The effect of synthetic rubbers on the electrical properties of graphene

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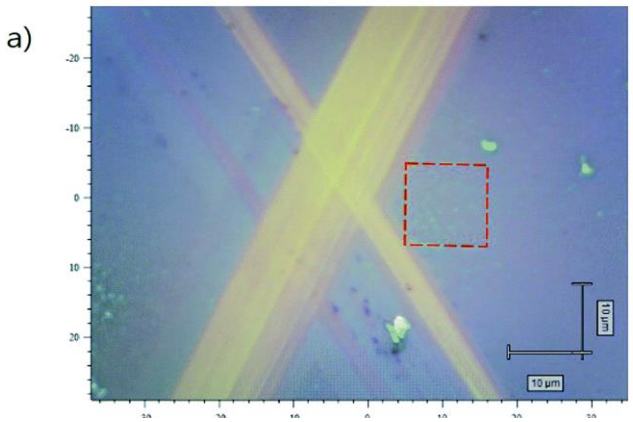
Problems with CVD graphene

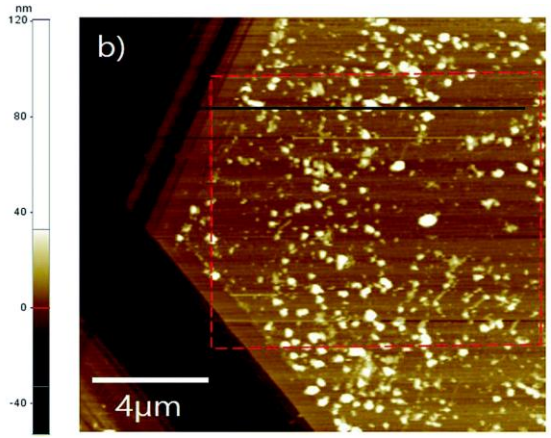
- Graphene is a promising candidate to be used as a filler material for rubber in tires. Graphene can fill the gaps in between rubber molecules to make it more stronger.

- The main issue with CVD graphene is the PMMA residues attached to the graphene during transfer and lithography process.

Graphene on Si/SiO_2



AFM image of Graphene on Si/SiO_2



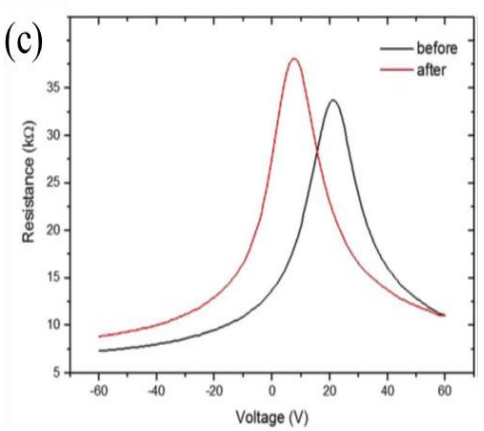


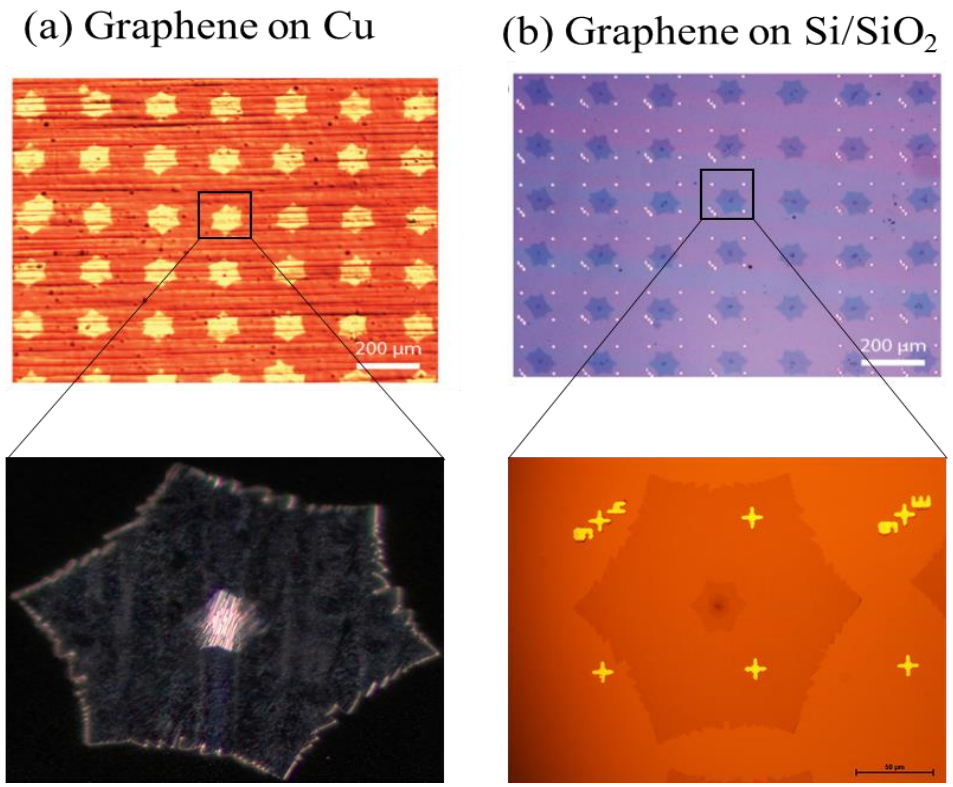
Table 1 Cleaning results of electronic properties for four different FET devices

	Electron mobility ($cm^2\ V^{-1}\ s^{-1}$)		Hole mobility ($cm^2\ V^{-1}\ s^{-1}$)		Dirac point shift (V)	
Sample name	Before	After	Before	After	Before	After
A	788.2	842.5	631.5	702.0	+33.0	+22.1
B	789.9	835.3	645.8	617.9	+21.6	+8.4
C	2047.1	2257.5	1440.9	1500.3	+24.2	+7.9
D	716.0	849.3	619.8	630.3	+22.3	+7.6

