“Ultra-Clean High Mobility Graphene on Technologically Relevant Substrate”

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Clean CVD graphene why and how?

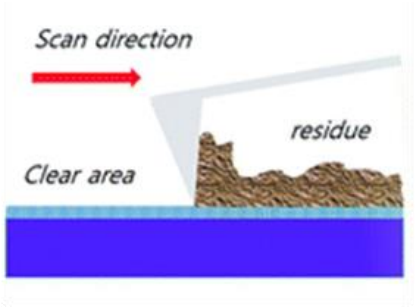
Why clean CVD graphene is needed?

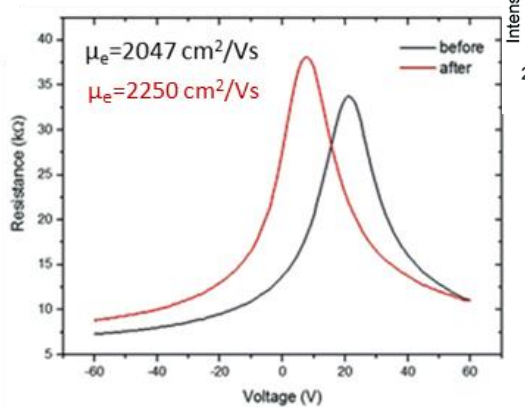
- To achieve high mobility at room temperature.
- To obtain high quality heterostructures from graphene with other 2D materials.
- To fabricate high quality optoelectronic devices such as, photodetectors, modulators etc.

Source of contamination in CVD graphene

- The main source of contamination for the CVD graphene are the polymers e.g., PMMA needed during different processes including transfer and device fabrication process.

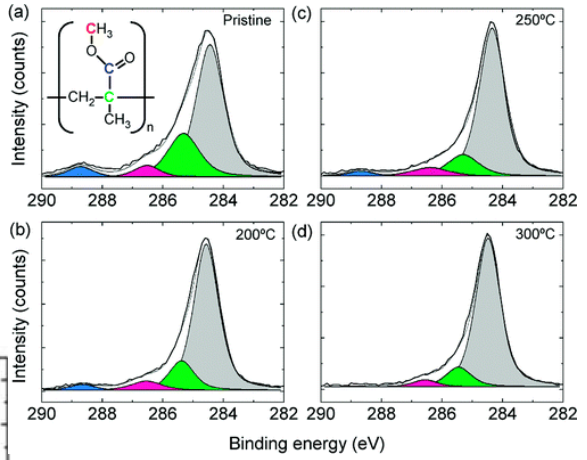
1). By using AFM tip





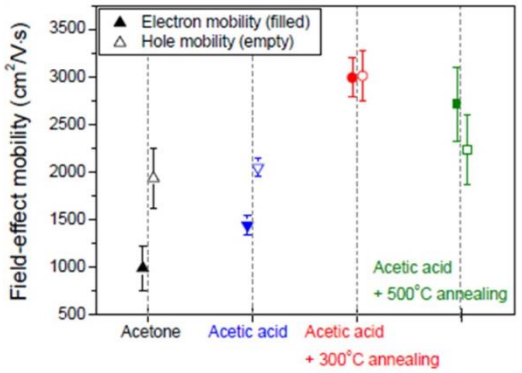
W. Choi *et al.*, *RSC Adv.*, 2017, **7** , 6943

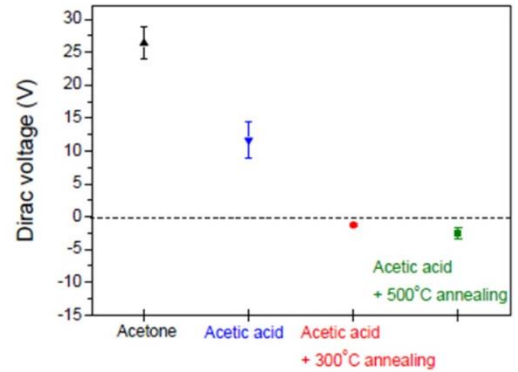
2). By annealing in vacuum



Lin et *al., Nano Lett.* 2012, 12, 414−419.

