Large Scale LiC6 for Electronic Applications

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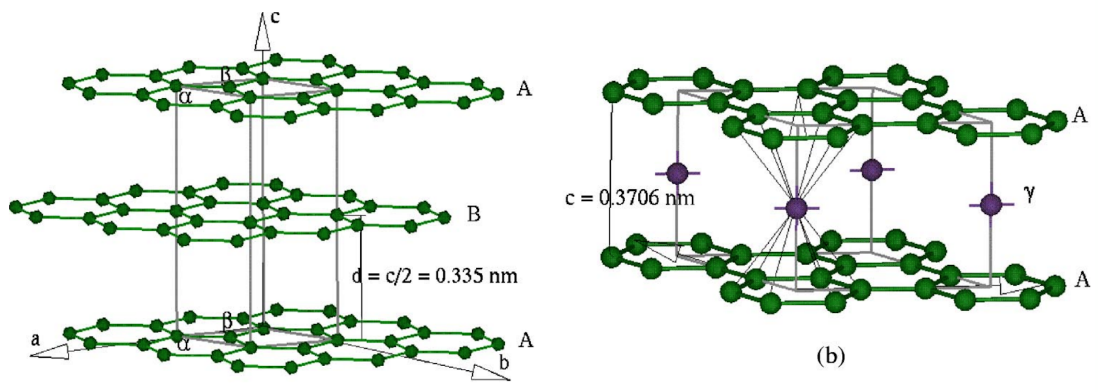
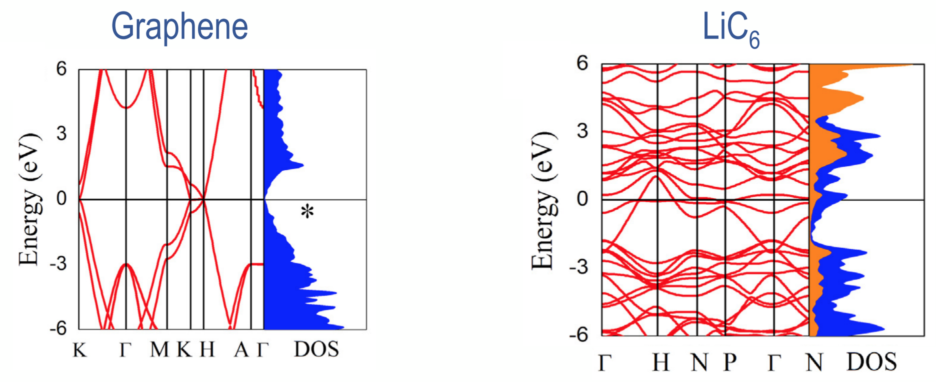
Introduction

While graphene exhibits extraordinary opto-electronic properties, it can be further enhanced by the introduction of lithium ions into the graphene structure. This lithiation process yields a material known as LiC_6, whereby one lithium atom exists for every six carbon atoms. The addition of lithium intercalants simulates heavy n-type doping, allowing for superior electrical conductivity, while also enabling Pauli blocking to improve optical transparency.