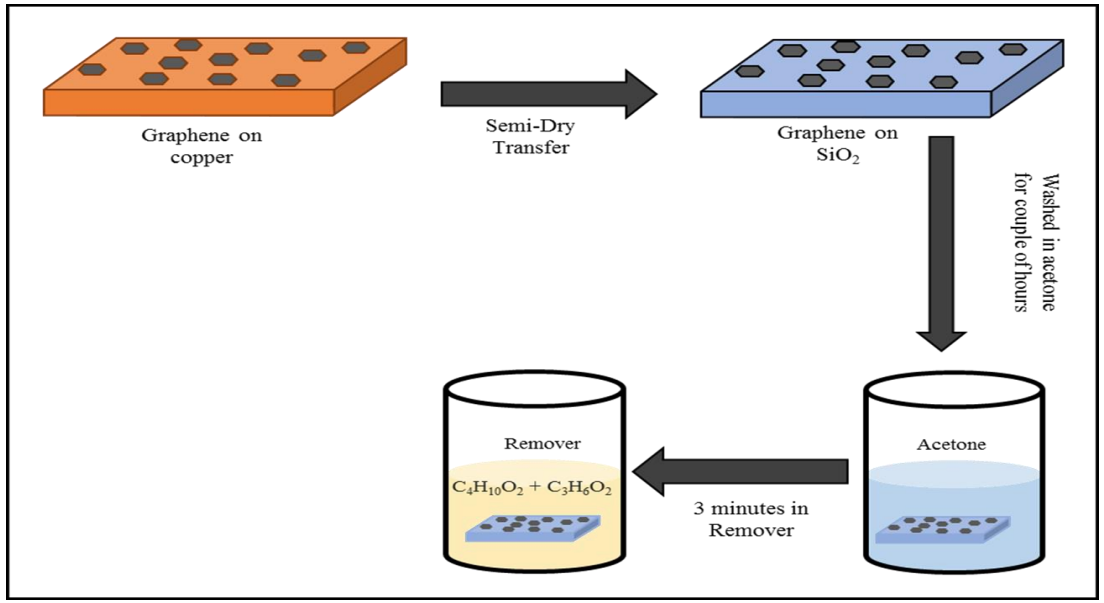
Choi W, Shehzad M A, Park S and Seo Y 2017 Influence of removing PMMA residues on surface of CVD graphene using a contact-mode atomic force microscope *RSC Adv.* **7** 6943–9

Project - 1

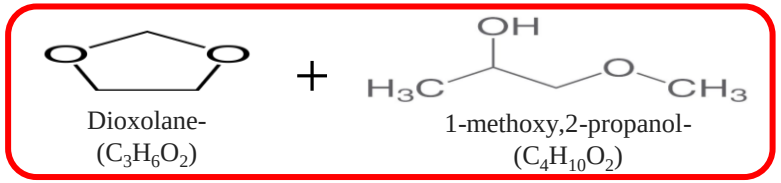
Two-step PMMA removal from CVD graphene used during transfer and lithography process towards high quality graphene



Miseikis V, Bianco F, David J, Gemmi M, Pellegrini V, Romagnoli M and Coletti C 2017 Deterministic patterned growth of high-mobility large-crystal graphene: A path towards wafer scale integration *2D Mater.* **4**



Schematic cleaning procedure of CVD graphene.



Dioxolane-
($C_3H_6O_2$)

\+

1-methoxy,2-propanol-
($C_4H_{10}O_2$)

Remover-(AR-600-71)

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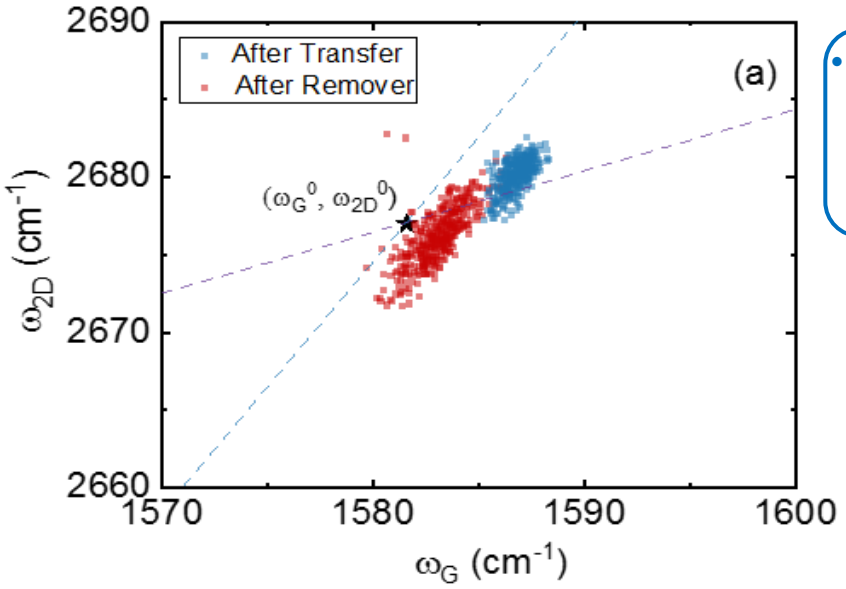
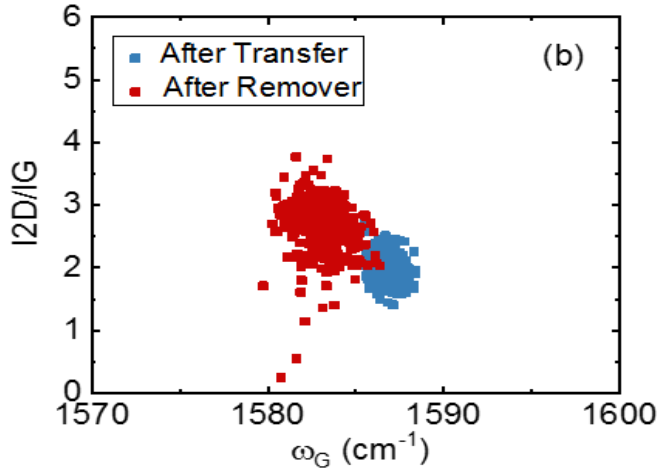
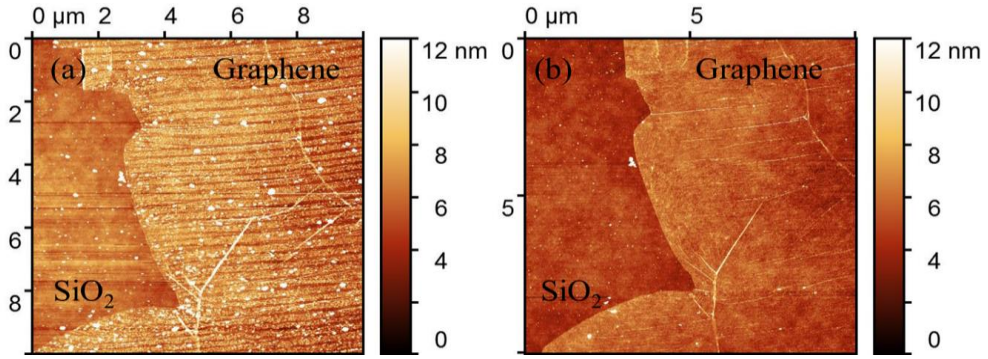
Raman and AFM results after transfer and cleaning with remover



