Nanoimprint-induced strain engineering of two-dimensional materials

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The high stretchability of two-dimensional (2D) materials has opened a window of possibilities to use external strain to manipulate their properties[1]. Hence, strain engineering has emerged as a promising technique to achieve better performance of materials by controlling the elastic strain field applied. A number of methods for straining 2D materials have been recently proposed, such as flexible substrate deformation[2], thermal expansion mismatch[3], etc. However, the nonhomogeneous and uncontrollable strength still appears as a key issue[4]. Here, nanoimprint is proposed to introduce controllable and periodic strain profile on graphene. In particular, the strain distribution is verified by the shift of the work function of graphene measured by Atomic Force Microscopy (AFM). The relationship between pressure, imprint depth and strain were investigated, which enables us to achieve controllable strain to graphene. A model to explain the strain distribution and predict the band gap-shifted behaviors and work function in the graphene layer after the nanoimprint process was also proposed. The nanoimprint-induced strain engineering will offer new opportunities for the applications in nanoelectronics and optoelectronics.

Figure 1(a) shows the scanning electron microscope (SEM) and AFM images of graphene on cyclic olefin copolymer (COC) after nanoimprint under 0.6MPa and 100C°. The topography images from figure (i)(ii) verify the successful transfer of graphene using PMMA-mediated wet transfer method and replicated nanogratings with corresponding periods on graphene/COC. The contact potential difference (CPD) map in figure (iii) shows similar grating structure, indicating the periodic work function induced by periodic strain. As are shown in figure (b)(c), the work function variation increases as pressure or displacement increases. It also suggests that strain increases with increasing pressure or imprint depth. Therefore, the elastic strain field can be controllable by tuning the pressure and imprint depth.

Figure 2(a) displays the schematic diagram of imprint process. For a periodic line-pattern mold, the strain distribution of nanoimprint can be predicted by a simplified two-dimensional plane strain model, as shown in figure 2(b).

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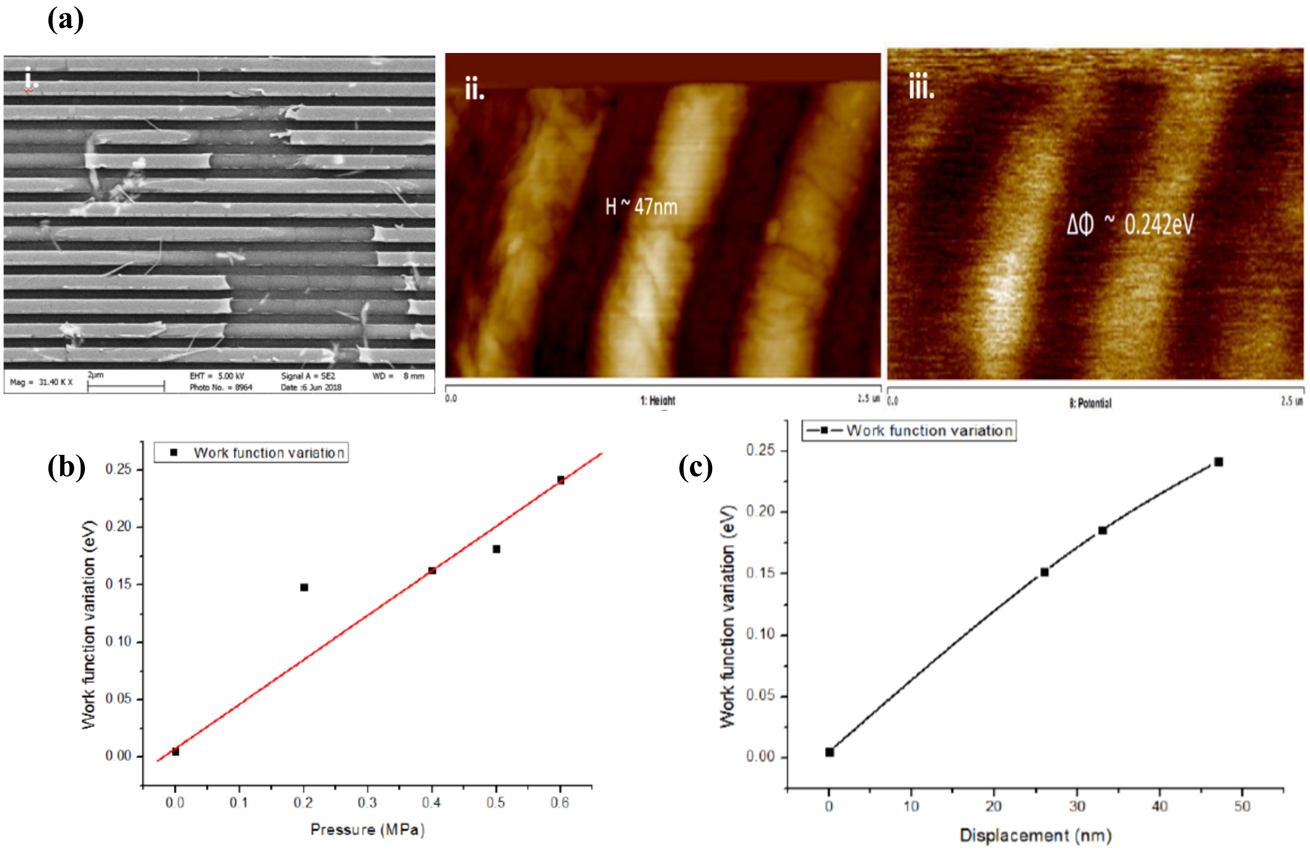