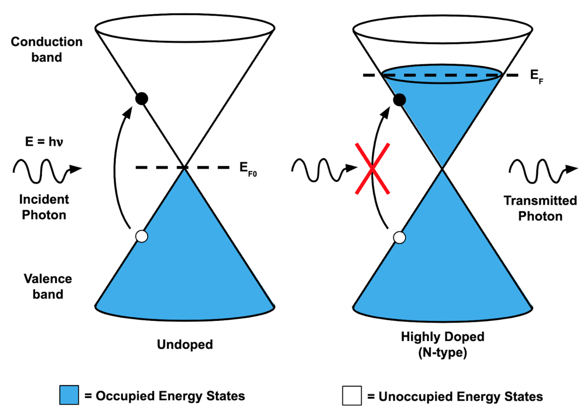


K. Kganyago et al. (2003)



Trade-off: Sheet Resistance & Optical Transmission

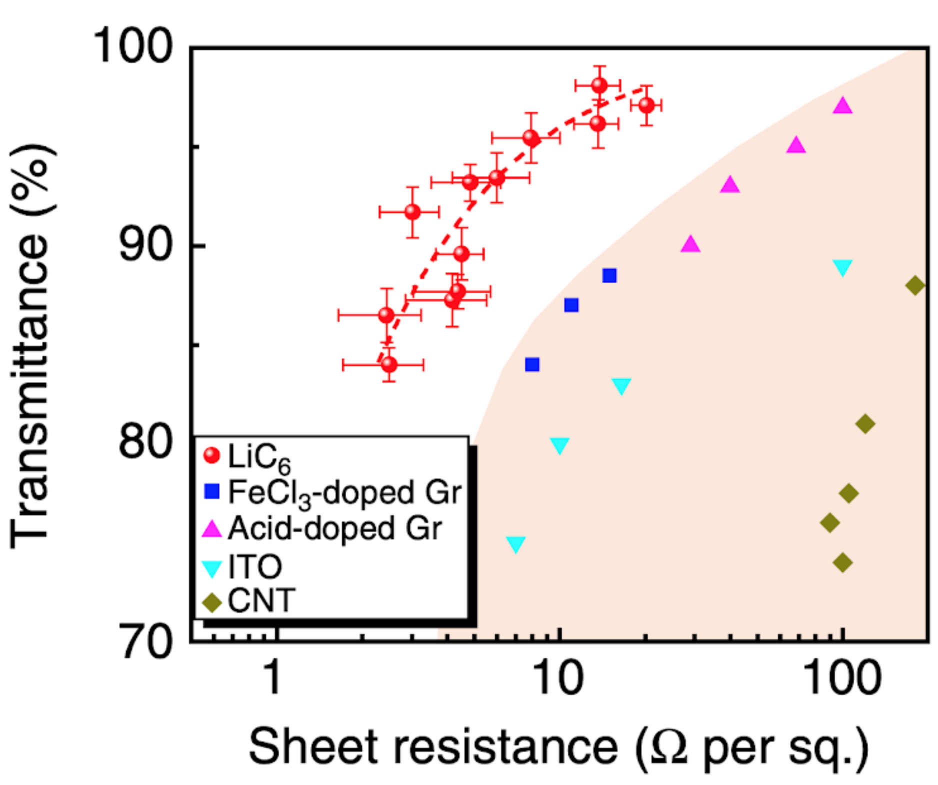
There exists a trade-off between sheet resistance and optical transmittance, as they are typically inversely proportional, resulting in a material-specific "figure-of-merit" (FOM). In its natural state, graphene's FOM does not compete with industry-standard indium-tin oxide (ITO). However, due to the large increase in charge carrier density from electron-donating lithium atoms, the Fermi level of the lithiated graphene rises well above the excitation energy for optical photons, increasing its FOM substantially.