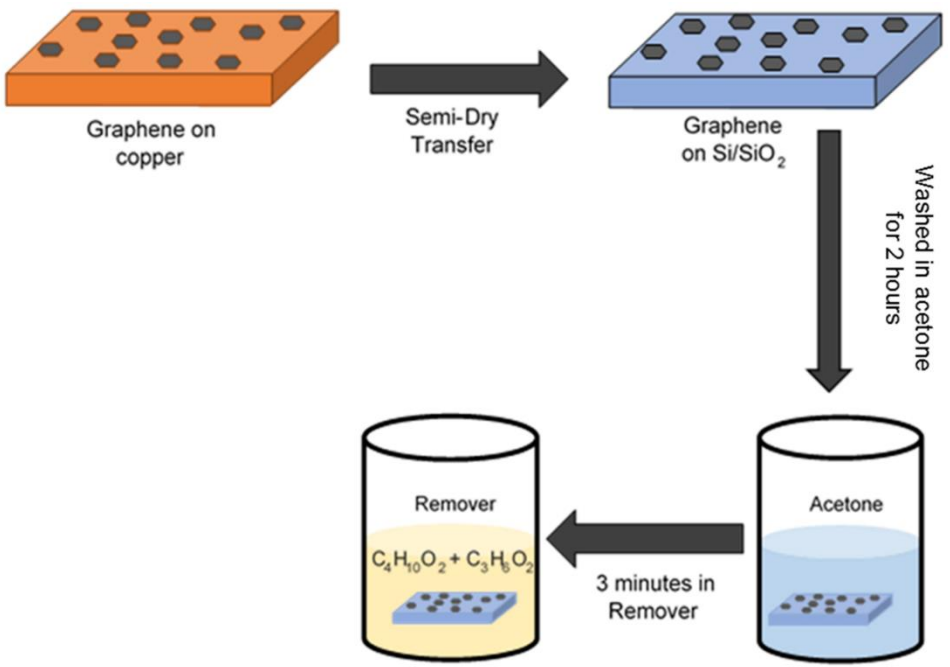
2). Chemical cleaning approach





H. Park *et al.*, 2018 *Nanotechnology* **29** 415303

Two-step cleaning approach and AFM analysis.

