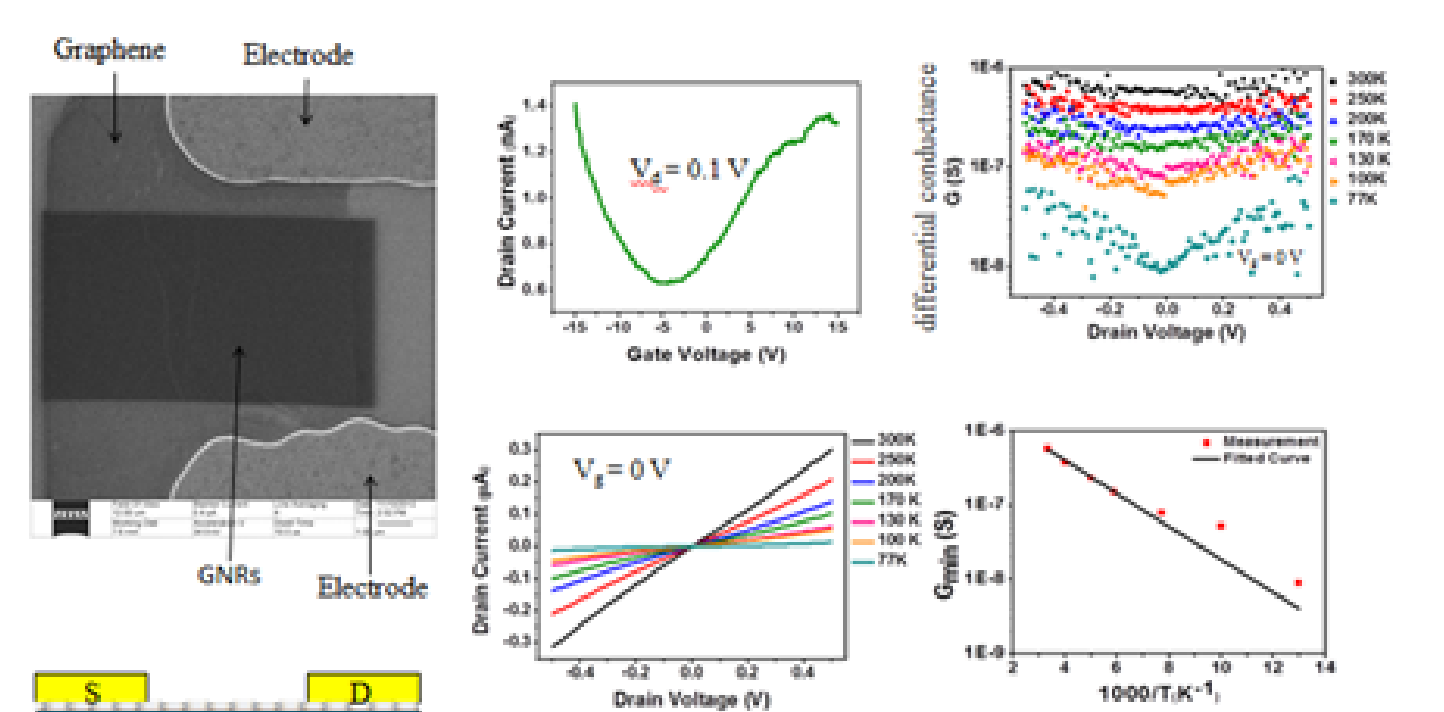


NIL using Mold Fabricated by HIBL



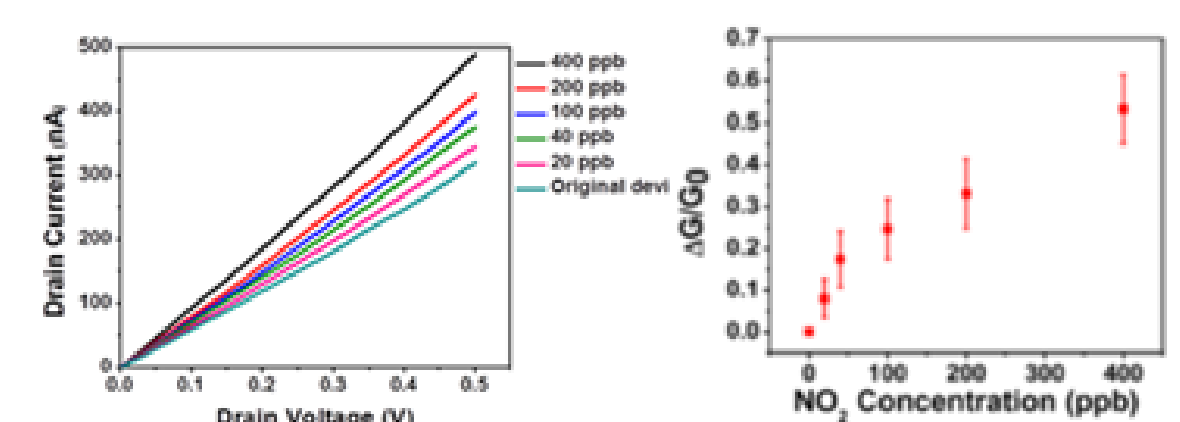
• Imprinted on glass substrate using UV NIL. • A thin Pt layer is coated to dissipate charge in SEM. • The roughness is due to the Pt coating.

GNRs FET NO₂ Gas Sensor



$$G_{min} = G_1 e^{-\frac{E_A}{k_B T}}$$

$E_A = 44 \text{ meV}$
 $E_G \geq 2 E_A = 88 \text{ meV}$



- NO₂ acts as an electron attractor
- Bandgap opening provides higher sensitivity
- Edge states are more active site to bond with NO₂
- Safe level of NO₂ is 0.2 ppm
- Detection of 20 ppb NO₂ has been demonstrated