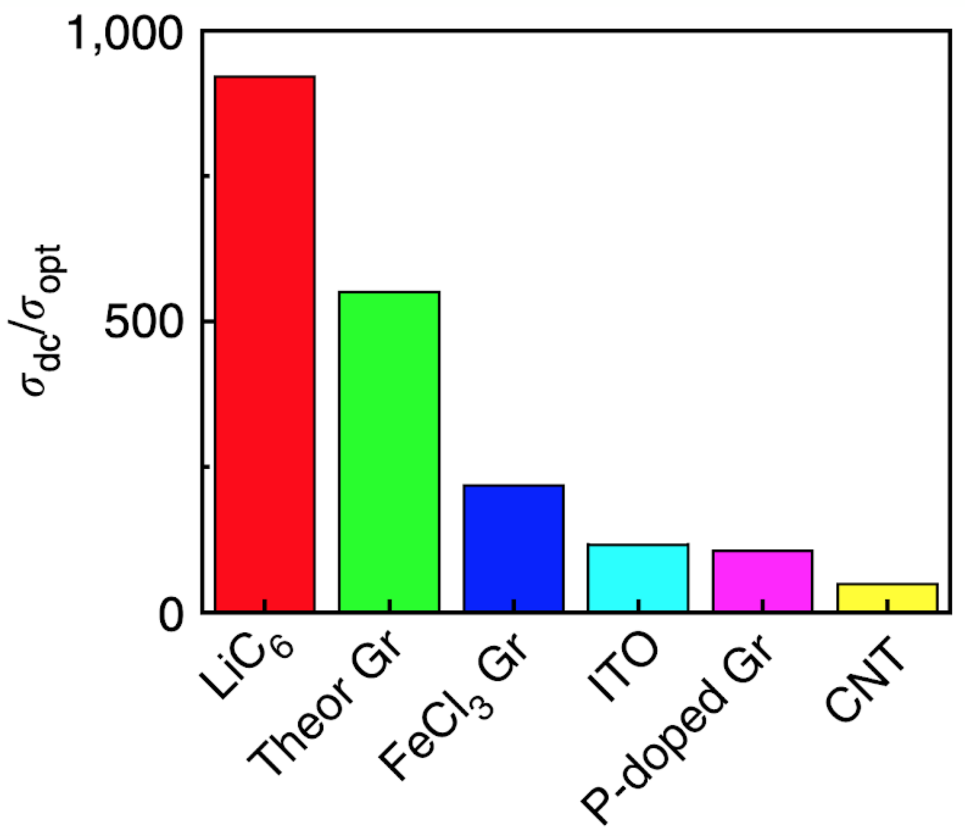


$$T = \frac{1}{\left(1 + \left(\frac{Z_0 t}{2}\right)\sigma_{OP}\right)^2}$$

$$R_s = \frac{1}{\sigma_{DC} t}$$

$$\mathrm{FOM} = \frac{\sigma_{DC}}{\sigma_{OP}} \qquad T = \frac{1}{\left(1 + \frac{Z_0}{2R_s}\frac{\sigma_{OP}}{\sigma_{DC}}\right)^2}$$