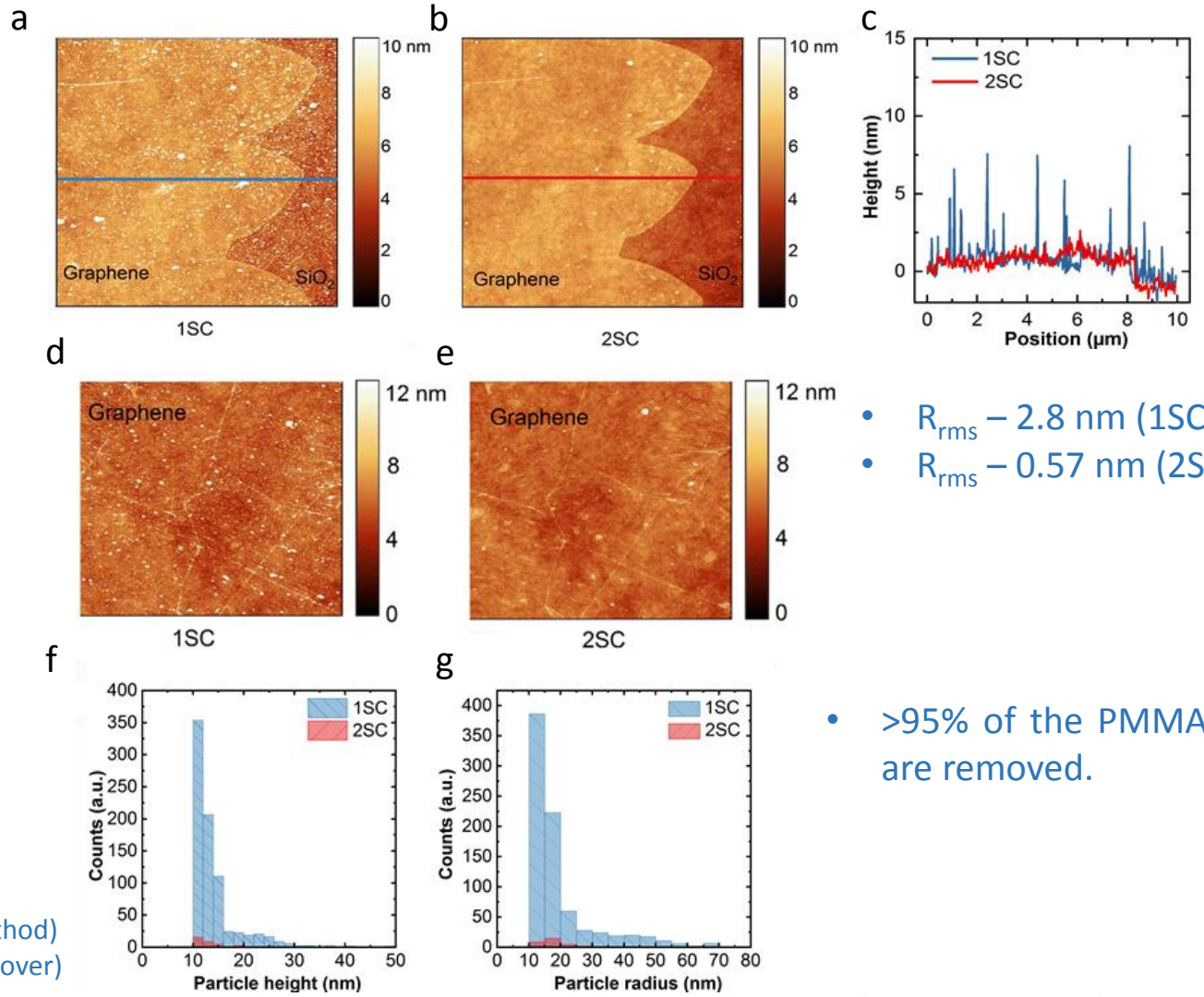


Schematics of wet chemical 2SC approach

Remover AR600-71 – (1, 3-Dioxolane and 1-Methoxy 2-Propanol)

- 1SC - One step cleaning (With conventional acetone method)
- 2SC - Two step cleaning (With acetone followed by Remover)

