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34th Cycle

Graphene/silicon Schottky photodiode fabricated by hot embossing transferring

Yiming Wanng

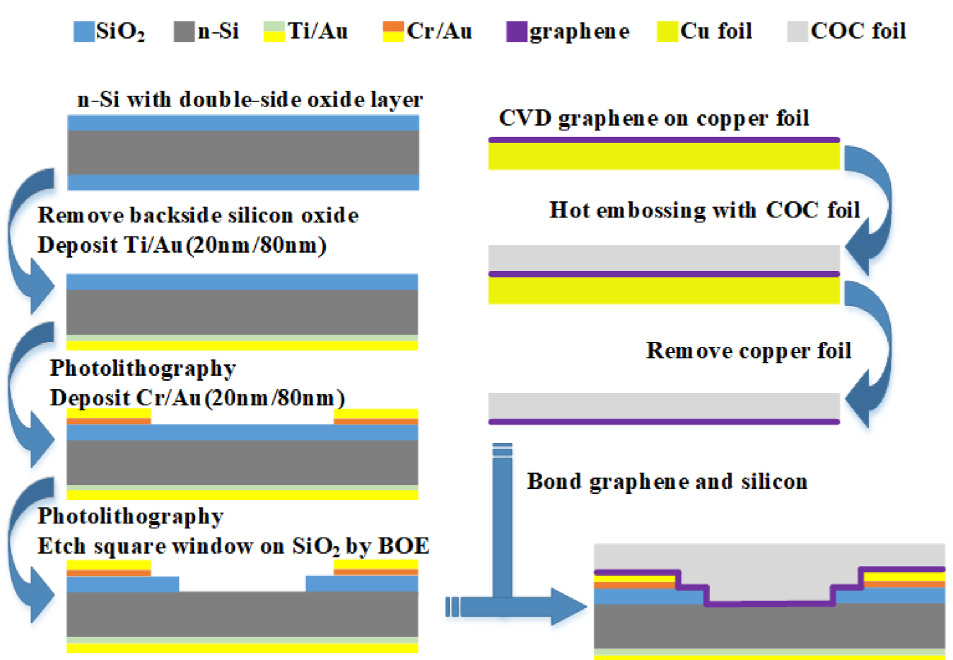
Supervisor: Prof. Fabrizio Pirri

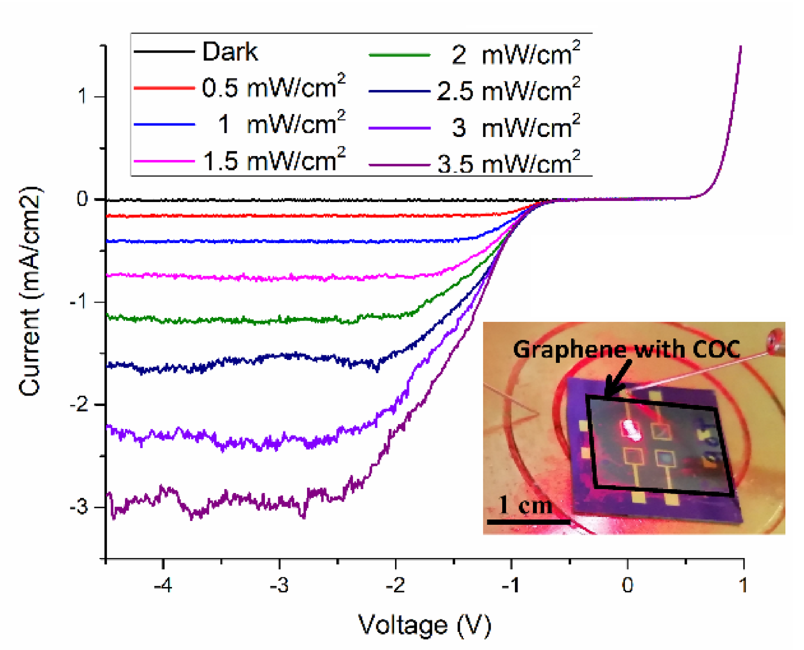
Research context and motivation

- Photodetectors with high responsivity play important roles in many field, such as optical communications, biological imaging, industrial processing control and environment monitoring. Graphene (Gr) photodetectors have experienced rapid development in the past decade, owing to the unique electrical and optical properties, like high charge carrier mobility and wide spectrum light absorption.
- Graphene/silicon Schottky junction photodiode can be easily formed by transferring graphene onto Si substrate, the most basic semiconductor with mature processing technology. Considering the good transparency (97.7% for monolayer graphene) and tunable work function by either external electrical field or chemical doping, the graphene/silicon junction provides a platform for photosensitive application and shows promising prospect compared with the traditional metal based Schottky junction.
- Chemical vapor deposition (CVD) is the most promising method for the synthesis of graphene. The most frequently used Gr transferring method is PolyMethylMethAcrylate (PMMA) sacrificial layer based metal etching processes, but it suffers from the residues of PMMA, and it is hard to scale to large area and match the semiconductor manufacturing compatibility.
- Hot embossing process can help to transfer CVD graphene from native metal substrate to Cyclic Olefin Copolymer (COC) foil without any sacrificial layer, which avoids the residues of PMMA and simplifies the processing steps. In this work, two-step hot embossing process is used to transfer graphene and to fabricate Gr/Si Schottky photodiodes, providing the possibility for large scale production.