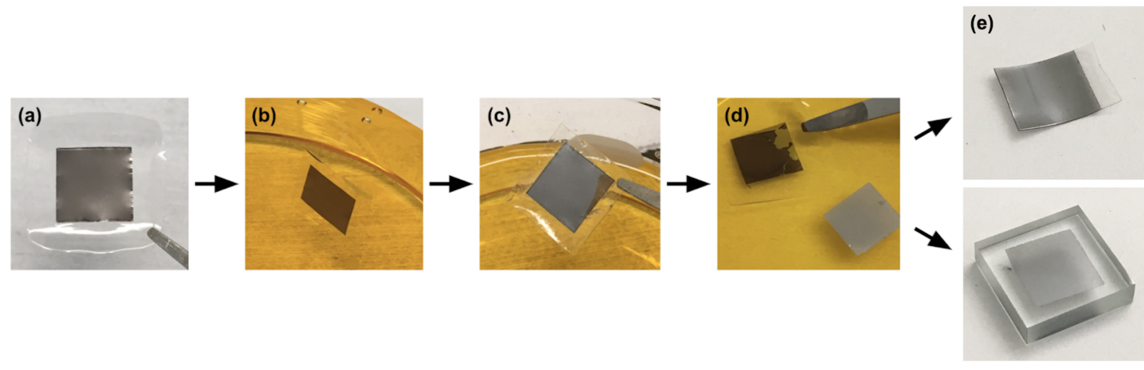


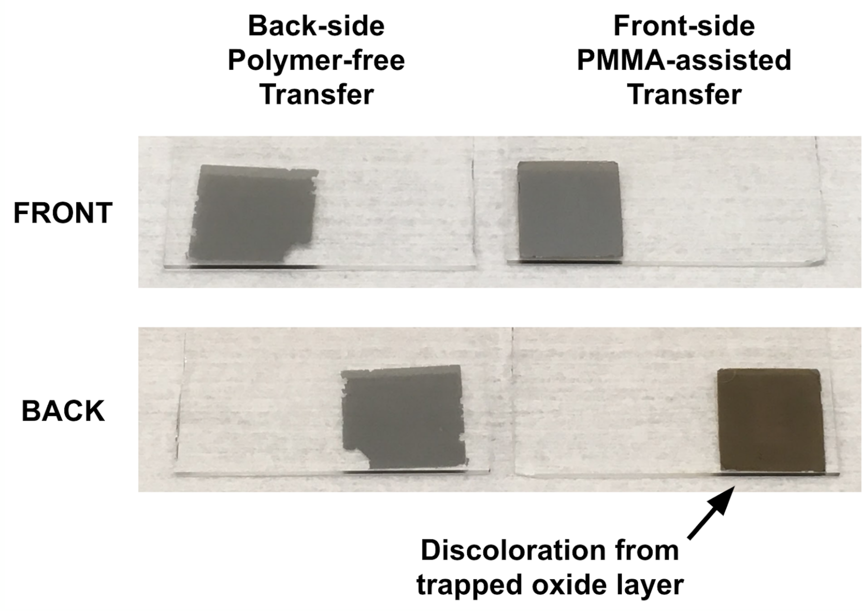


Bao et al. (2014)

