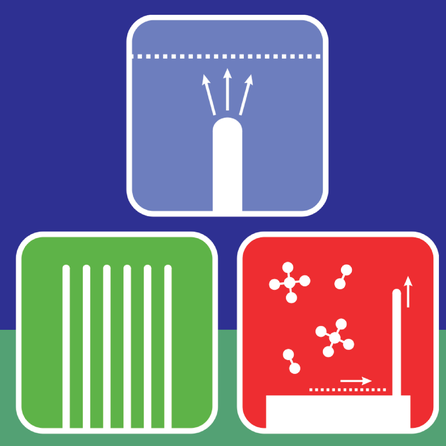
Enhanced Mechanical Properties of Graphene Transferred by HPL & UVA



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Introduction

Graphene holds much promise for the realisation of truly flexible and transparent electronic devices [1-2]. Large area graphene production necessitates the use of chemical vapour deposition (CVD), however, the catalyst supported graphene requires transfer from the often conductive growth substrate, typically using a polymer support. Cast poly-methylene metacrystalate (PMMA) is commonly used as this intermediary transfer layer, taking the graphene from the growth substrate and transferring it to any arbitrary destination substrate. This transfer method is limited to a few cm-square in scale, is costly, requires highly trained staff, is time consuming, and often stimulates pin hole, defects and ripples formation in the graphene. Direct transfer using lamination and adhesive-based transfer techniques offer many benefits including large-area compatibility, low cost, and low process complexity.

CVD-Graphene Transfer by HPL & UVA

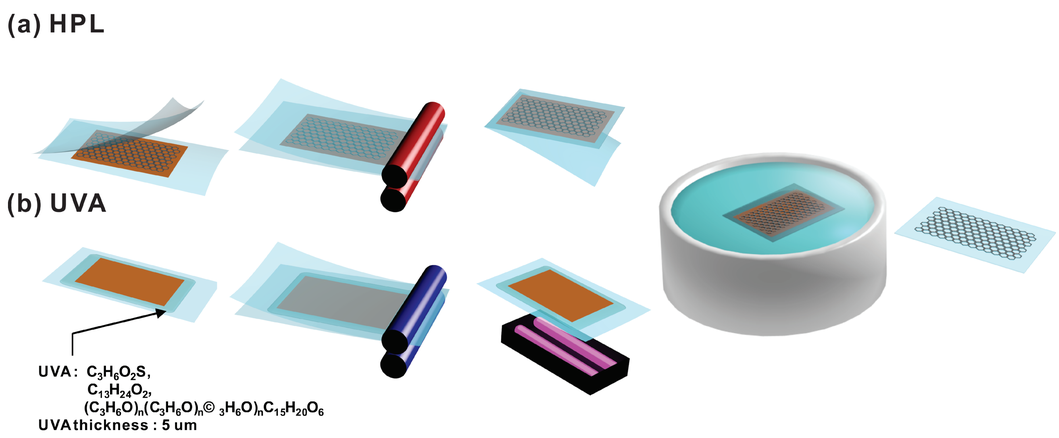


Figure 1. Graphene transfer to flexible transparent substrates by; (a) Hot Press Lamination (HPL) and (b) UV Assisted Adhesion (UVA).

In HPL transfer the as-grown CVD-graphene is attached to a laminate (ethylene vinyl acetate + PET) and compressed with a roller heated to around 120 °C. The graphene binds to the laminate and the rear-side catalyst is subsequently wet-etched. For UVA transfer the graphene is attached on PET using UV-assistve adhesive and exposed to a UV optical source for 20 min, with the catalyst latterly removed in a copper etchant. Using these two direct transfer methods, the transfer time can be dramatically reduced with large area transfers being realised.

