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Adhesive interactions between graphene and substrates

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ABSTRACT

Dry transfer of graphene has been an integral part of its history from the earliest days when scotch tape was first used to exfoliate graphene from graphite. This approach produces relatively small flakes of variable thickness. Chemical vapor deposition of graphene on thin (35 μm) large area Cu foil, and related metal foils such as commercially available Cu–Ni foils, produces large area graphene, up to meters in in-plane dimension. Graphene has also been grown on copper film (~1 μm) that has been deposited on silicon wafers and relatively thick (5 mm) copper sheet. No matter which approach is taken, the same problem remains: transferring the graphene to its destination substrate for the myriad of applications that are currently being considered. Some applications may require intermediate carrier films to be used, so several contact and separation events can be expected. In most cases, the adhesive interactions that are involved in contact and separation are likely to be van der Waals in nature, but the details could vary significantly depending on the contact pair. The strongest interactions may be between graphene and its seed metal; interactions between graphene and target substrates are expected to be weaker but may be modified by surface functionalization. Other interactions such as electrostatic effects, retarded van der Waals, and capillary forces cannot be ruled out and are likely to be modified by roughness and rate and mixed-mode fracture concepts. This presentation reviews our study in characterizing the adhesive interactions between graphene and its seed layer as well as graphene that has been transferred to other materials. The main experimental vehicles for this effort have been fracture tests such as laminated beam and blister tests in which the graphene has been supported by other layers. In many cases local crack tip opening or surface displacements have been used to support analyses for extracting traction–separation relations and adhesion energies associated with the various contact pairs that have been considered. The toughness of the graphene/seed layer interface is surprisingly high. The most striking feature of the interactions associated with transferred graphene that have been measured so far is their relatively weak and long range nature when compared to van der Waals forces.