High-quality uniform dry transfer of graphene to polymers

Evgeniya H. Lock[1], Mira Baraket[1,†], Matthew Laskoski[2], Shawn P. Mulvaney[2], Woo K. Lee[2], Paul E. Sheehan[2], Daniel R. Hines[3], Jeremy T. Robinson[4], Jacob Tosado[5], Michael S. Fuhrer[5], Sandra C. Hernàndez[1,†], Scott G. Walton[1]

[1]Plasma Physics Division, Naval Research Laboratory, Washington DC 20375
[†]NRL/NRC Postdoctoral Research Associate
[2]Chemistry Division, Naval Research Laboratory, Washington DC 20375
[3]Laboratory for Physical Sciences, College Park, MD 20740
[4]Electronics Division, Naval Research Laboratory, Washington DC 20375
[5]Center for Nanophysics and Advanced Materials, University of Maryland, College Park, MD 20742, USA

Supplemental information includes X-ray photoelectron spectroscopy spectra of polystyrene before and after CO_2 plasma treatment (Figure 1, 2) illustrating the incorporation of the desired oxygen functionalities namely hydroxyl and carboxyls into the inert polystyrene structure. Figure 3 shows optical images of polystyrene films before and after transfer. Graphene is not visible on the sample after transfer. However, to make graphene visible, the substrates to which graphene is transferred have to meet certain requirements. In the case of SiO_2/Si, there is an optimal SiO_2 thickness – from 90 to 280 nm[1, 2]. Graphene has been imaged on very thin films using different filters: with blue light on 50 nm Si_2N_4 and with white light on 50 nm thick PMMA[1]. Other authors suggest using substrates with refractive index of one[2]. In our case, we have 250 μm thick opaque polystyrene film with index of refraction of 1.59. Thus, the fact that optical images do not show graphene is not surprising. To overcome this, we analyzed the graphene residues on the Cu foil (Figure 4) by dissolving the foil and transferring the residues to SiO_2/Si wafers, where the oxide thickness is 300 nm. The polymer samples were smaller than the graphene/Cu substrates and so in cases PS H and PS R (Figure 4 a, c) the residues on the Si wafers are the edges of the graphene/Cu foil that did not come into contact with the polymer surface during print. Thus, these images suggest that in PS H and PS R cases graphene was completely transferred to the whole adhesion treated polystyrene surface, while in the case of PS Ref. graphene is clearly visible (Figure 4 e, f).

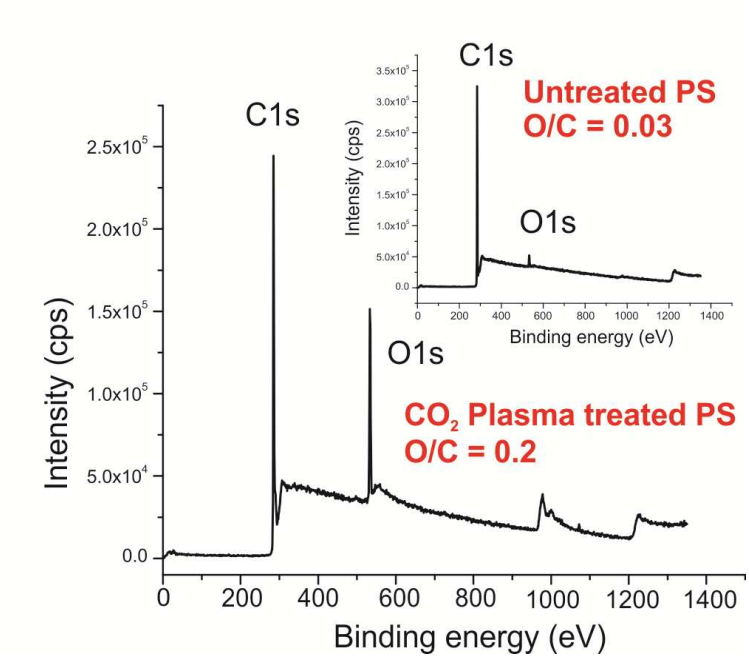

Figure 1. Survey X-ray photoelectron spectroscopy spectra of untreated (a) and CO_2 plasma treated (b) polystyrene. PS denotes polystyrene.