Mechanical Testing

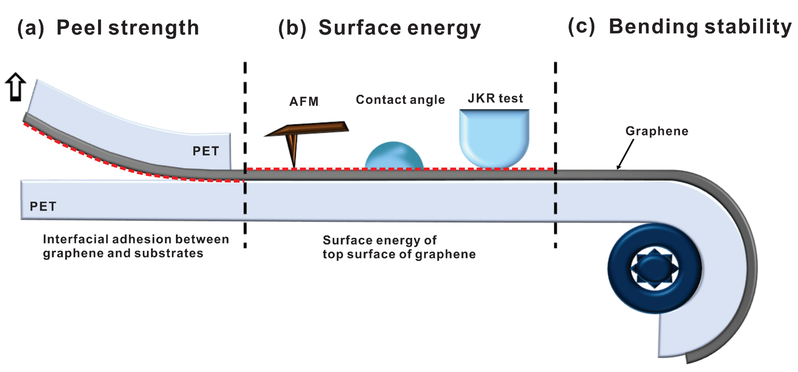
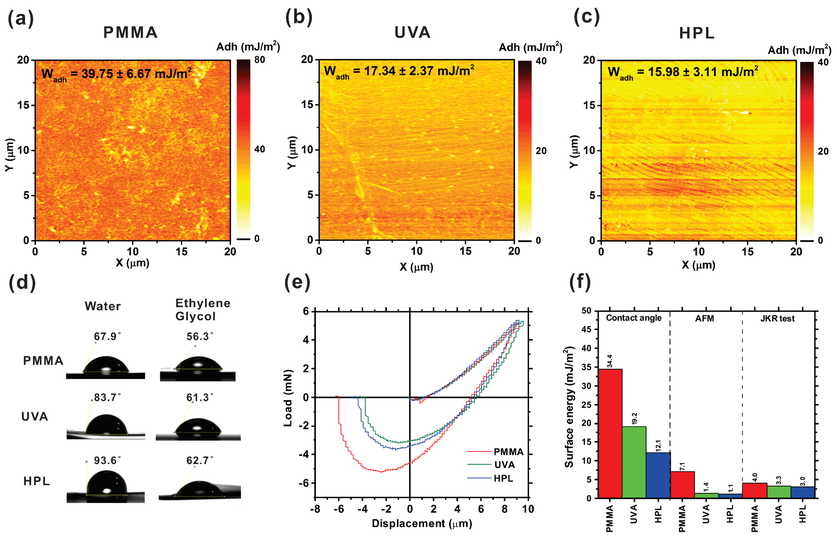


Figure 2. A schematic depicting our standard mechanical analysis methods used in determining the mechanical properties of our CVD graphene transferred on PET substrates by PMMA, UVA and HPL. These include; (a) interfacial adhesion peel test, (b) graphene surface energy, and (c) bending stability, repeatability and robustness.

Surface Energy



Defective graphene has a high surface energy and high areal density of lattice vacancies. This increases the surface polarity thereby increasing the surface energy [3-5]. Our data suggests that UVA and HPL transfer techniques do not stimulate significant defect formation compared to conventional PMMA transfer making them well-suited for e-displays and other large-area applications.

Figure 3. AFM-assesed work of adhesion of (a) PMMA-, (b) UVA-, and (c) HPL-transferred graphene. (d) Variation in contact angle (water and ethylene glycol) as a function of transfer method. (e) Typical JKR load-displacement curves for each transfer method. (f) Summary of the surface energies from AFM, Contact angle, JKR measurements.

Graphene-to-Substrate Adhesion

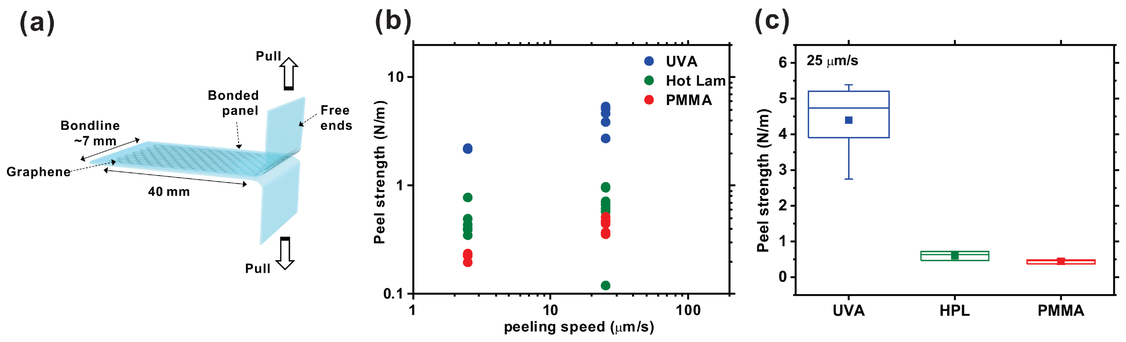
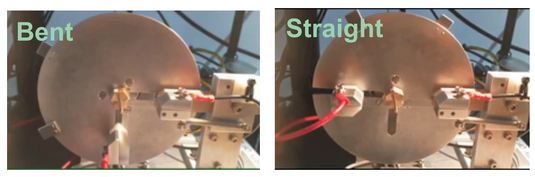