Figure 1. (a) SEM and AFM images of graphene/COC after nanoimprint under 0.6MPa and 100C°. (i) SEM topography. (ii) AFM topography of graphene/COC with depth of 47 nm. (iii) CPD map of graphene/COC with work function variation of 0.242eV. (b) The work function variation as a function of pressure. (c) The work function variation as a function of imprint displacement.

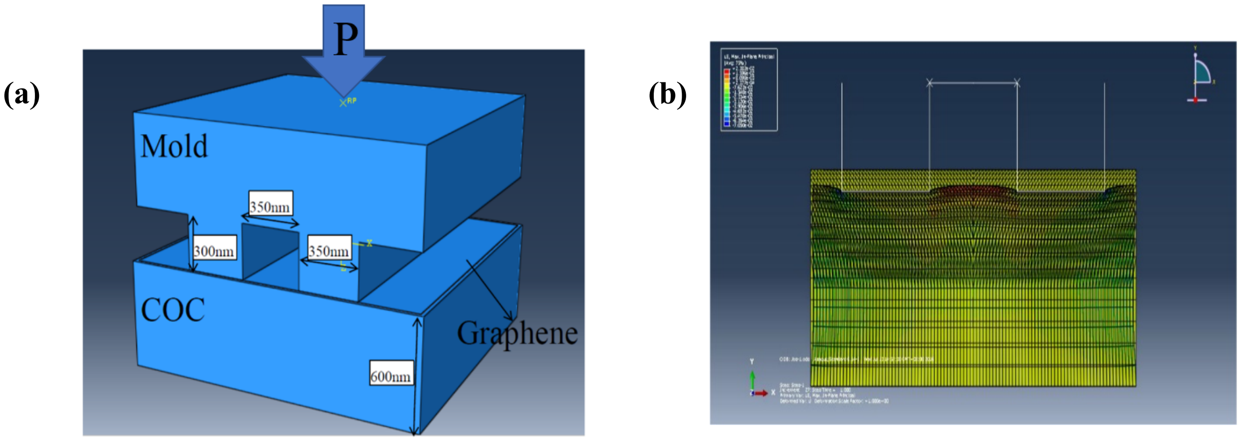

Figure 2. Nanoimprint process and its analytical model: (a) schematic diagram of imprint process, and (b) simplified 2D plane strain analytical model