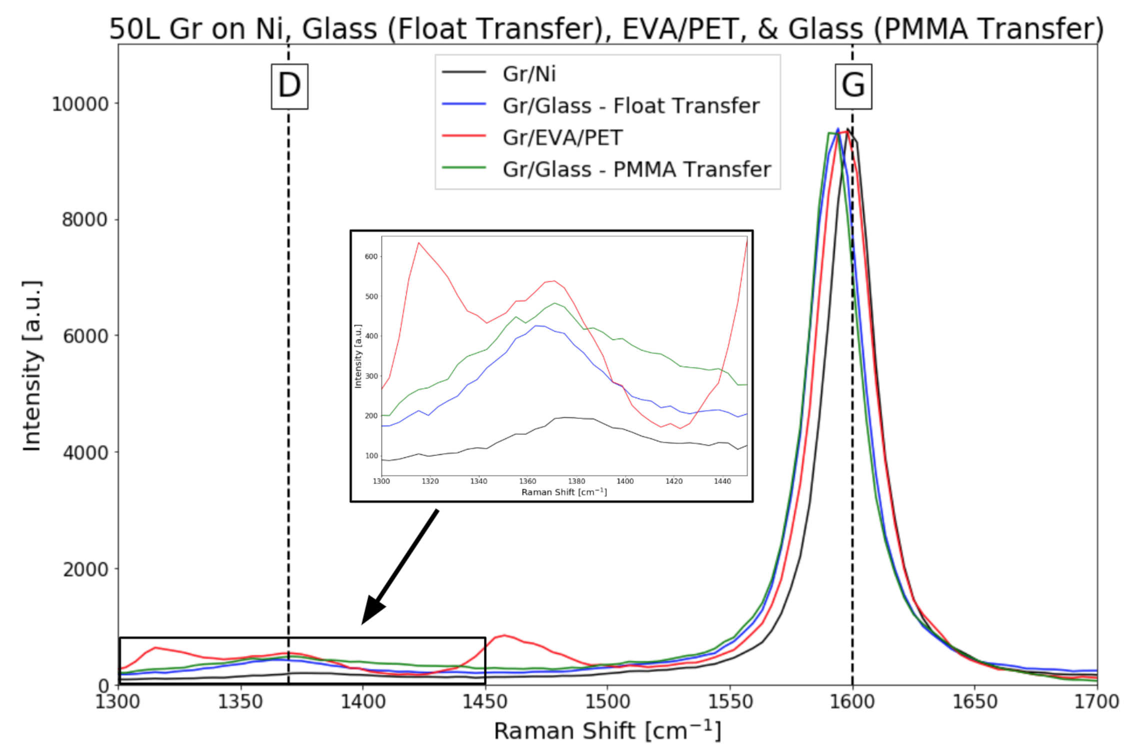
Bifacial Transfer Mechanism

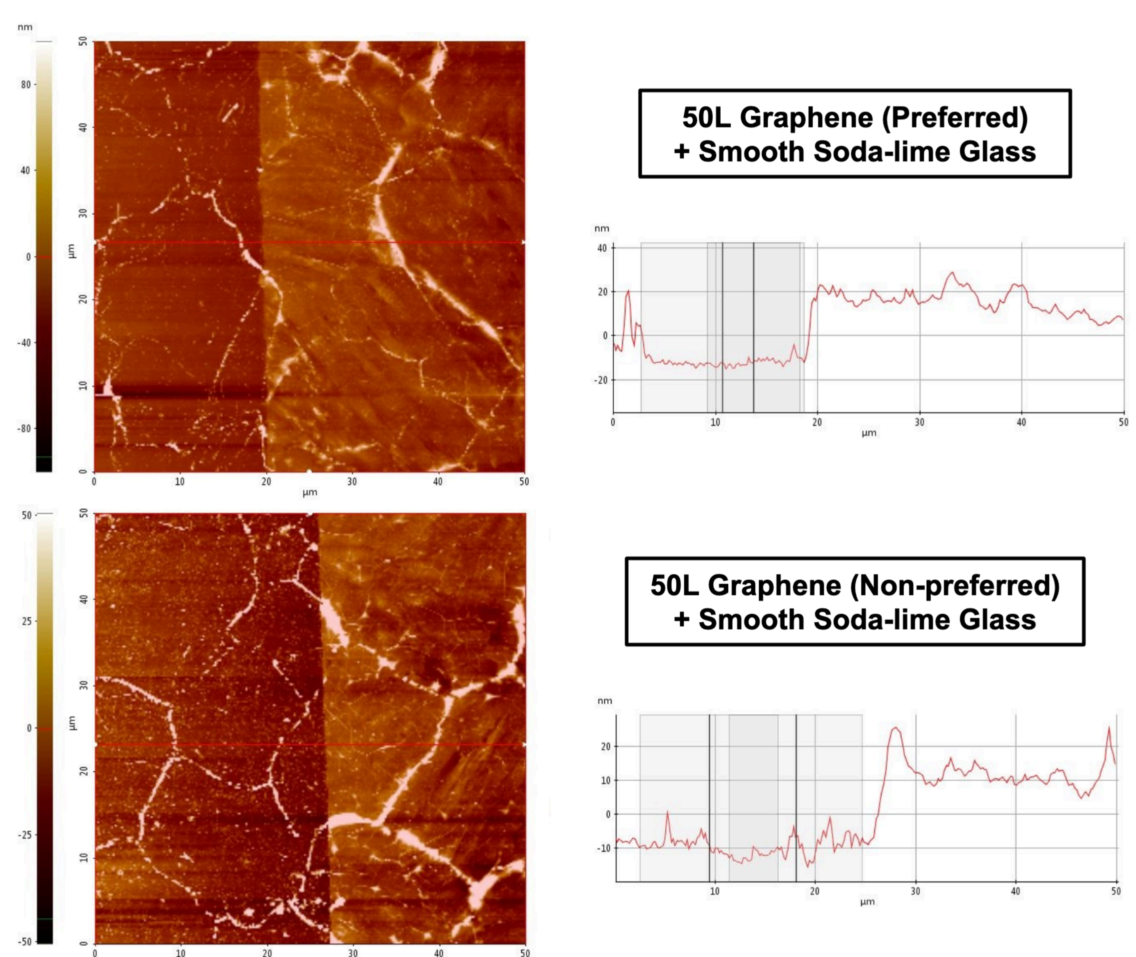
The following demonstrates a novel technique for bifacial transfer of multilayer graphene. The method involves hot-press lamination of a graphene/nickel/graphene film to polymer substrate, followed by etching of the metal substrate in a ferric chloride ($FeCl_3$) solution for a short period of time. Due to the formation of an oxide layer between opposing graphene films, the exposed film is able to release from the remaining stack, for further transfer to a new target substrate.