Figure 4. (a) T-peel test scheme. (b) Variation in peel strength as a function of peel speed. (c) Distribution in the peel-strength across the considered transfer methods (25 μm/s peeling speed).

As shown in Figure 4, the highest peel strength of 4.39±1.09 N/m was found for UVA transfers, resulting in significantly enhanced mechanical adhesion between the substrate and CVD graphene. The adhesion of graphene transferred using UVA and HPL are around 880% and 29% higher, respectively, than that of mechanically exfoliated graphene on SiO_2 (0.45±0.02 N/m) [6].

Robust Flexibility



Photographs depicting our custom-built, automated bending cycle stress system. A bending angle of 90° is denoted “Bent”, and 0° as “Straight”. Bending diameters of 2-10 mm were considered. The sample resistance (R) was measured after each bending cycle, with a total of 10,000 bend cycles measured.

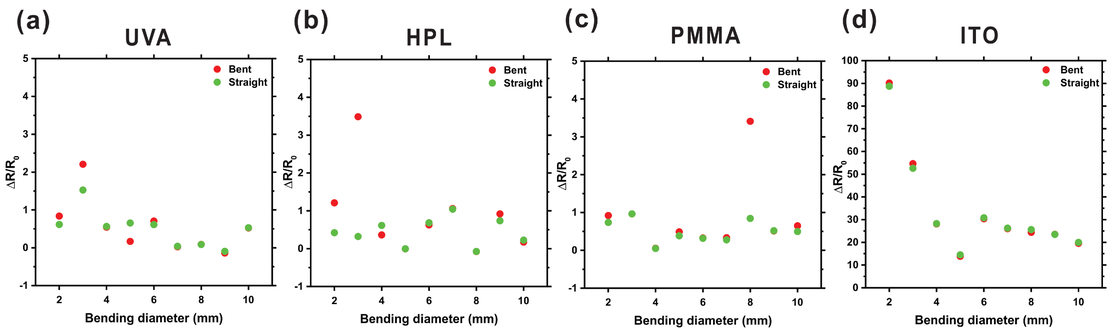


Figure 5. Resistance variation ($\Delta R/R_0$) after 10,000 bending cycles, as a function of bend diameter.

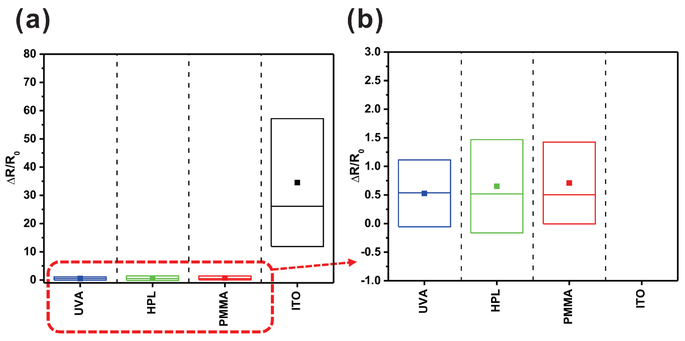


Figure 6. $\langle \Delta R/R_0 \rangle$ across all bend diameters.

The flexibility of graphene is found to be consistently superior to ITO . UVA-graphene showed the lowest resistance change and the highest peeling strength. Bending resulted in the deterioration of the interfacial adhesion between the graphene and the substrate. The UVA transfer was found to be more robust against bending with a notably higher adhesion to the substrate.

References

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Acknowledgements

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