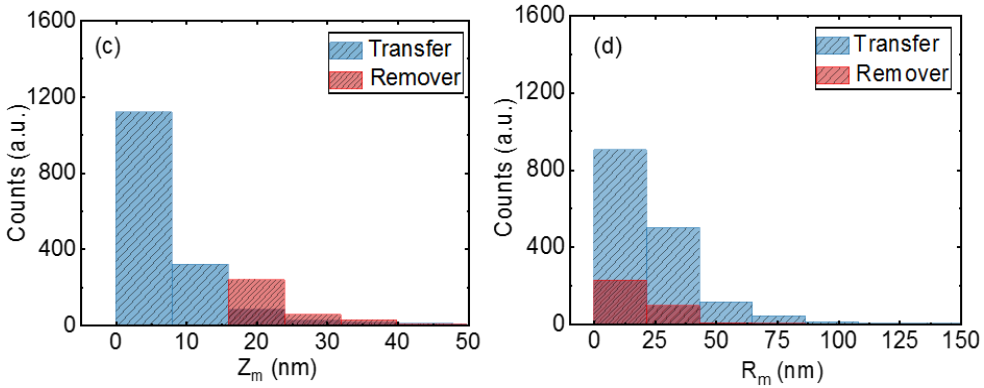
- Strain and doping effect decoupling by using Raman correlation between 2D and G peak positions.



- Intensity ratio increment confirming the doping reduction.



- PMMA residues are detached from the graphene surface by using remover which were left after conventional acetone treatment.



- Height and size of the PMMA residues calculated using the AFM data which is in agreement with Raman results.

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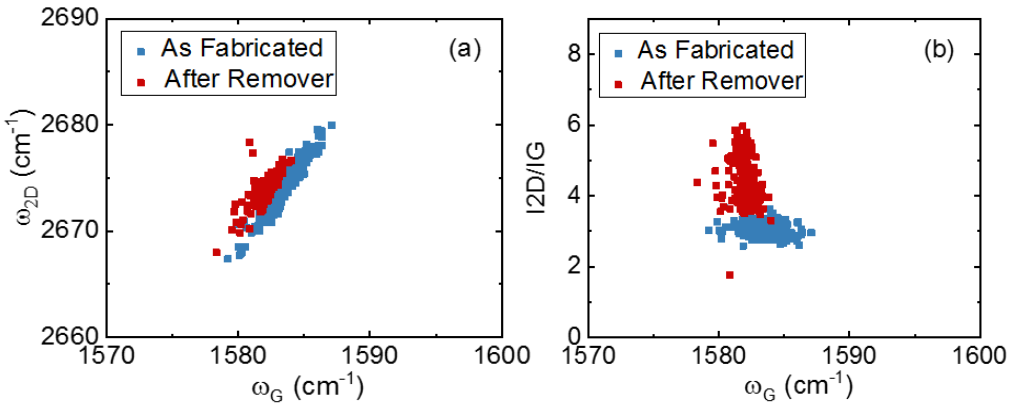
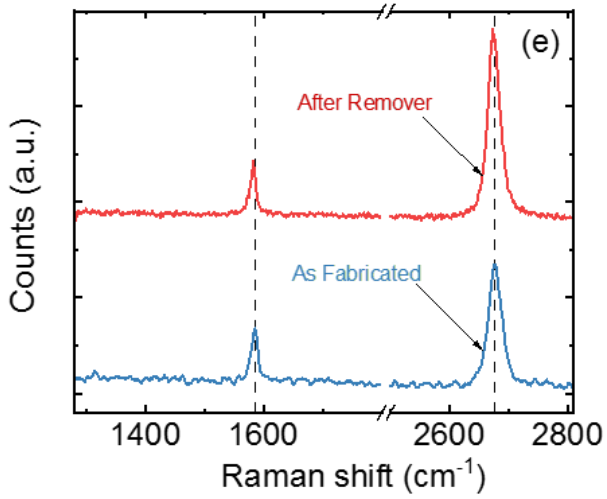
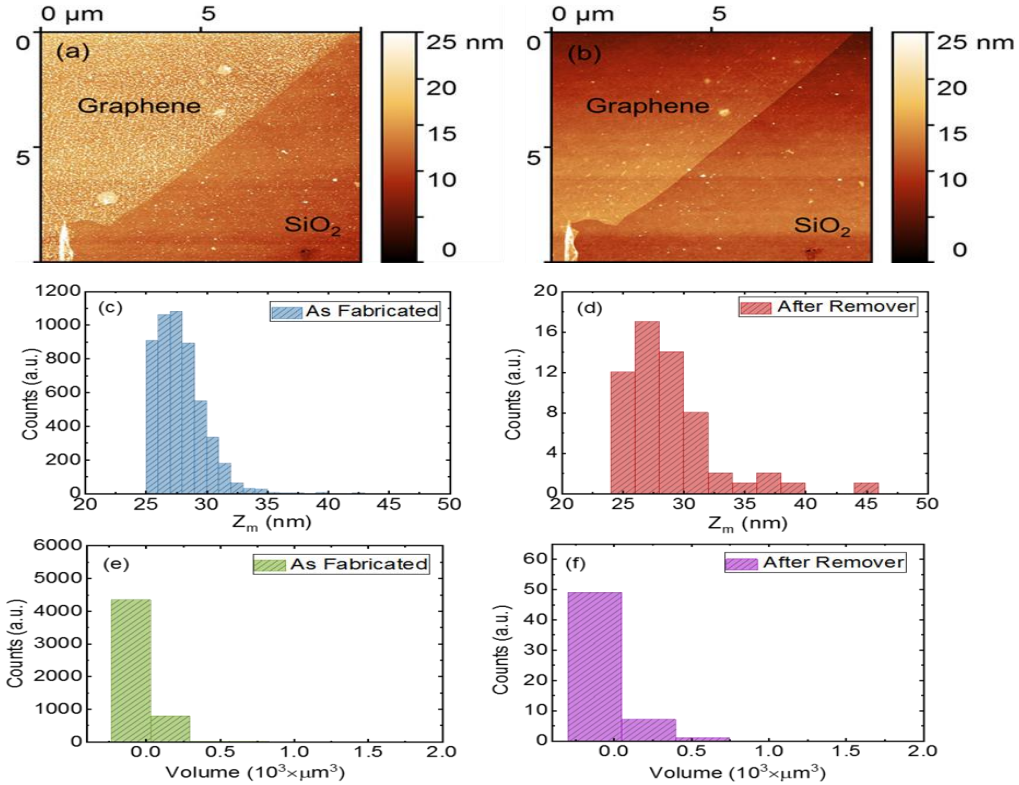
Raman and AFM data after device fabrication and cleaning with remover





