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Towards Industrial Applications of Graphene Electrodes

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1. Introduction

There have been many efforts to utilize the outstanding properties of graphene for macroscopic applications such as transparent conducting films useful for flexible/stretchable electronics. However, the lack of efficient synthesis, transfer, and doping methods limited the scale and the quality needed for the practical production of graphene films. In this presentation, we introduce ultra-large scale (~30 inch) synthesis, roll-to-roll transfer, and chemical doping of graphene films showing excellent electrical and physical properties suitable for practical applications. Considering the outstanding scalability/processibility of roll-to-roll and CVD methods and the extraordinary flexibility/conductivity of graphene films, we expect the commercial production and application electrodes replacing the use of ITO can be realized in near future.

2. Results and Discussions

Graphene and related materials have attracted tremendous attention for the last a few years due to their fascinating electrical , mechanical, and chemical properties. There have been many efforts to utilize these outstanding properties of graphene for macroscopic applications such as transparent conducting films useful for flexible/stretchable electronics. However, the lack of efficient synthesis, transfer, and doping methods limited the scale and the quality needed for the practical production of graphene films. For example, a conventional transparent electrode, indium tin oxides (ITO), that are commonly used in solar cells, touch sensors and flat panel displays show a sheet resistance smaller than 100 Ohm/square with ~90 % optical transparency as well as unlimited scalability, while the best records of graphene has still remained around ~500 Ohm/square sheet resistance, ~90% transparency, and a few centimetre scale at the moment.

On the other hand, typical CVD methods inevitably require a rigid substrate that can stand high temperatures close to ~1000 °C and an etching process for removing metal catalyst layers, which are main obstacles for the direct use of graphene on as-grown substrates. Therefore, the transfer of graphene films onto a foreign substrate is essential. However, the transferrable size of graphene has been limited below a few inches scale due to the size limit of rigid substrates and the inhomogeneous reaction temperature inside a CVD furnace. This can be overcome by using roll-type metal foils fitting the tubular shape of the furnace. In addition, the flexibility of graphene and Cu foils allow efficient etching and transfer processes employing a cost and time-effective roll-to-roll production system.

There are three essential steps in the roll-to-roll transfer (Fig. 1), which are i) adhesion of polymer supports to the graphene on a Cu foil, ii) etching of Cu layers, and iii) release of graphene layers and transfer on to a target substrate. In the adhesion step, the graphene film grown on a Cu foil is attached to a thin polymer support such as thermal-release tapes between two rollers. In the subsequent step, the Cu layers are removed by electrochemical reaction with a Cu etchant. Finally, the graphene films are transferred from the polymer support onto a target substrate by removing the adhesive force on the polymer support. In the case of using thermal release tapes, the graphene films are detached from the tapes and released to counter substrates by thermal treatment (Fig. 1).

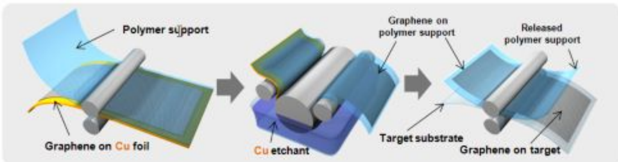

Fig. 1. Schematic of the roll-based production of graphene films grown on a Cu foil, including adhesion of polymer supports, Cu etching (rinsing), and dry transfer-printing on a target substrate. A wet chemical doping can be carried out using the similar set-up used for etching.

3. Summary

We have developed and demonstrated the roll-to roll production of graphene on ultra large copper substrates. The multiple transfer and simple chemical doping of graphene films considerably enhances its electrical and optical properties. Given the scalability and processability of roll-to-roll and CVD methods and the flexibility and conductivity of graphene films, we anticipate that the commercial production of large-scale transparent electrodes, replacing ITO, will be realized in the near future.

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References

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