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XXXIII Cycle

A novel Graphene transfer for sensors and diode fabrication

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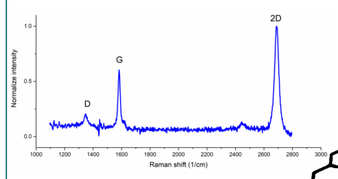
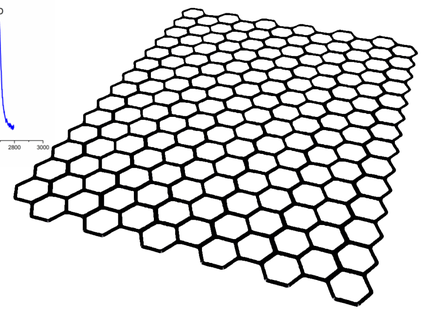
Research context and motivation

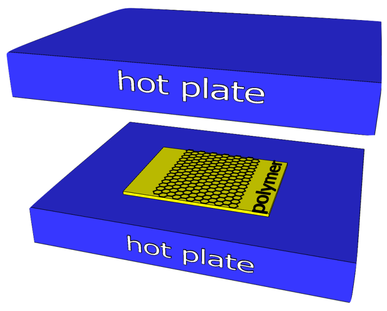
- In the last years, Single Layer Graphene (SLG) has been widely studied for its unique electrical and mechanical characteristics and it has been successfully exploited as a conductor or semiconductor in transistors and biosensors. High quality SLG is usually obtained by Chemical Vapor Deposition (CVD) on Cu or Ni foils and then PMMA-assisted transferred on an insulator layer. This method however lacks repeatability, it is extremely time consuming and it is hard to be scaled-up and integrated in an industrial process.
- In this work, a novel hot embossing approach has been developed to simplify the SLG transferring process and improve the final quality of the transferred SLG.

Addressed research questions/problems

- Graphene is a material that has been widely investigated recently and has attracted a lot of interest due to its peculiar electrical and mechanical characteristics.
- One of the main problems to its widespread use is how it is fabricated: the most common method is to grow it on a Cu foil and then transfer it exploiting a polymer substrate; this process is long and complicated and it isn't possible to scale on an industrial level.



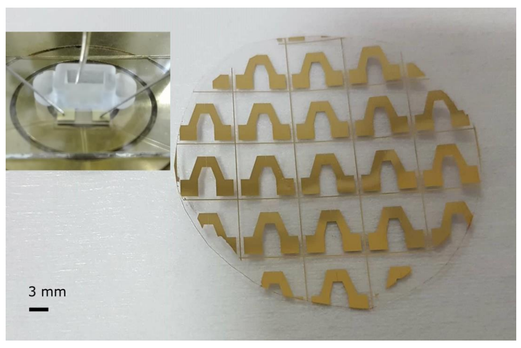


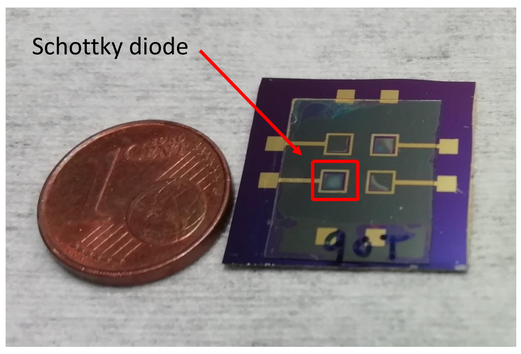


- In order to avoid these problems, the idea of this work is to use a hot embossing machine to imprint the graphene from the Cu foil directly on a polymer substrate, avoiding the transfer steps and thus allowing better preserving the quality of the Graphene as it was just after the growth.

Novel contributions

- With this novel process a Graphene Field Effect Transistor (G-FET) and a Graphene/Si Schottky diode were successfully fabricated.
- In the first case a COC (Cyclic Olefin Copolymer) was chosen as a substrate. Thus allowed to have a polymeric substrate to perform the embossing, while also having a flexible and transparent substrate resistant to many chemicals and solvents. Electrodes were patterned on it, then Graphene was transferred onto the electrodes and patterned with oxygen plasma. The devices were finally passivated with polyimide and tested.
- Also in the second device COC was chosen as the embossing polymer. Graphene was first embossed onto the COC, then the foil was embossed again on the silicon substrate, previously prepared to show a silicon window.