- Remover consistently improves the properties of graphene even after fabrication without creating any defect in the graphene.



- Height and the volume analysis of the PMMA residues strongly correlates with the Raman results.

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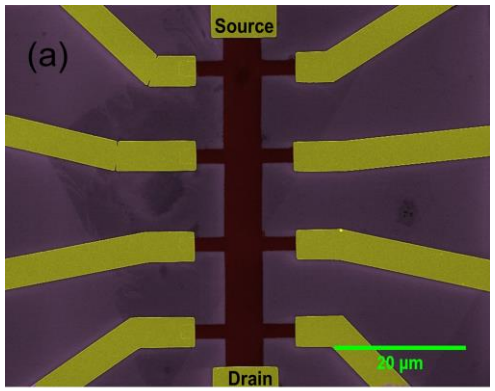
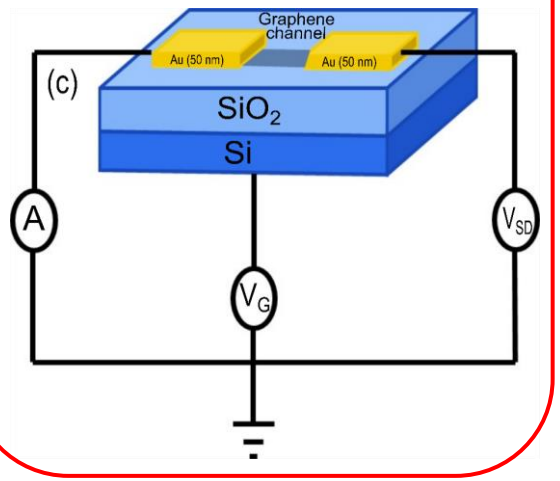
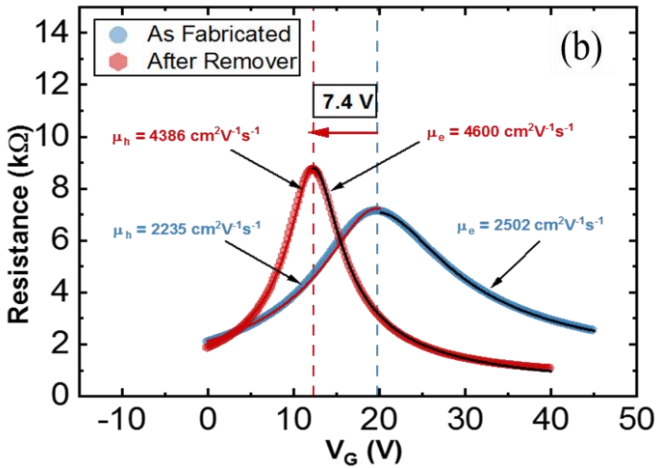
Mobility calculation of graphene with and without Remover

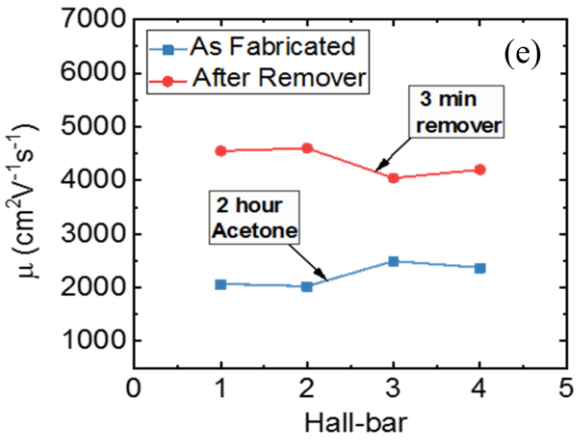


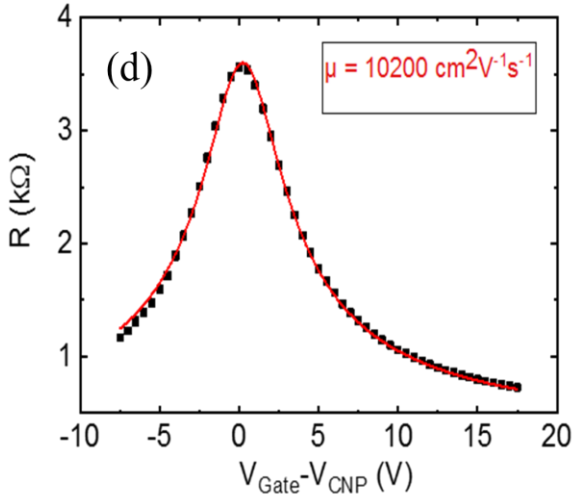
Graphene Hall-bar fabricated using e-beam lithography on Si/SiO_2.



