Enhancement in Thermal Conductivity of CNT/Polymer Composite Ribbons via Optimization of Casting Conditions and Post-treatment

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Continued development and miniaturization of high-efficiency electrical circuits led to significant increment in power density, which consequently leads to huge waste-heat generation. Since the undesired heating of the electrical circuits is a major threat to their performance and durability, flexible materials possessing high thermal conductivity (TC) for the thermal management of equipments are getting significant research interest. In this regard, carbon nanotube (CNT), with theoretically calculated TC of more than 6000 W/mK, is of great importance[1]. Apart from this, CNTs are also lightweight, corrosion-resistant, and flexible materials. Although the theoretical calculation of isolated CNTs exhibits exceptional TC, the difficulty in handling them as aggregates limits the application of CNTs. In aggregates, CNTs are quite entangled due to the high aspect ratio and strong van der Waals interaction. Therefore, orientation techniques are desirable to utilize the individual-CNT's thermal properties at a macroscopic scale.

We have recently established a new orientation technique to fabricate scalable films of CNT/polymer composite through a programmable robotic dispenser, as schematically shown in Fig. 1(a) [2]. Using this technique, ribbon-like films are obtained on the desired substrates by drawing the CNT/polymer composite ink, which is extruded through a narrow needle. Moreover, CNT orientation can also be optimized by tuning the casting parameters, wettability of the ink to the substrate, and ink composition.

In this work, CNT/polymer composite films were fabricated using the robotic dispenser and CNT-orientation intensity of films was estimated by the mapping of G-band intensity ratio ($I_{00^\circ}/I_{90^\circ}$). For the oriented films, improvement in the corresponding thermal diffusivity and TC was also obtained. Moreover, it was found that the post-treatment, done for peeling the film off the substrate, also affected the TC, which can be attributed to variation in the residual organic components in the peeled film. To probe it further, the film fabrication conditions and post-treatment conditions were varied, and it was observed that the corresponding TC increased with decreasing cross-sectional area, as shown in Fig. 1(b). Through optimization of post-treatment of the oriented CNT/polymer composite ribbons, i.e., by varying the dipping time and temperature of the solvent bath, the in-plane TC of more than 200 W/mK was obtained, which is among the highest TC reported for the composite films fabricated with different types of fillers[3].

In the literature, increase in TC by increasing the filler loading is typically reported in the literature; however, often, there is a trade-off between film flexibility and the TC. Rather, the key advantages of the present technique, such as i) scalability, ii) cost-efficient processability, iii) orientation, iii) flexible and freestanding film, and iii) high TC, match the desired requirements for the commercialization.

The optimizations concerning dispersion, film fabrication parameters, and the post-treatment will be discussed in detail during the presentation.

Reference
[1] B. Kumanek, D. Janas, J. Mater. Sci. 54, 7397 (2019).
[2] M. Pandey et al., Appl. Phys. Express 13, 065503 (2020)
[3] H. Ma et al., J. Mater. Sci. 56, 1064 (2021)

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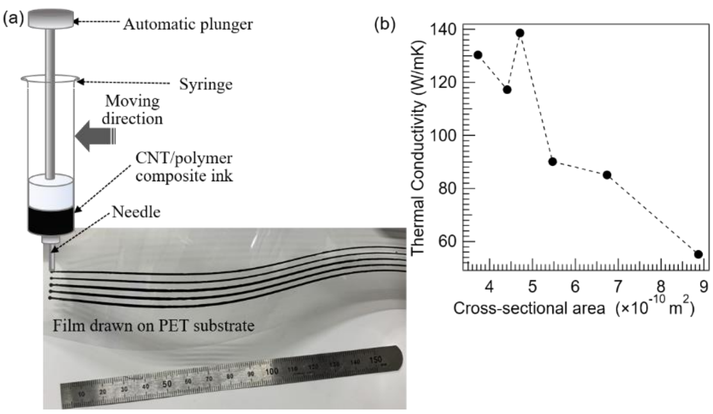

Fig. 1. (a) Schematic representation of film fabrication via robotic dispenser and photograph of the coated films. (b) Variation in thermal conductivity of peeled CNT/polymer composite ribbons with respect to its cross-sectional area changed by the removal of organic components.