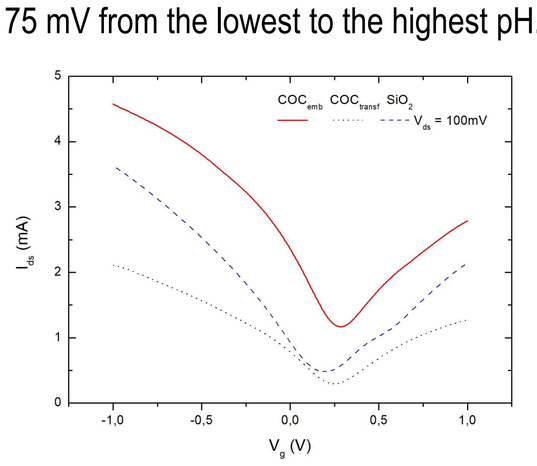


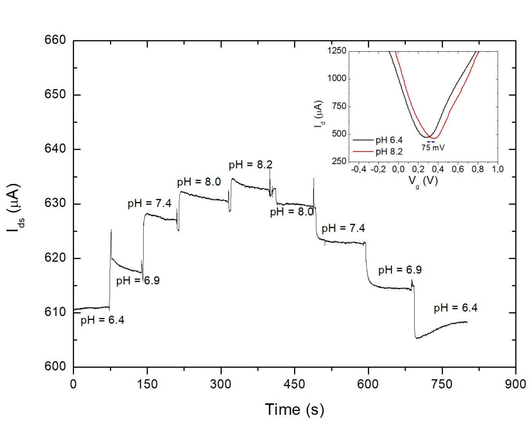
List of attended classes

- 01SDDKI – Additive manufacturing polimerico (11/7/2018, 4)
- 01SGURV – Intellectual Property Rights, Technology Transfer and Hi-Tech Entrepreneurship (22/3/2018, 6)
- 01REIRR – Terapie avanzate (nanomedicina, terapia genica e cellulare) in chirurgia (29/6/2018, 4)
- 01QORRV – Writing Scientific Papers in English (21/2/2018, 3)
- 01TGTKI – Physical Chemistry of Materials for Nanotechnologies (18/7/2019, 7)

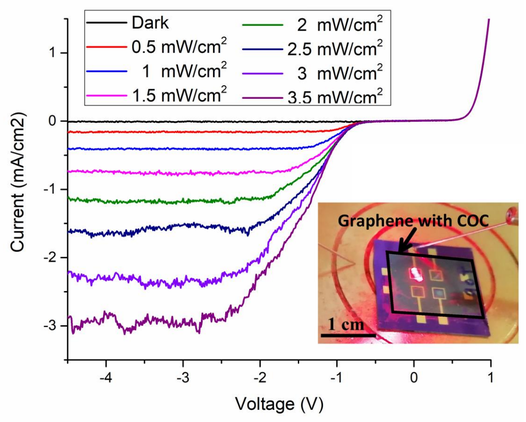
Adopted methodologies

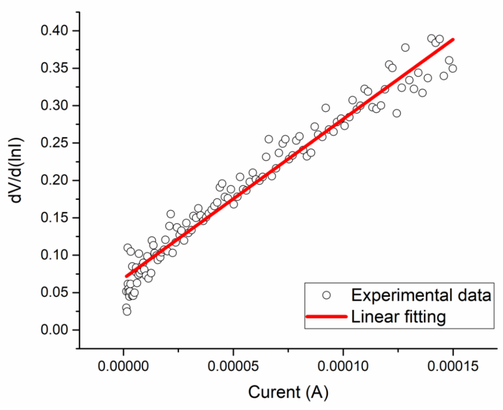
- For the G-FETs preliminary tests were performed in order to show the typical behaviour of a G-FET and to compare the same devices made with the usual transfer technique. Then the devices were tested in order to evaluate the possibility to use them as sensors. The sensing tests were performed in a range of pH from 6.4 to 8.2 and showed a difference of 75 mV from the lowest to the highest pH.





- For the Graphene/Si Schottky diode tests were performed with 633 nm illumination in the range from 0 to 3.5 mW/cm^2 and showed a strong rectifying and photodiode behavior. The responsivity was found to be 0.75 A/W.
- The photocurrent response was also measured with -3 V of reverse BIAS and an optical signal with a periodic pulse. The signal to noise ratio was found to be 200.





- The results were compared with models and previous work, showing consistent results with a R_s= 2 kΩ, an ideality factor of 2.66 and a Φ_B of 1.01 eV.

Future work

- In this work Graphene was successfully transferred from a Cu foil to a COC substrate patterned with Au electrodes allowing the fabrication of a fully functional G-FET sensor and onto a silicon wafer for the fabrication of a fully functional Schottky photodiode. Both processes avoided PMMA assisted transfer.
- A switch in the process steps could also be tried, and Graphene will need to be functionalized in order to detect cancer biomarkers.
- Parameters optimization could improve the performances and organic semiconductors (such as PEDOT:PSS) could be used for full flexible electronics.

Submitted and published works

- Parmeggiani, M., Ballesio, A., Verna, A., Frascella, F., Cocuzza, M., Pirri, C.F., Marasso, S.L., "*A novel electrolyte gated graphene field effect transistor on cyclo olefin copolymer foil*", IEEE Sensors, New Delhi, 2018
- Ballesio, A., Parmeggiani, M., Verna, A., Frascella, F., Cocuzza, M., Pirri, C.F., Marasso, S.L., "*A novel Graphene transfer process for flexible electronics*", Microelectronic Engineering, V. 209, 2019, pp. 16-19
- D'Angelo, P.; Marasso, S. L.; Verna, A.; Ballesio, A.; Parmeggiani, M.; Sanginario, A.; Tarabella, G.; Demarchi, D.; Pirri, C. F.; Cocuzza, M.; Iannotta, S., "*Scaling Organic Electrochemical Transistors Down to Nanosized Channels"*, SMALL, 2019
- Parmeggiani, M.; Verna, A.; Ballesio, A.; Cocuzza, M.; Piatti, E.; Fra, V.; Pirri, C. F.; Marasso, S. L., "*P3HT Processing Study for In-Liquid EGOFET Biosensors: Effects of the Solvent and the Surface*", PROCEEDINGS, 2019
- Wang, Y., Yang, S., Ballesio, A., Parmeggiani, M., Verna, A., Cocuzza, M., Pirri, C.F., Marasso, S.L., "*The fabrication of Schottky photodiode by monolayer graphene direct-transfer-on-silicon*", Microelectronic Engineering, 2019

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