Schematics of back-gated graphene FET.







- Graphene mobility is nearly doubled after cleaning with remover as the PMMA residues are dissolved which act as external scattering centers for the carriers in graphene.

- By slightly modifying the process recently even we have achieved µ = 10k $cm^2V^{-1}s^{-1}$ which is basically among the highest values till now reported on Si/SiO_2.

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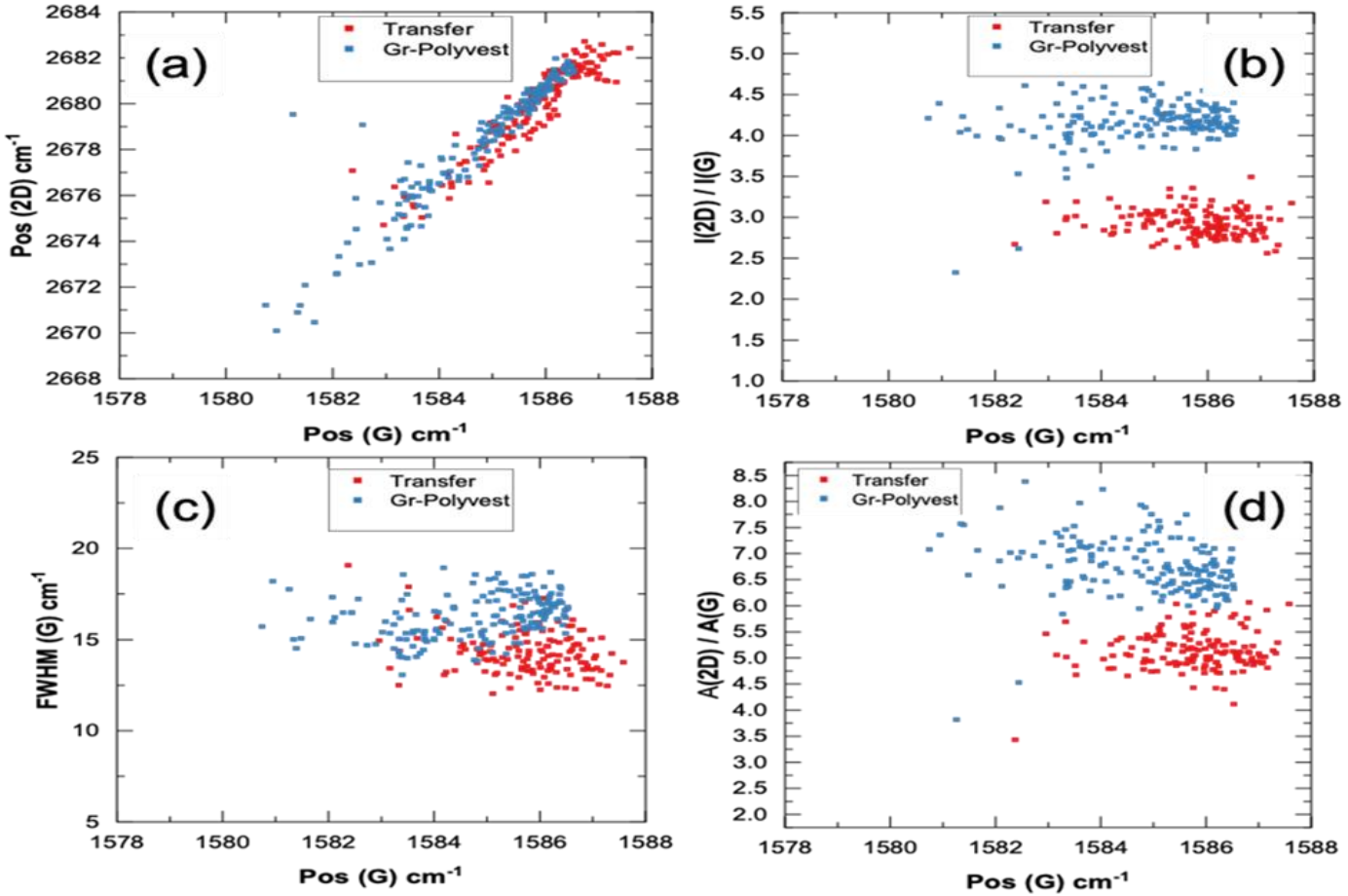
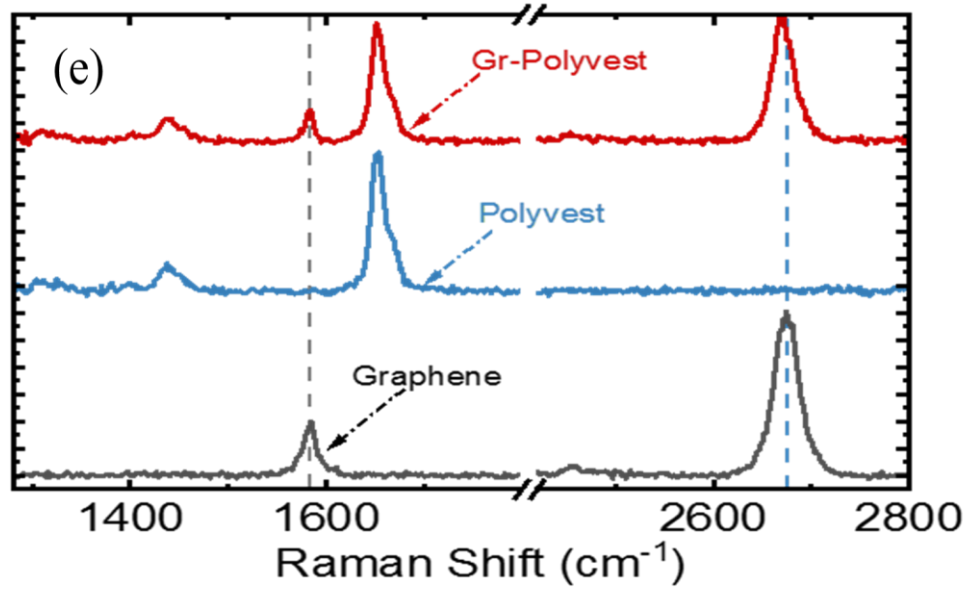
Project - 2

