A Graphene-based Capacitive Monolithic Microphone with Minimized Air Gap Thickness

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The application of graphene to acoustic sensing devices has been a popular idea since its first successful synthesis in 2004[1]. The extraordinary mechanical and electrical properties of graphene[2, 3] make it an ideal material for fabricating movable plates of high-sensitivity microelectromechanical system (MEMS) capacitive microphones. In a capacitive microphone, the movable plate is suspended above a fixed plate, forming an air gap. Thickness of the air gap is a key parameter to the microphone sensitivity, where smaller air gaps lead to better sensitivity[4]. However, a challenge is that smaller air gaps also result in larger air damping in MEMS[5] and devices with too small air gaps are too damped to vibrate. In our work, we designed a microphone[6] and have been minimizing the air gap thickness from 8.8 μm[6] to 1.5 μm (this work) by etching a vent hole to connect the air inside and outside the gap to decrease damping. In addition, the two-chip-assembled structure[6] has been integrated into a monolithic device.

In this work, we report a graphene-based MEMS capacitive microphone with a 1.5 μm air gap and a vent hole. Fig. 1 shows design of the device. Fig. 2 illustrates the fabrication process. The two silicon-dioxide (SiO_2)-etching steps have been optimized. Commercial chemical vapor deposited (CVD) graphene has been transferred to the substrate with a wet method. Fig. 3 shows the optical microscope image of a fabricated device. Coherence Scanning Interferometry (CSI) has been used to confirm that the membrane has been suspended without touching the structures below. The membrane has been actuated electrothermally, electrostatically and acoustically for characterization. Laser Doppler vibrometry (LDV) has been used to read-out the membrane vibration optically. Details of the design, fabrication and characterization of the microphone will be presented.

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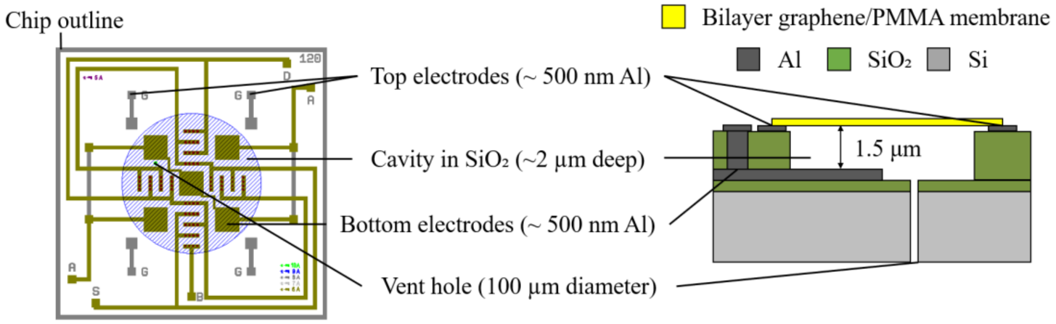

Figure 1: Top (left) and side (right) view design of the MEMS microphone: As the movable plate, bilayer membrane of 6-8 layers of graphene (~ 2 nm) and ~ 350 nm poly(methyl methacrylate) (PMMA) has been suspended above a 3.5-mm diameter, 2 µm deep cavity. 500 nm aluminum (Al) electrodes lie at the bottom of the cavity as the fixed plate. The Si substrate has been penetrated with a 100-µm-diameter vent hole to decrease air damping.

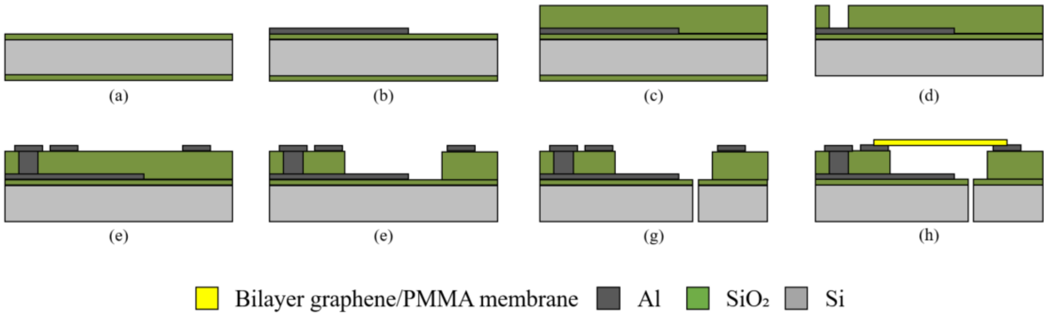

Figure 2: Fabrication process of the microphone: (a) 70 nm SiO_2 deposited on Si substrate by low-pressure chemical vapor deposition (LPCVD) on both front and back side of the wafer; (b) 500 nm Al deposited by lift-off as bottom electrodes; (c)2 µm SiO_2 deposited by PECVD; (d) front-side PECVD SiO_2 etched by optimized hybrid wet + dry etching method, while back-side LPCVD oxide removed; (e) vias filled in and top electrodes create by depositing another 500 nm Al; (f) 3.5 mm cavity etched out by hybrid wet + dry etching SiO_2; (g) Si substrate penetrated by deep reactive ion etching (DRIE); (h) graphene/PMMA membrane wet transferred to substrate.

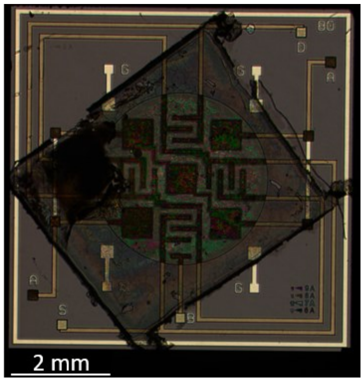

Figure 3: Leica microscope image of a fabricated microphone device.