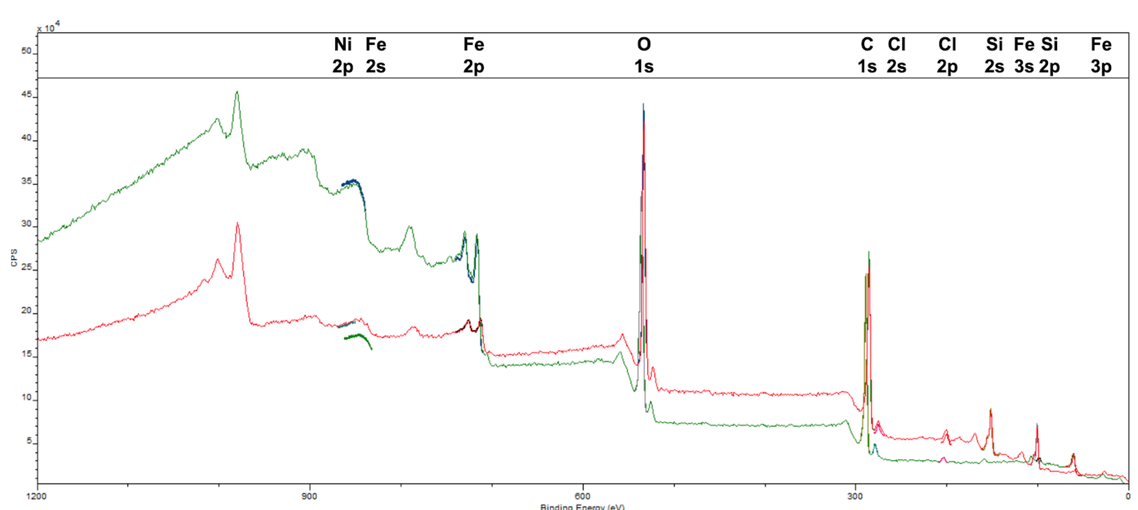


Raman spectroscopy and atomic force microscopy (AFM) measurements were performed to characterize the quality of graphene films transferred from both sides of the native nickel substrate. With regard to transfer-induced defects, the D/G ratio of each of the transferred graphene films is comparable to standard PMMA transfer.



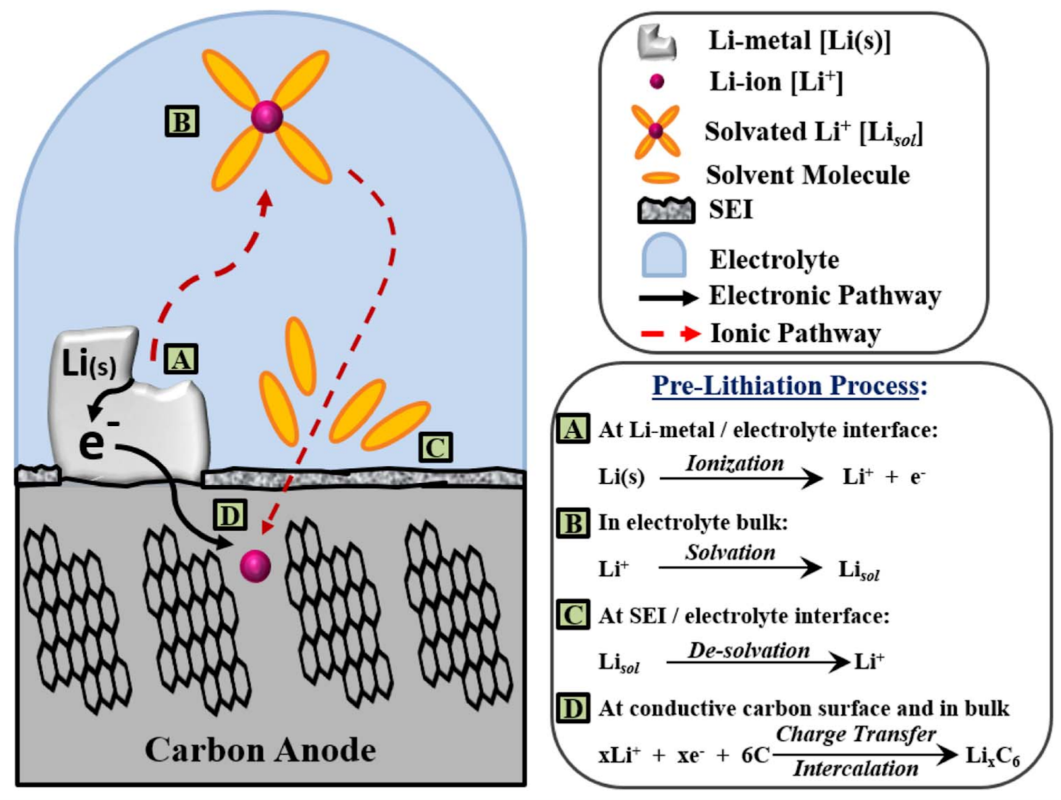


X-ray photoelectron spectroscopy (XPS) identifies an oxide layer that develops between the opposing graphene films as the nickel substrate is etched in $FeCl_3$ solution. This oxide layer is suspected to facilitate the separation of the exposed graphene film, which is usually discarded by oxygen plasma etch.