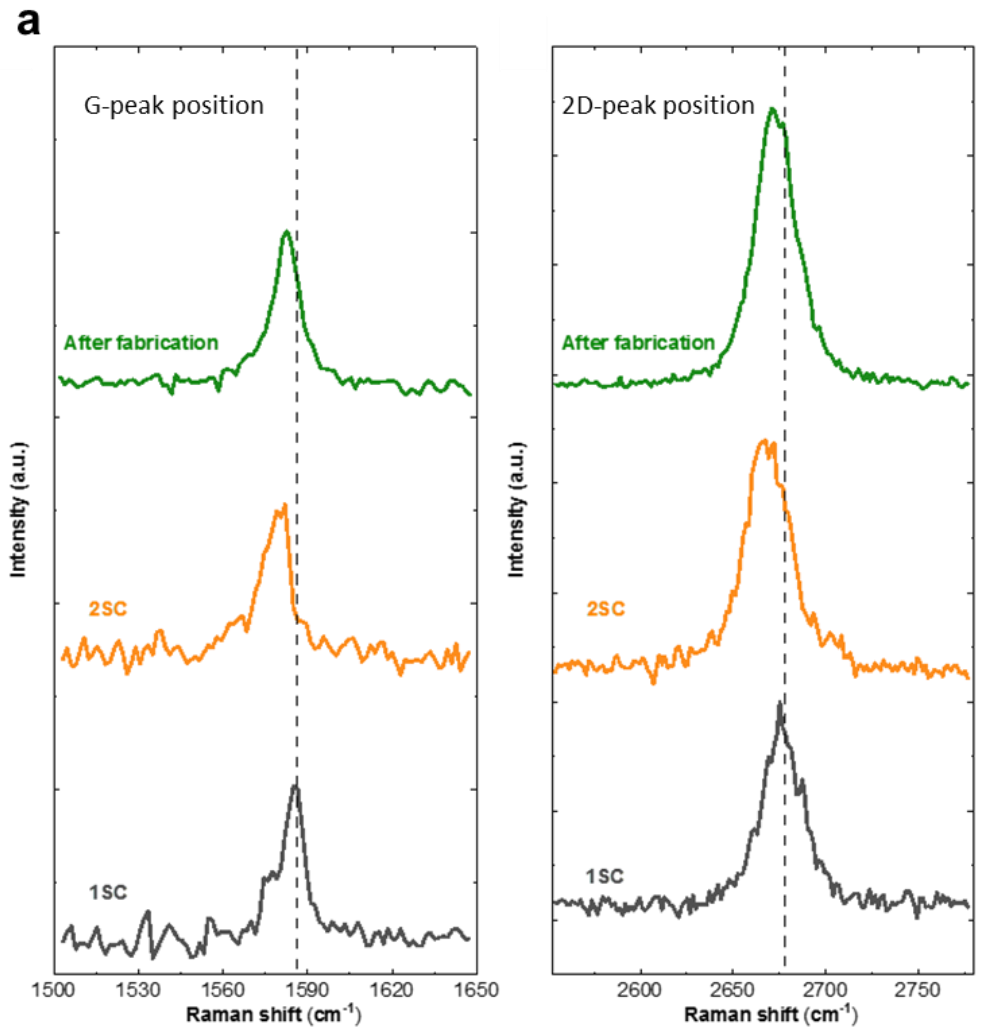
Tyagi et al submitted.



- R_{rms} – 2.8 nm (1SC)
- R_{rms} – 0.57 nm (2SC)

- >95% of the PMMA residues are removed.

Raman spectroscopy for 2SC approach.

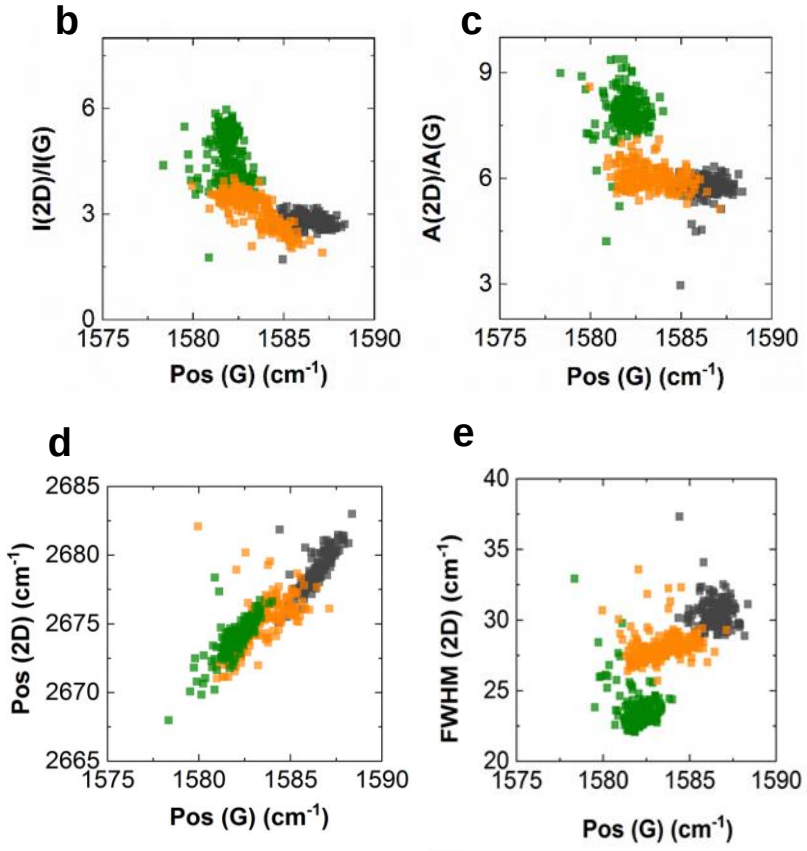


Raman spectra of graphene at various processing stages.