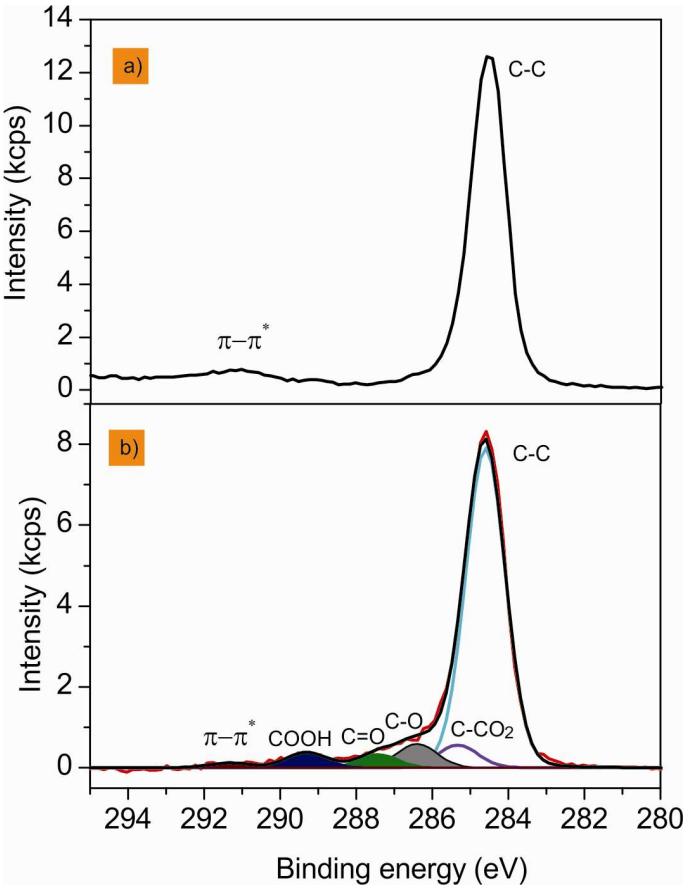

Figure 2. High-resolution C1s X-ray photoelectron spectroscopy spectra of untreated (a) and CO_2 plasma treated (b) polystyrene.

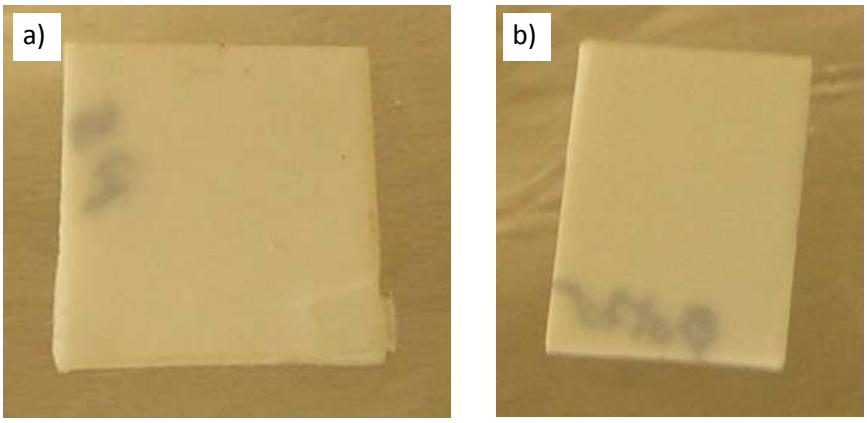

Figure 3. PS H before (a) and after (b) transfer print.