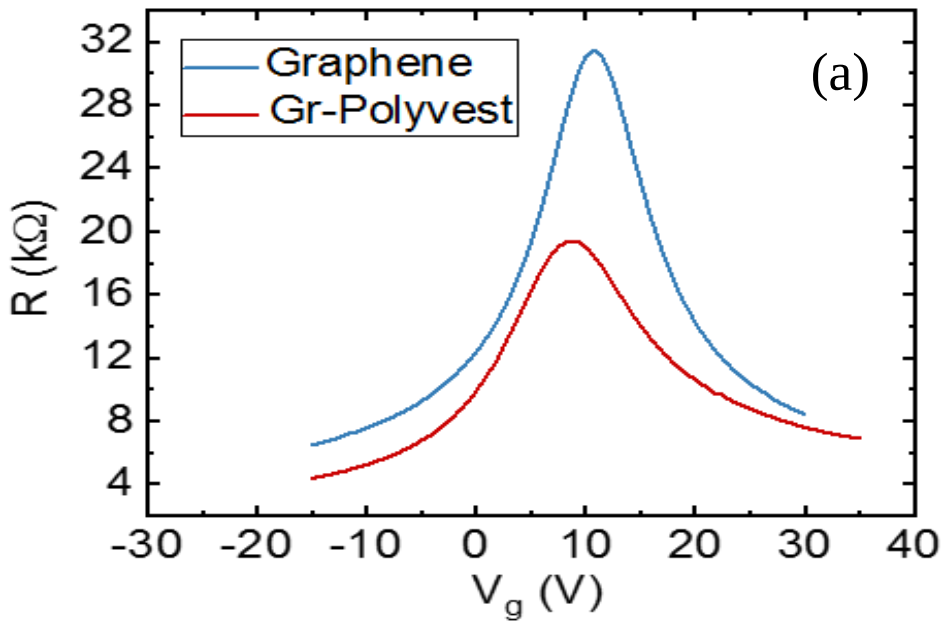
Graphene-Polyvest (Polybutadiene): Raman analysis

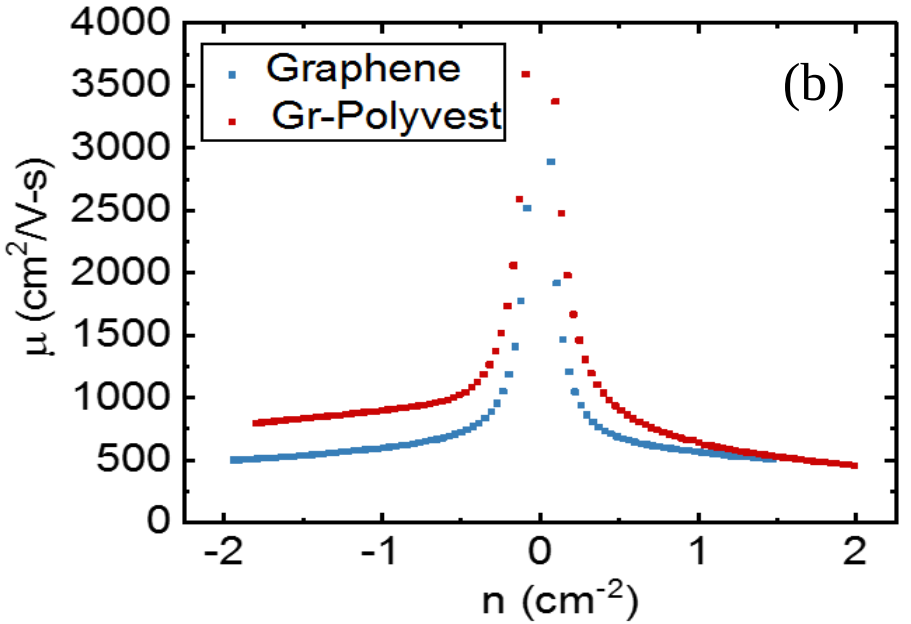


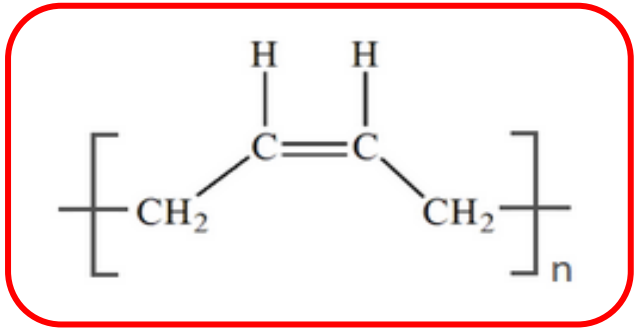


Raman data indicate doping reduction in p-type doped graphene as I(2D)/I(G) A(2D)/A(G) and FWHM(G) increase.

Graphene-Polyvest (Polybutadiene): electrical transport







Polyvest
(Polybutadiene)

Polyvest has excess electrons that by charge transfer might reduce the p-type doping in graphene towards charge neutrality.