Addressed research questions/problems

- The novel Gr transferring method by hot embossing was developed by Ballesio et al, which can directly transferring CVD graphene from native metal substrate to COC film. The graphene layer will be bonded tightly with COC under a certain temperature and pressure (80 ° C, 10,000 N). However, silicon is a kind of semiconductor crystal with high hardness and melting point, to fabricate Gr/Si Schottky photodiode, the two-step hot embossing process was developed, as shown in the figure below. The silicon substrate part with back electrode, top electrode, square window and graphene part on COC foil are prepared respectively, then the two part are bonded together by hot embossing to form Gr/Si Schottky junction. The COC foil remains on top of graphene to protect the diode from ambience.





- Current-voltage curves of Gr/n-Si Schottky photodiode under various incident light powers are shown in the figure above, inset is photoelectrical characterization layout. The responsivity of the hot embossed Gr/n-Si heterojunction was measured to be 0.75 A/W under 633 nm illumination.
- For Gr/Si Schottky photodiode, the photocurrent mainly origins from the photovoltaic effect. The photoexcited electron-hole pairs are separated by the build-in electric field and flow to positive or negative electrode respectively. According to thermionic emission theory and Cheung's functions, the ideality factor and Schottky barrier height are 2.66 and 1.01 eV, respectively.

Submitted and published works

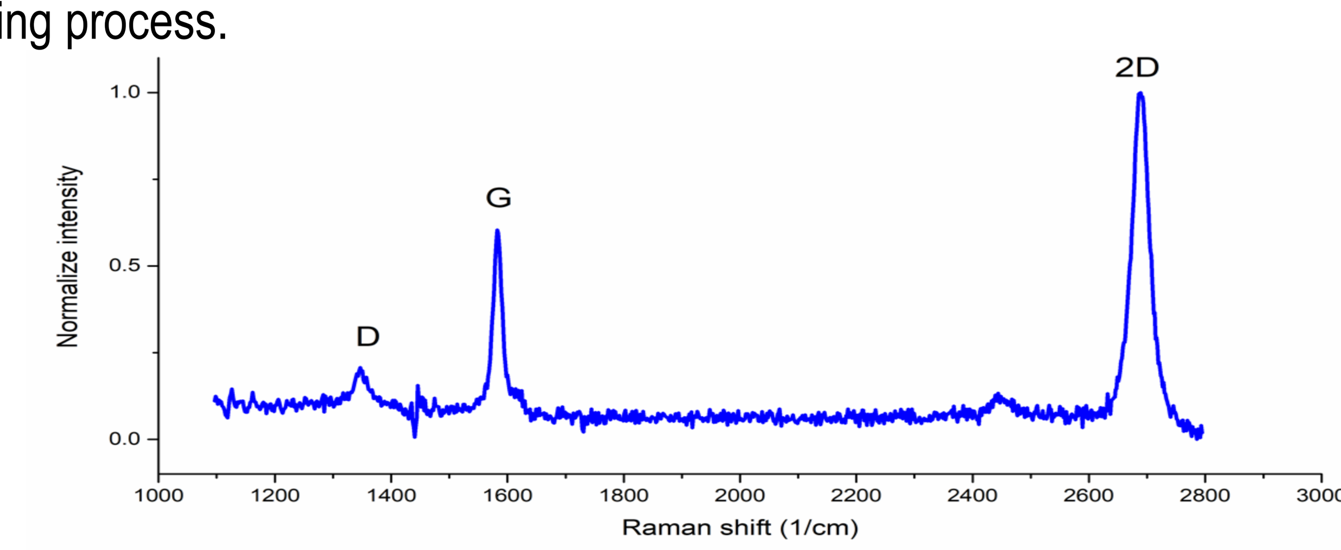
- Yiming Wang, Shuming Yang, Alberto Ballesio, "the fabrication of Schottky photodiode by monolayer graphene direct-transfer-on-silicon", Microelectronic Engineering (Submitted)

Novel contributions

- The two-step hot embossing process was developed to fabricate Gr/Si Schottky photodiode. Hot embossing process was used both to transfer CVD Gr from copper to COC, and to bond Gr with Si substrate to form Schottky contact. The COC foil remains on top of graphene to protect the diode from ambience. This work also provides the possibility for large scale production of graphene photoelectric devices.
- The responsivity of as prepared Gr/Si photodiode reaches 0.75 A/W under 633 nm illumination with a reverse bias of -3V, which can be attributed to the high Schottky barrier height of 1.01 eV.

Adopted methodologies

- Wet etching, e-beam evaporation, photolithography and hot embossing were employed to fabricate the Gr/Si Schottky photodiode.
- Raman microscope (Renishaw plc, Wotton-under-Edge, UK) equipped with a Leica DMLM microscope with a 50× objective was used to characterize the Gr transferred by hot embossing process.



- Electrical and photoelectrical characterizations have been performed with a Keysight B2912A Source/Measure unit 633 nm semiconductor laser (laser power has been calibrated with Sanwa LP-1 before the measurements).
- Thermionic emission theory and Cheung's functions were used to extract the ideality factor and Schottky barrier height from current-voltage curve of the Gr/Si Schottky diode.

Future work

- From the results, the high photoresponsivity of 0.75 A/W can be attributed to the high Schottky barrier height; but we still have not figured out why the Gr/Si Schottky photodiode fabricated by hot embossing have high Schottky barrier height. Further investigation needs to by applied to analyze the influence of hot embossing parameters on the property of Schottky diode.

List of attended classes

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering