BAPVC Annual Project Report

Project Title: Graphene Electrode Engineering for Photovoltaic Applications

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Summary:
The UCSB group has been developing a graphene synthesis process, which can significantly reduce the cost of high-volume graphene production, during the past year. They found it is possible to achieve 90% transmittance and small sheet resistance of 10 Ω/□ by engineering the number of graphene layer as well as the grid density. Using electrochemical transfer method, the fabrication cost of graphene was significantly reduced to \$7.5/m^2, which is close to the cost of ITO (\$6/m^2).

Key Accomplishments:

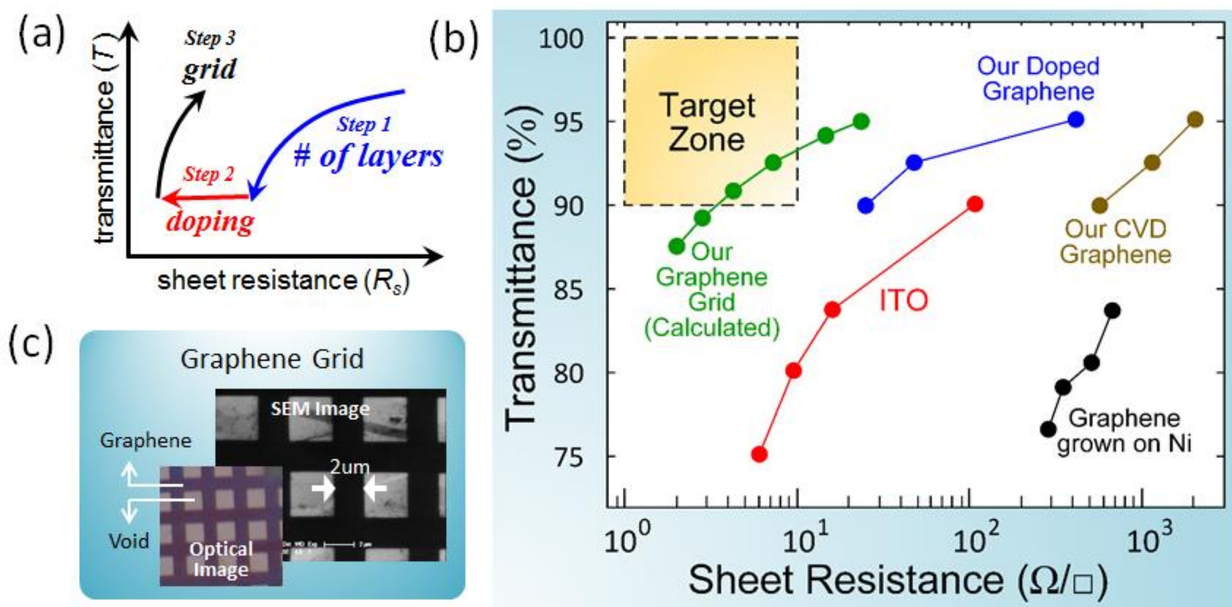

Figure 1. Graphene-based gird. (a) The principle of transmittance and sheet resistance engineering of graphene grid. (b) Comparison of sheet resistance and transmittance from the work at UCSB and other results from the literature. (c) Optical image of the fabricated graphene grid.

The UCSB group has theoretically and experimentally studied surface charge transfer doping[1], substrate doping[2] and intercalation doping of FLG. In the second year of the BAPVC project, their study revealed that intercalation doping is an efficient and stable doping method. By using intercalation doping, 4 layer graphene can attain small sheet resistance of 20 Ω/□, which is the smallest value reported compared with any reported values to date. However, this method requires long process time (12 hours), which in turn increases the fabrication cost. Hence, it is highly desirable to explore a new method to reduce the sheet resistance of graphene, while keeping the high transmittance of graphene film. Recently, they found that it is possible to achieve the 90% transmittance and small sheet resistance of 10 Ω/□ by engineering the number of graphene layers as well as the grid density (Fig.1a). The sheet resistance and transmmittance of graphene grid is even better than that of intercalation doped few layer graphene (Fig.1b).