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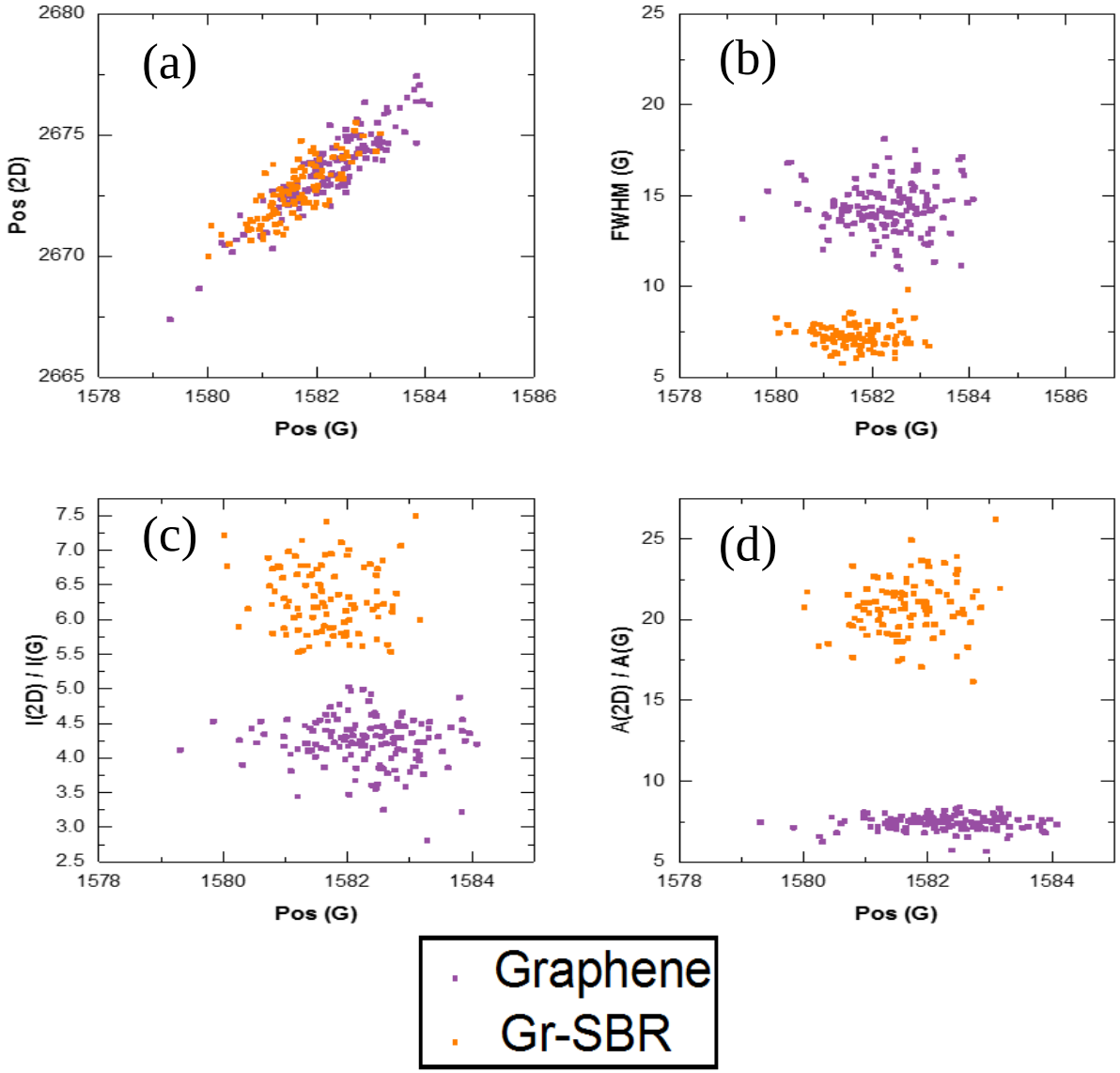
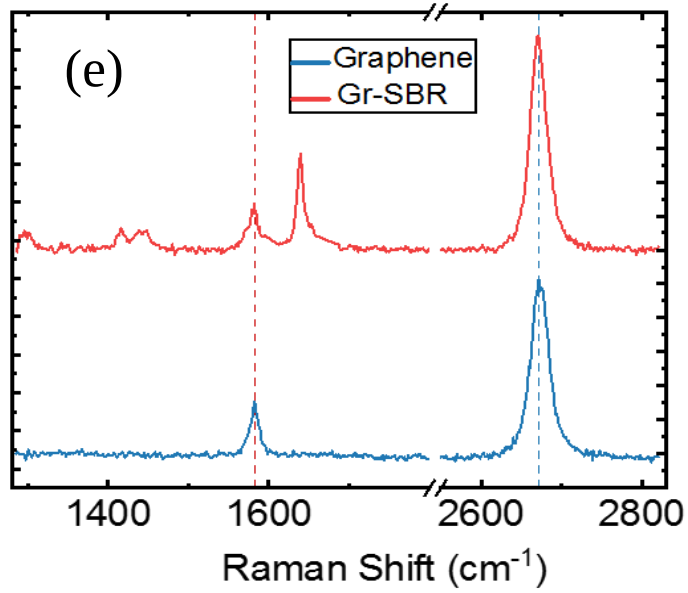
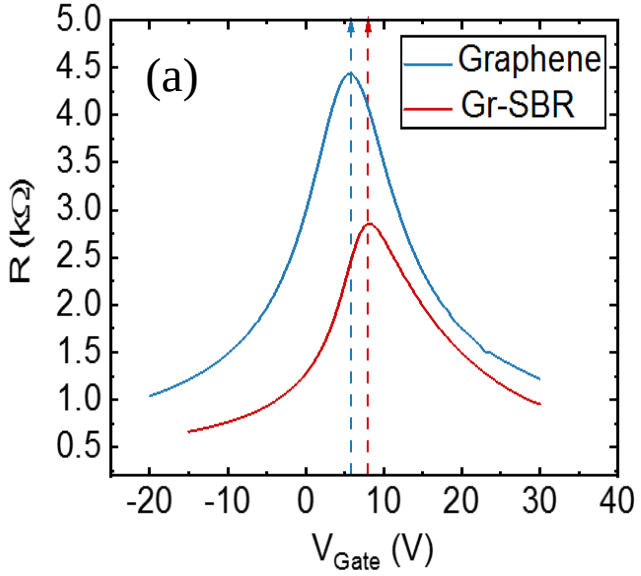
Graphene-SBR (styrene butadiene): Raman results

