Graphene Based Mechanical Resonators Fabricated via Direct Dry Transfer

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We present here the fabrication of large suspended sheets of graphene for mechanical resonators. The diameter of the circular resonators varies from 1.2 µm to 26.5 µm resulting in diameter-to-thickness aspect ratios as large as 74000. The membranes were fabricated in arrays with yields of up to more than 90%. Assuming low to moderate tensile stress, <1 GPa, the mechanical resonance frequency of these structures potentially spans the range from ~1 MHz to ~1 GHz. The successfully fabrication of graphene membranes will allow us to first study their mechanics (resonance frequency and damping) and later explore their use for various sensing applications, including mass sensing.

Resonating micro- and nanomechanical mass sensors have evolved rapidly over the last three decades. Downscaling of the sensing unit has been a dominating trend and one of the key factors enabling microscopic sensors with atomic mass resolution [1]. As a consequence, the sensing unit itself has been reduced to a minimum which poses challenges due to the small sensing area and small vibrational amplitudes that needs to be detected precisely. The introduction of two-dimensional (2D) materials as a material for mechanical resonators offers an opportunity for upscaling of the sensing area, while still keeping the intrinsic mass of the sensor at a minimum. Increased size will also impact the requirements for the transduction of these structures in a positive way.

2D material-based mechanical resonators are typically released through the removal of a sacrificial layer after the 2D material transfer [2]. An alternative approach is to transfer the 2D material directly onto structures with pre-defined cavities, whereby post-transfer processing is minimized [3]. We successfully use this strategy to fabricate circular graphene membranes ranging in diameter from 1.2 µm to 26.5 µm. The fabrication process is illustrated in figure 1. Graphene is first grown via chemical vapor deposition on copper foil. A layer of poly(methyl methacrylate) (PMMA) is spin-coated on top to provide mechanical protection. Graphene on the backside of the foil is etched in an oxygen plasma. Patterned polydimethylsiloxane (PDMS) is mounted on top of the PMMA before etching the copper foil in 5% HCl with a small amount of H_2O_2 added. The graphene-polymer structure is rinsed thoroughly in filtered DI water and dried in air before transferred onto a silicon chip with holes defined by reactive ion etching, using photoresist as etch mask. The PDMS is peeled off and the PMMA is burned away at 400°C in a hydrogen and argon atmosphere. We used graphene but anticipate that other 2D materials could be used with little or no modification of the process.

Figure 2 shows circular graphene membranes with diameters ranging from 1.2 µm to 26.5 µm. A comparison of an intact and broken membrane can be seen in figure 2e. Residues from the PMMA are typical for this kind of transfer and are also visible in all the 5 SEM pictures in figure 2. The use of low molecular weight PMMA is known to have a positive effect on this problem [4] and we are currently testing this approach. Figure 3 shows an array of membranes with a diameter of 5 µm. The yield of the membranes within this array is more than 90%.

The successfully fabrication of graphene membranes will allow us to first study their mechanics and later explore their used in various types of sensing applications.

[1] Jensen et al., Nature nanotechnology, (2008), 533-537.
[2] Chen et al., Nature nanotechnology, (2009), 861-867.
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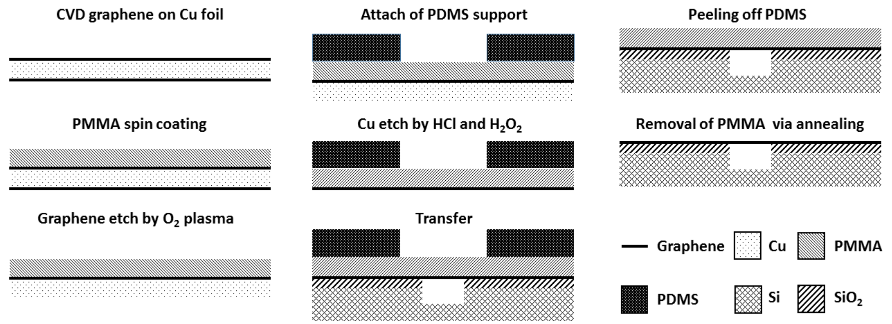

Figure 1: Schematic representation of the dry transfer process used for the fabrication of suspended sheets of graphene. Graphene deposited via CVD on Cu foil is first protected by PMMA. Graphene on the backside of the Cu foil is then etched in an oxygen plasma. PDMS is added for additional support. The graphene-polymer structure is transferred to a silicon chip with 290 nm oxide and predefined holes. After peeling off the PDMS, the PMMA is removed by annealing at 400 °C in a hydrogen and argon atmosphere.

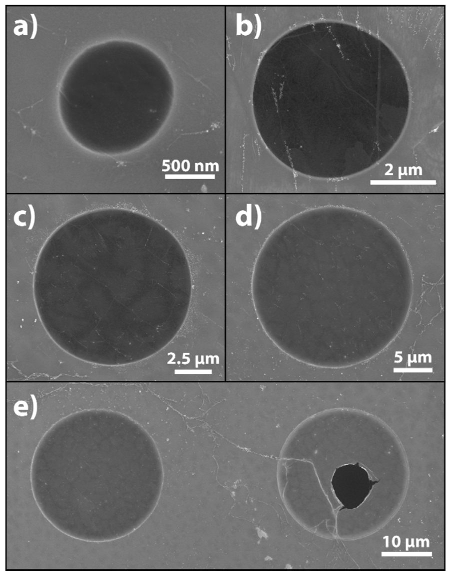

Figure 2: SEM micrographs of suspended sheets of graphene. a-e) the diameter of the membranes are: 1.2, 4.9, 11.2, 21.4 and 26.5 µm, respectively. e) Intact and broken membranes are easily identified in the SEM.

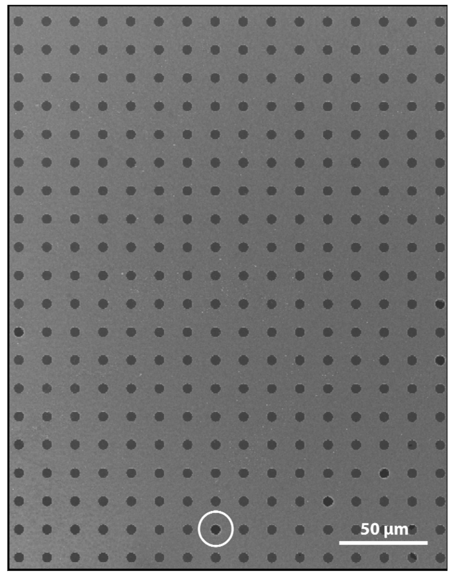

Figure 3: Array of graphene membranes with a diameter of 5 µm. The yield exceeds 90%. One of the broken membranes, for comparison, is marked by a white circle.