Interlayer bonding characterization of rGO-based electronics

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Introduction
Adhesive and cohesive properties of layered structures are critical to their strength. Analysis of mechanical properties of micro/nano-fabricated devices, which are usually synthesized in a layer-by-layer process is challenging due to their small scale and associated low strength, especially when the devices are created on a flexible substrate.

Methods
• Drop casting:
  ➢ Kapton was selected as a flexible substrate and high thermal chemical stability.
  ➢ Substrates were treated by O2 for 5 min to activate the surface for bonding.
• Thermal reduction:
  ➢ Sonication bath for one hour
  ➢ Drying in oven with temperature of 36°C overnight
  ➢ Reduction in argon environment with temperature ramped to 350°C in 10 minutes

• Peel test:
  ➢ Peel tests were performed using the peel test method proposed by Rezaee et al (2019) to control significant factors on peel test measurement. In this method, a fixed peel rate and peel angle of 90° were consistently generated using the Instron MTS and a 45° tilted test fixture. JM Scotch® Magic™ 810 tape (with the width and thickness of 19 mm and 0.060 mm respectively) was used in testing. To prevent the Kapton film from lifting or deforming during testing, it was attached to an aluminum testbed with a thin double sided Kapton tape. The tape was pulled up in a direction parallel to the normal vector of the substrate surface by extension rate of 1 mm/sec using the Instron MTS. Measurements were recorded by Omega LCL-010 full bridge load cell with the capacity of 45 N (10 lb.).

• Image processing:
  ➢ After peeling, the tape with remnants of rGO was transferred onto an overhead transparency film and a light pad was employed to take images of visible rGO particles stuck on the tape after peeling using a Canon EOS Rebel T6 18 megapixel DSLR camera with a 55mm lens at a distance of 300 mm from samples. After converting images to grayscale, a threshold-base image processing technique was used to identify the profile of visible rGO particles along the tape. In addition to the total amount of peeled rGO, measurements of actual width of peeled rGO were done across the width of the tape at every pixel which is in average corresponding to 1/20th of millimeter.

Result
• Thermal reduction stability evaluation:
  ➢ Overall Cohesive Failure (OCF)
  ➢ Effective Covered Area (ECA)
  ➢ Effective Peel Region (EPR)

  ➢ The percentage of peeled rGO particles with respect to the whole area of sample.
  ➢ A percentage whole area of sample which is covered by rGO particles after thermal reduction process.
  ➢ A percentage of effective covered area in which the rGO particles were peeled off from sample

• Performance Ratio (PR)
  ➢ The ration of ECA over EPR representing an index to evaluate the stability of thermal reduction process.

Conclusions
• A controlled peel test produced repeatable results so that the compatibility with image processing output and bonding force model has been approached.
• High correlation between variations of peel force and unpeeled width was promising fact which led to mathematical model to calculate the release energy associated with failure modes of bonding.
• Cohesive failure energy is highly dependent to the amount of peeled rGO particle from substrate which was expected.
• Adhesive failure energy was found with less correlation with linear trend in comparison to cohesive failure.

Selected References:

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