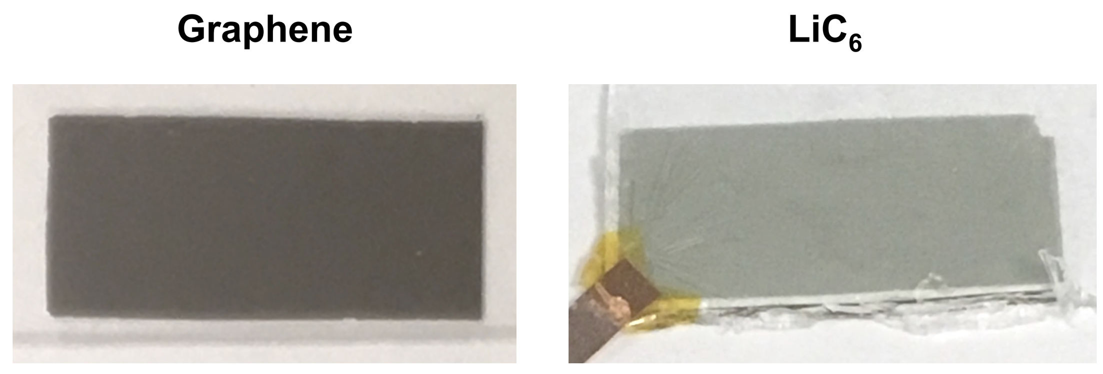
LiC_6 Fabrication

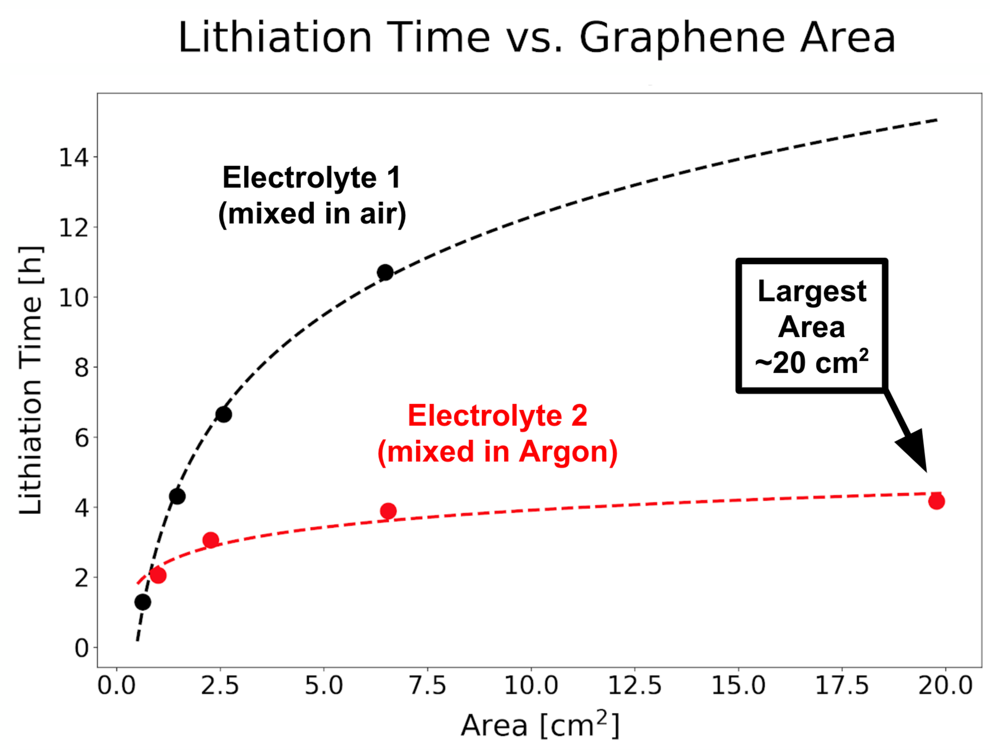
To facilitate lithiation, while under inert Argon atmosphere, lithium metal foil is exposed directly to the graphene sample in a small amount of lithium hexafluorophosphate ($LiPF_6$) solution. Complete lithiation to LiC_6 occurs within several hours, at which point the lithium foil and remaining electrolyte are removed, followed by a rinse with diethyl carbonate (DEC).