- Pos(G) peak – 1586.5 cm^{-1} (1SC) and 1583.4 cm^{-1} (2SC) .
- Pos(2D) peak – 2680 cm^{-1} (1SC) and 2674.9 cm^{-1} (2SC) .

- A(2D)/A(G) and I(2D)/I(G) – doping estimation.
- A(2D)/A(G) (1SC) - 5.3 with n~5×10^{12} cm^{-2}
- A(2D)/A(G) (2SC) – 7.9 with n~1×10^{12} cm^{-2}

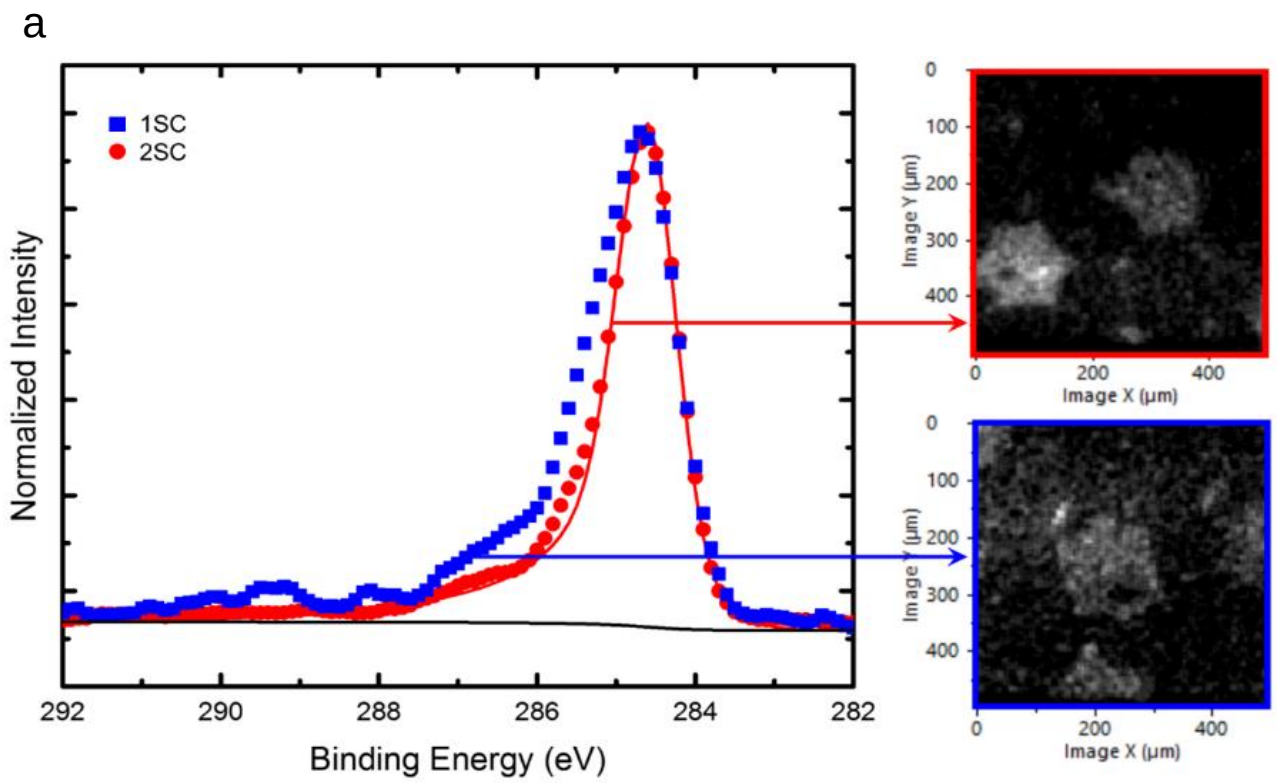
- Shift in Pos(G) and FWHM(2D) – strain variation