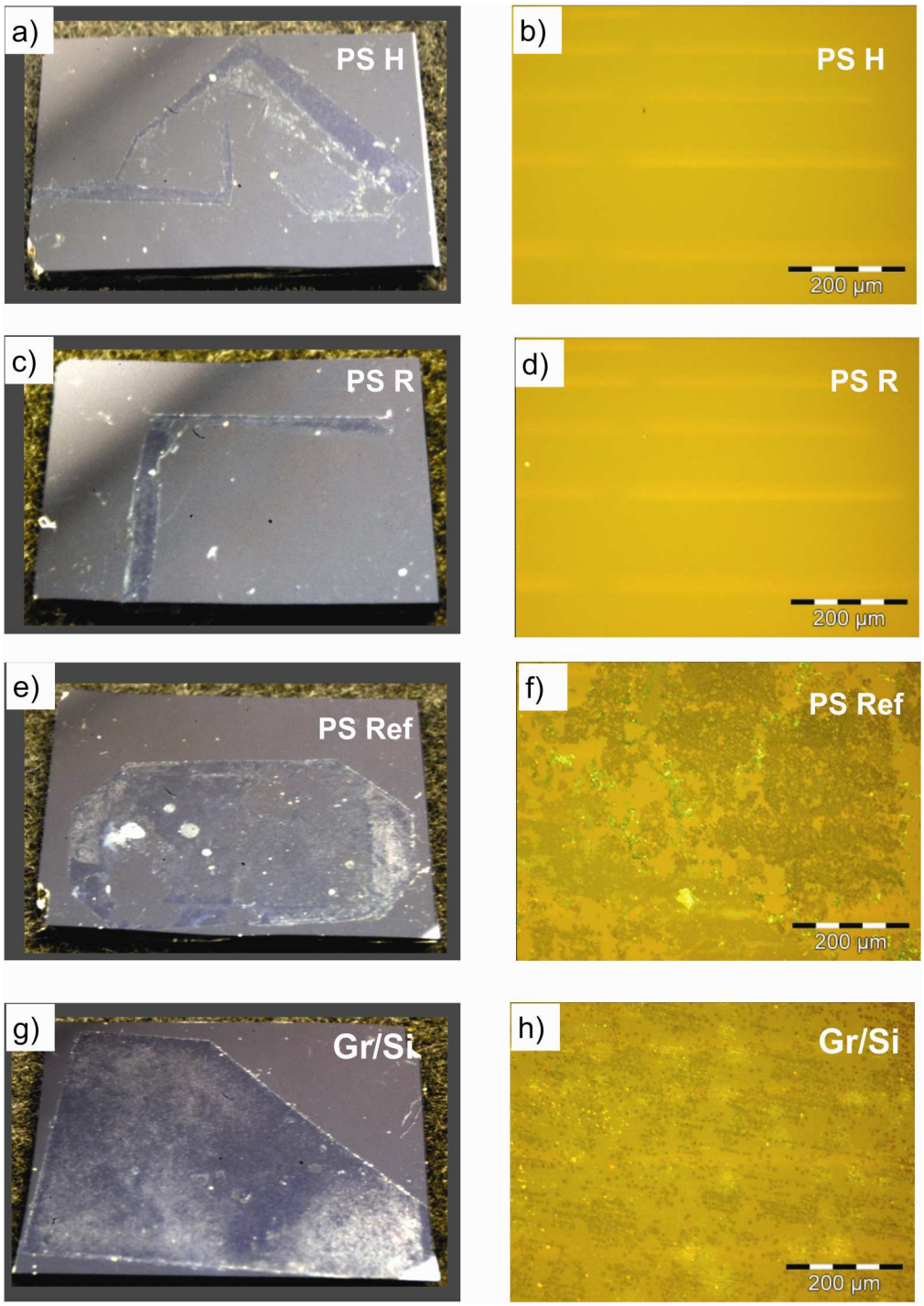

Figure 4. Photographs (left column) and corresponding microscope images (right column) for PS-H (a, b), PS-R (c,d), PS ref (e, h) and graphene on SiO_2/Si (g, h). In this work the polymer samples were smaller than the graphene/Cu substrates and so in cases (a) and (c) the residues on the Si wafers are the edges of the graphene/Cu foil that did not come into contact with the polymer surface during print. Thus, these images (a, c) suggest that in PS H and PS R cases graphene was completely transferred to the whole adhesion treated polystyrene surface.

References:

1. Blake, P.; Hill, E. W.; Castro Neto, A. H.; Novoselov, K. S.; Jiang, D.; Yang, R.; Booth, T. J.; Geim, A. K., Making graphene visible. *Appl. Phys. Lett.* 2007, 063124.

2. Wang, X.; Zhao, M.; Nolte D. D., Optical contrast and clarity of graphene on an arbitrary substrate. *Appl. Phys. Lett.* 2009, 081102.