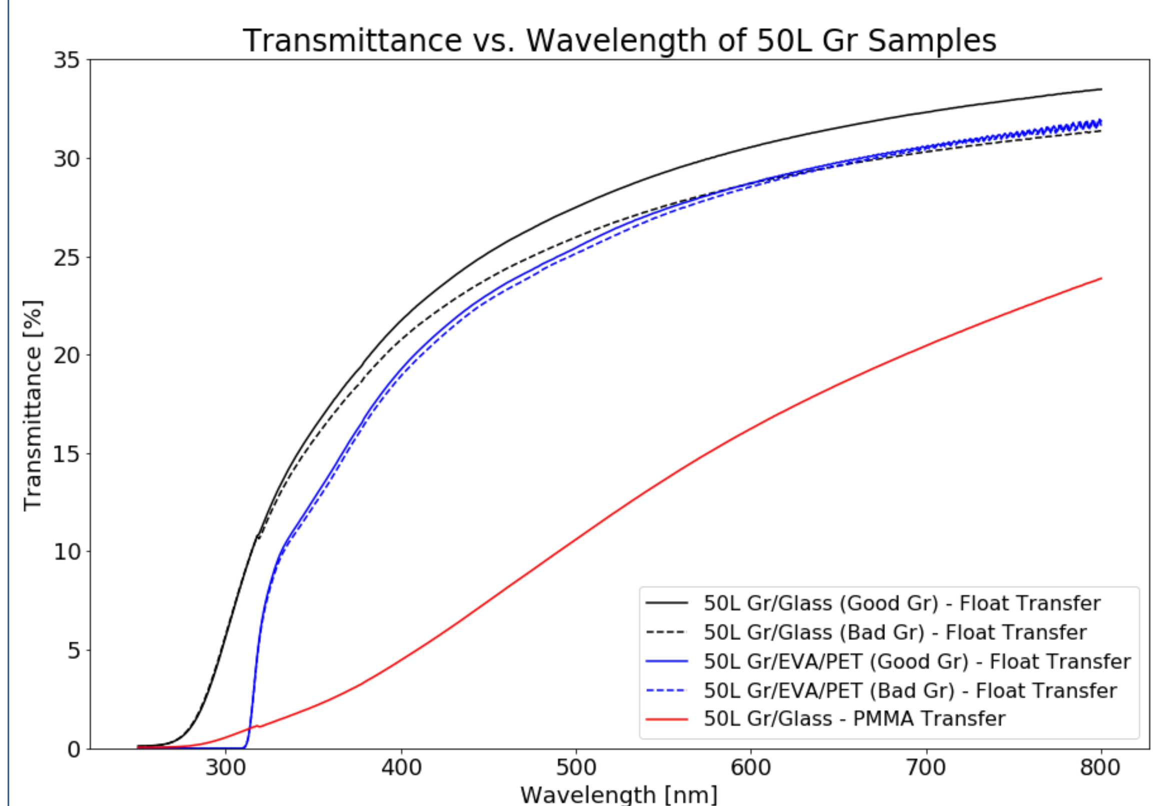


Shellikeri et al. (2017)

Post-lithiation, optical transmittance and electronic conductivity of the graphene sample are both significantly improved, greatly increasing the FOM of the original graphene film. To show scalability, areas of up to 20 cm² were lithiated using the method described above, and electronic measurements demonstrate sheet resistance as low as ~2.8 Ω/sq.







Conclusion And Perspectives

This work demonstrates both cost-effective use of both sides of graphene film grown on native nickel foil substrate, and successful lithiation to improve electrical and optical properties. By effectively doubling the usable graphene area, significant savings in both cost and time are achieved, thereby improving the prospects of scalability of graphene for application. Potential technologies such as transparent batteries, smart watches, and flexible electronics may benefit greatly from these insights.

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