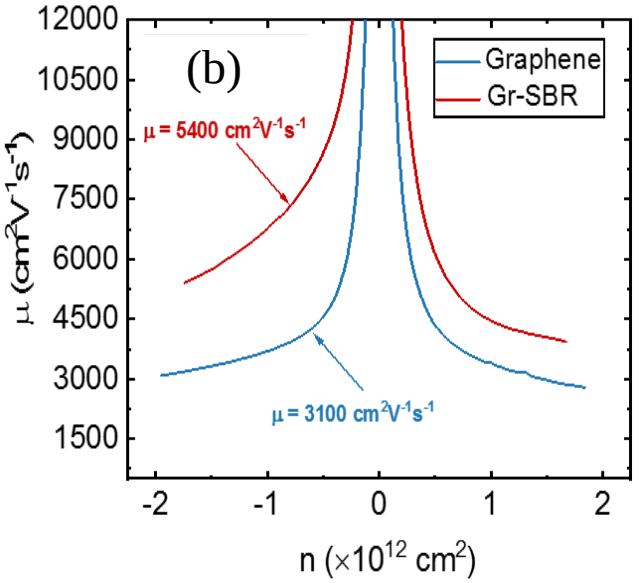


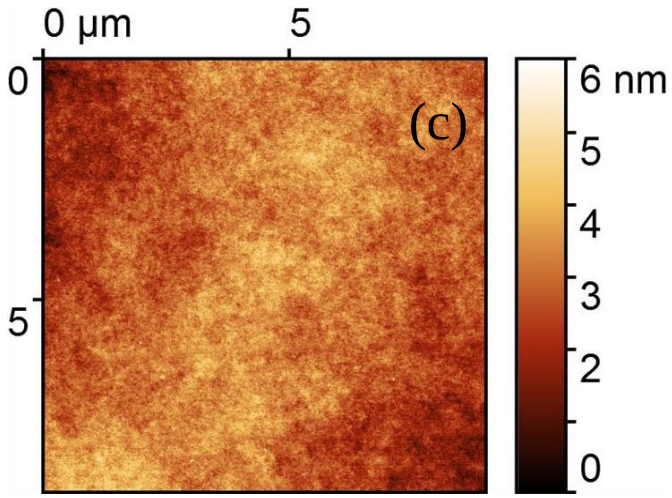


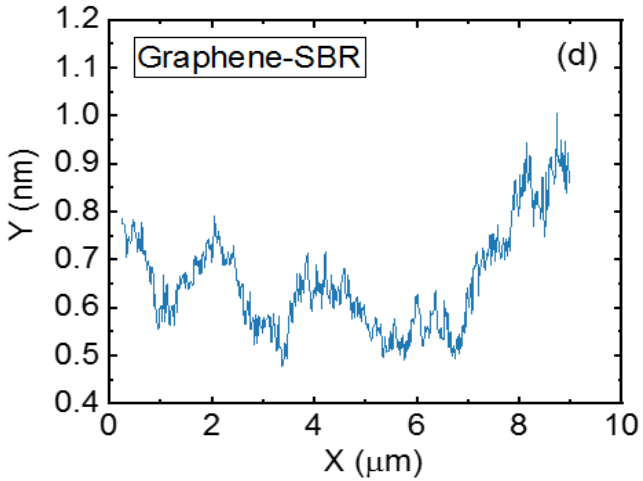
Graphene-SBR Raman data indicate even stronger doping reduction in graphene than when using polyvest.

Graphene-SBR (styrene butadiene): electrical transport and AFM data

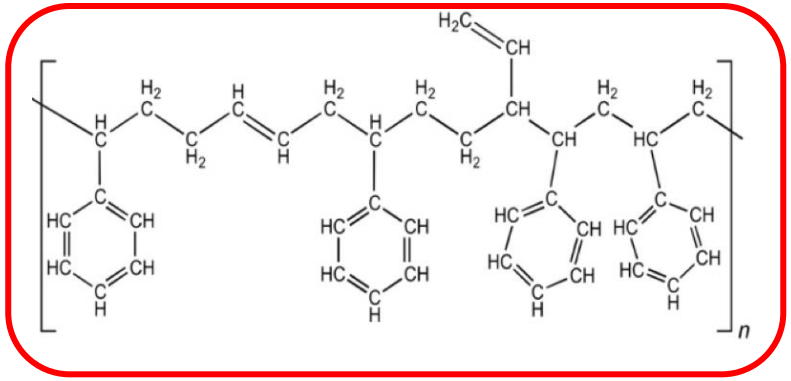








Graphene mobility became almost twice after depositing SBR thin film.



SBR (Styrene butadiene)

Graphene-SBR AFM confirms conformal and homogenous SBR coating over graphene with roughness(RMS) of < 1 nm.

Conclusion and Future Perspective

Project-1

- An efficient and rapid way of cleaning CVD graphene is developed.
- Electrical and morphological properties are enhanced.
- The clean graphene can be used for different applications i.e., high performance electrical and optical devices, to get high performance heterostructures with other 2D materials etc.

Project-2

- Change in the properties of graphene by using polymers i.e., Polyvest (polybutadiene) and SBR (styrene butadiene) is investigated.
- These results are the important steps to understand the interaction between graphene and rubbers as a filler material for the graphene tires.
- These two polymers could be the promising candidates as a polymeric dielectric material.
- Effect of pyrroles together with graphene/rubber adducts is in process.

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