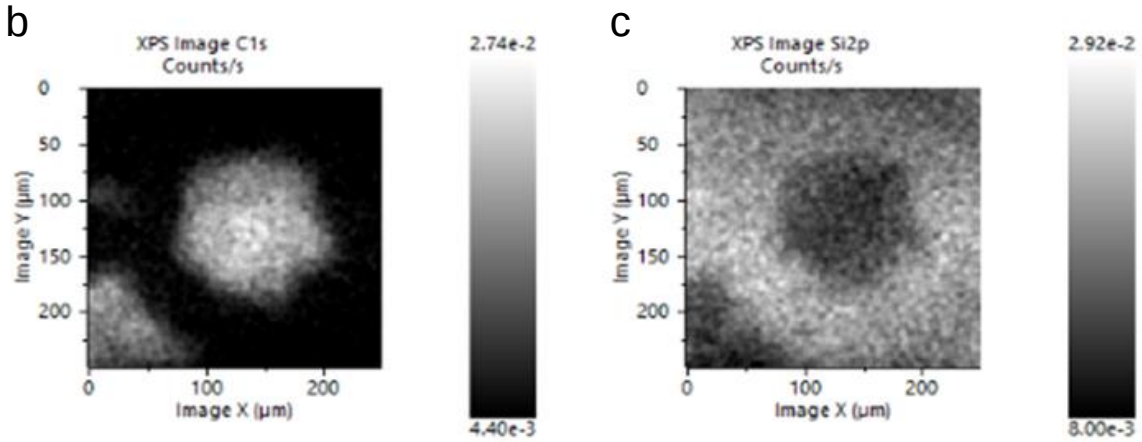


Strain and doping reduction in graphene by using 2SC process.

Tyagi et al submitted.

Chemical mapping by XPS for 1SC and 2SC approach

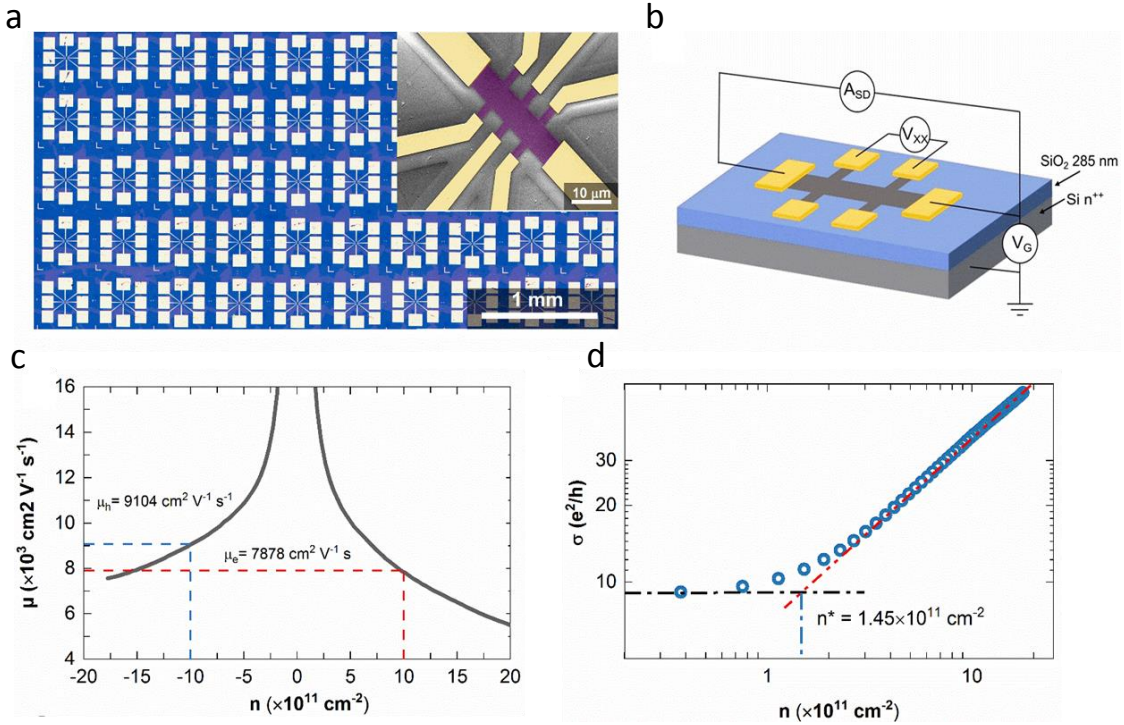




- C1s map recorded at 284.5 eV.