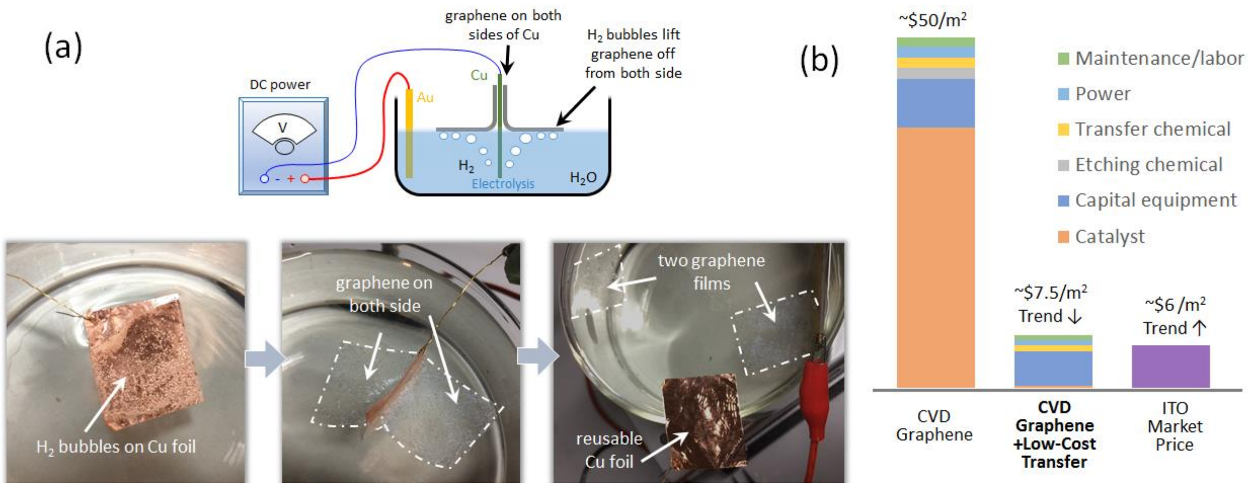

Figure 2. (a) The schematic (upper) and optical images (lower) of bubble transfer method. (b) The cost analysis of graphene growth compared with the current cost of ITO.

The bottleneck of the application of graphene in industry-scale is the high fabrication cost of graphene film, which is also the major concern from the industry members of BAPVC. UCSB group conducted a comprehensive cost analysis of graphene synthesis. From the analysis results (Fig.2b) it was concluded that the consumption of catalyst leads to the high cost because the catalyst has to be etched away to separate the graphene from the catalyst film. In addition, this etching process requires use of etcher and solvent to remove the supporting PMMA layer on top of the graphene. These chemicals will also increase the cost. UCSB group developed a bubble method (Fig.2a) which can separate graphene films from the two sides of the catalyst without the catalyst etching process. Hence, the catalyst film can be reused many times (100 times for 25 µm film). In addition, the etcher is not necessary for the transfer. This method is totally green compared with the normal etching transfer method. More importantly, the cost of the UCSB graphene film is around \$7.5/m^2 which is close to the ITO market price (\$6/m^2), but predicted to continue increasing in the future. It is worth noting that the UCSB graphene process is still lab-scale and the cost will reduce when produced in high-volume. Additionally, this price (\$7.5/m^2) can be further reduced by using non-PMMA supporting layer, which does not require the solvent remover in the near future.

Future Work:
A new supporting material should be developed to replace PMMA. Using this new chemical, the usage of solvent such as acetone can be avoided to further reduce the cost.

1. Khatami, Y.; Liu, W.; Kang, J.; Banerjee, K. *Proc. SPIE 8824, Next Generation (Nano) Photonic and Cell Technologies for Solar Energy Conversion IV*, 88240T, September 25, 2013.
2. Khatami, Y.; Li, H.; Liu, W.; Banerjee, K., *IEEE Transactions on Nanotechnology*, Vol. 13, No. 1, pp. 94-100, 2014.