Sub-10 nm wide suspended graphene nanoribbon by HIM

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Helium ion microscopy (HIM) and milling are known for highest resolution. It is therefore actively employed for graphene device fabrication and modification [1, 2]. However, when the necessary dose to modify the graphene exceeds a certain value, the substrate starts to swell due to helium bubble formation. This deformation can cause damage to the graphene [1] and methods to mitigate this are actively searched. Here, we avoid damage from substrate swelling by suspending the graphene. Additionally, knock-on damage from the beam-substrate interaction is reduced, leading to sub-10 nm resolution.

The suspended graphene nanoribbons were fabricated at JAIST from exfoliated HOPG graphene flakes. The fabrication process is shown in Figure 1a. The nanoribbons were patterned using PMMA etching mask and oxygen RIE, followed by Cr/Au lift-off of source and drain contacts. Finally, the ribbons were released by hydrofluoric acid etching followed by critical point drying. In order to remove the PMMA contaminants, which is necessary to avoid hydrocarbon deposition inside the HIM, the samples were annealed using an infrared furnace in Ar+H_2 atmosphere at 250°C for two hours. Here, we used a heat shield above the suspended structures as illustrated in Figure 1b to avoid direct exposure to the infrared radiation which causes failure of the suspended devices otherwise. The cause of the failure is attributed to the irregular heating of the surface layer and the consecutive down bending of the partially suspended Cr/Au layers. The devices were then transferred to AIST (we have found that devices with length up to 1 µm do not collapse from the typical vibrations experienced during transport) where the Zeiss Orion Plus HIM was used to perform the precise nano-machining.

Fig 1c shows a 45 nm wide and 300 nm long bi-layer graphene nanoribbon before and after thinning in the HIM. The milling of the silicon dioxide directly below the GNR is visible in Fig. 2d, clearly showing that the GNR is still suspended and not deformed. Here we used an ion dose of $1.1\text{x}10^{18}$ ions/cm^2 (beam current 1 pA). We have furthermore performed hole matrix milling on a tri-layer suspended GNR as shown in Fig 1e. An optimized dose of $5\text{x}10^{19}$ ions/cm^2 has been found for the holes (1x1 px, 16 nm spacing). Fig 1f shows the intensity profile across the hole matrix showing the hole diameter of ~3 nm. We will discuss applications and possible device designs that can be realized based on such devices.

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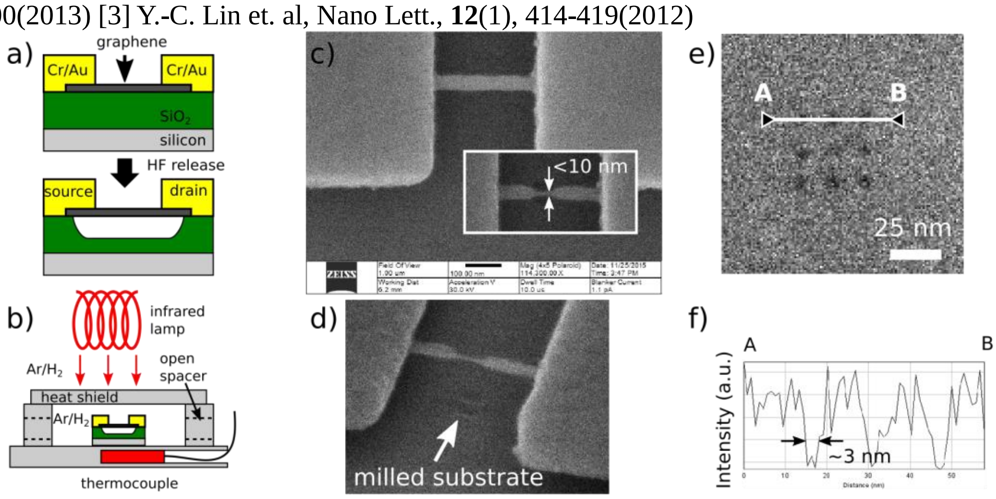

Figure 1: (a) Fabrication schematic of suspended graphene device. (b) Heat shield method used in infrared furnace during annealing to avoid device failure. (c) Suspended bi-layer graphene narrowed down to sub-10 nm width. (d) The same structure as in (c) tilted showing the milled substrate below. The device has not been deformed. (e) 16 nm pitch matrix of holes in tri-layer graphene. Hole size of 3 nm is achieved (f).