Tyagi et al submitted.

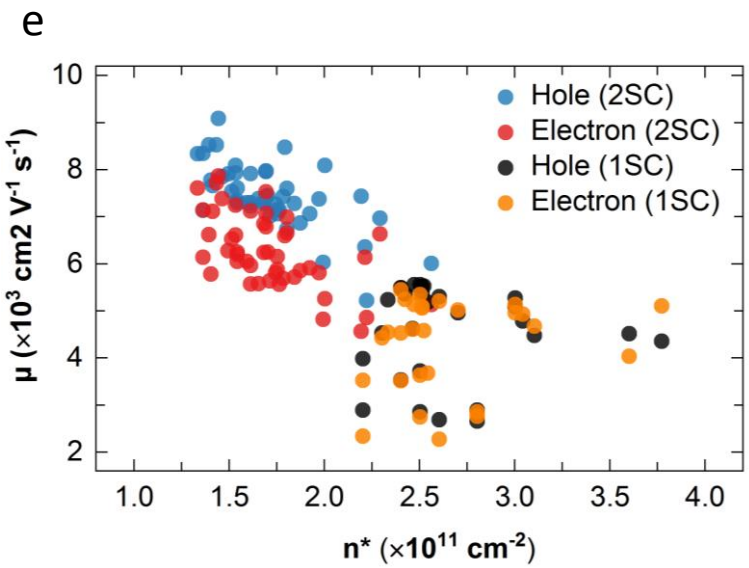
Electrical transport measurement with 2SC and 1SC.



$\mu = 1/ (n\ e\ R)$

$R = V_{XX}/I_{SD}$ L/W=1

I_{SD} = 1 µA

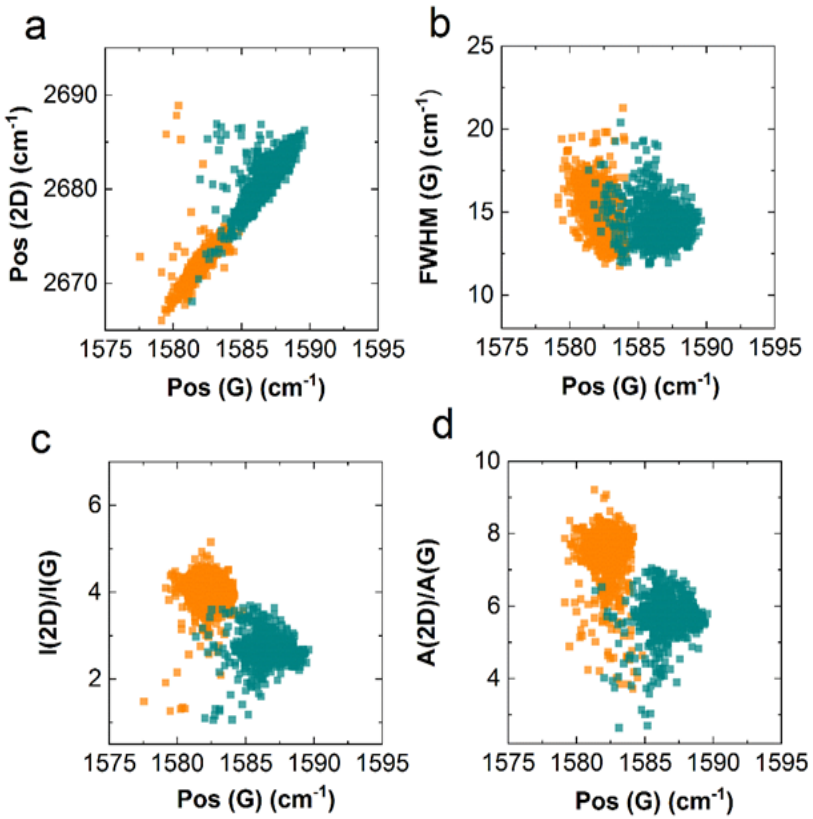


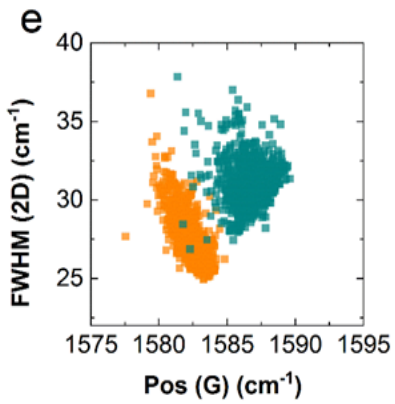
- 50 Hall-bars – 2SC, 28 Hall-bars- 1SC
- Highest hole and electron mobility - $\mu_h \sim 9100$ cm² V⁻¹ s⁻¹, $\mu_e \sim 7900$ cm² V⁻¹ s⁻¹
- Low residual carrier density (n*) – 1.45 x10¹¹ cm⁻².
- Consistent with Raman data.

- Average of $\mu_h \sim 4600$ cm² V⁻¹ s⁻¹, $\mu_e \sim 4500$ cm² V⁻¹ s⁻¹ (1SC)
- Average of $\mu_h \sim 7500$ cm² V⁻¹ s⁻¹, $\mu_e \sim 6300$ cm² V⁻¹ s⁻¹ (2SC)
- Also average n* ~ 2.9×10¹¹ cm⁻² (1SC) and 1.7×10¹¹ cm⁻² (2SC)

Tyagi et al submitted.

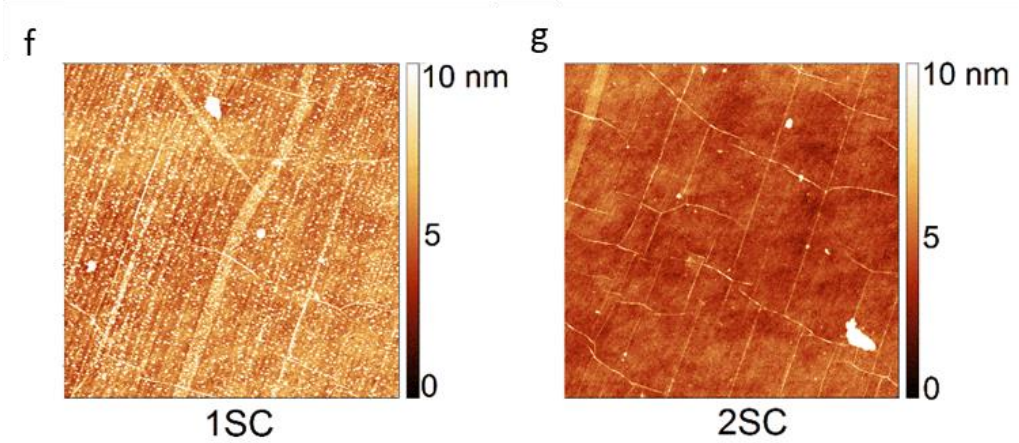
2SC for wet transferred polycrystalline graphene





1SC
2SC

- Both doping and strain are reduced after 2SC.



- R_{rms} – 2.2 nm (1SC)
- R_{rms} – 0.7 nm (2SC)

Tyagi et al submitted.

Conclusion

- Effective and rapid two-step cleaning (2SC) method is developed.
- This approach is scalable and easy to be used to clean CVD graphene.
- AFM and XPS confirms the high quality of graphene surface after 2SC.
- Raman and electrical measurements indicates low doping and strain relaxation with high mobility.
- Works well for both single crystal and polycrystalline graphene.
- Can be easily integrated in optoelectronics and photonics devices.

Acknowledgements

GRAPHENE FLAGSHIP

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