Electronic Supplementary Material (ESI) for Nanoscale

Single-Layer Graphene Sound-Emitting Devices: Experiments and Modeling

—Supporting Information

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SUPPLEMENTARY FIGURES AND LEGENDS

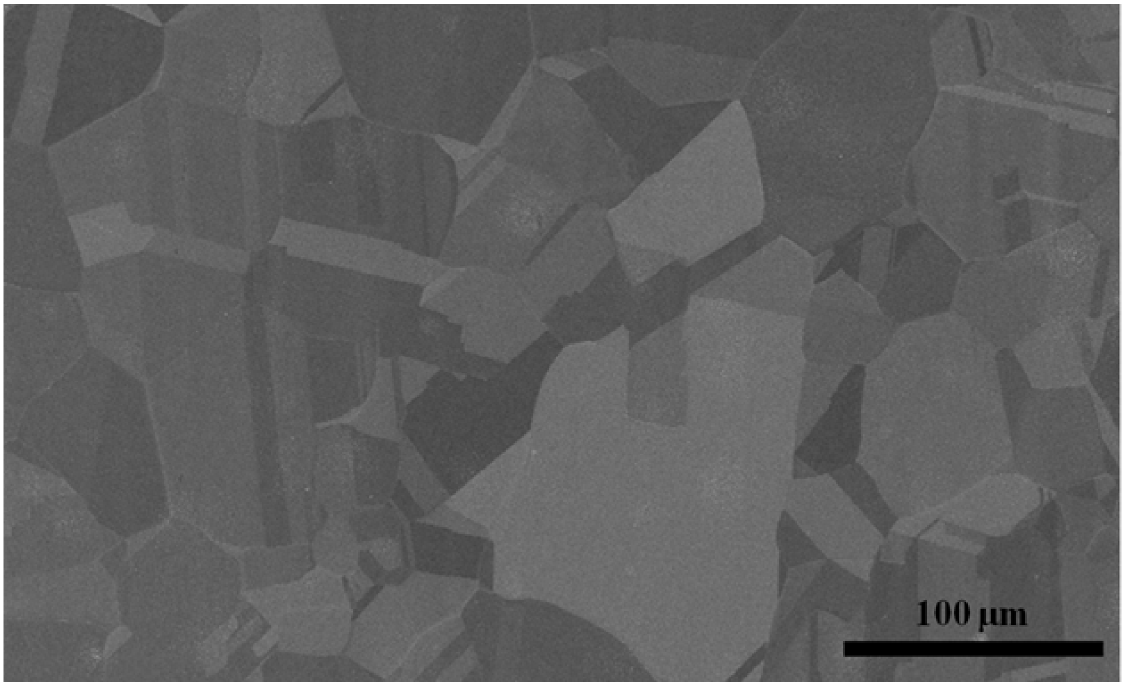

Figure S1. The SEM image of graphene films. These graphene films were grown on copper foil and continuous covering copper surface steps and grain boundaries.

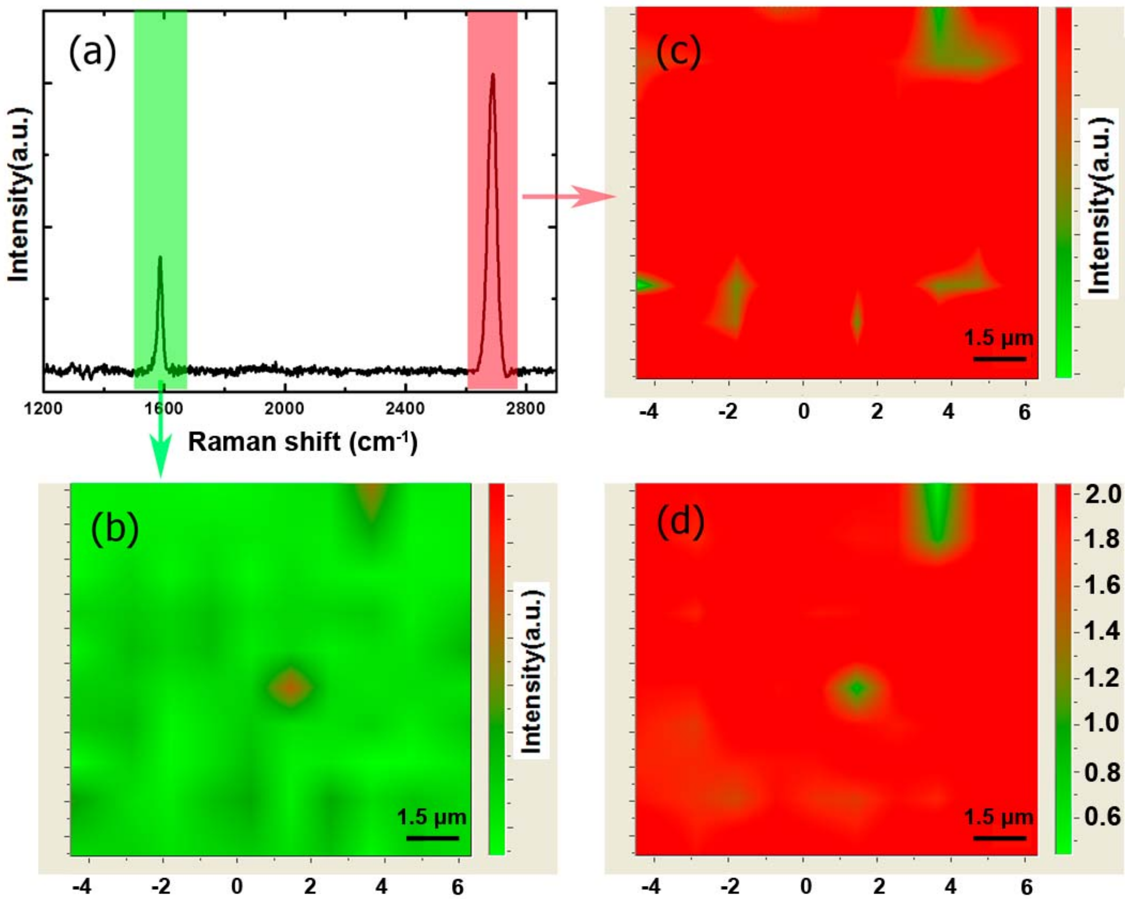

Figure S2. The Raman mapping of graphene films. (a) Raman spectrum of as-deposited graphene showing G and 2D peaks. 2D micro-Raman intensity mapping of (b) G band (1587 cm-1) and (c) 2D band (2690 cm-1). (d) 2D micro-Raman intensity ratio (I_{2D}/I_G) mapping from the same region as (c) and (d). It is indicated that films is single-layer (>90%) with lower disorder

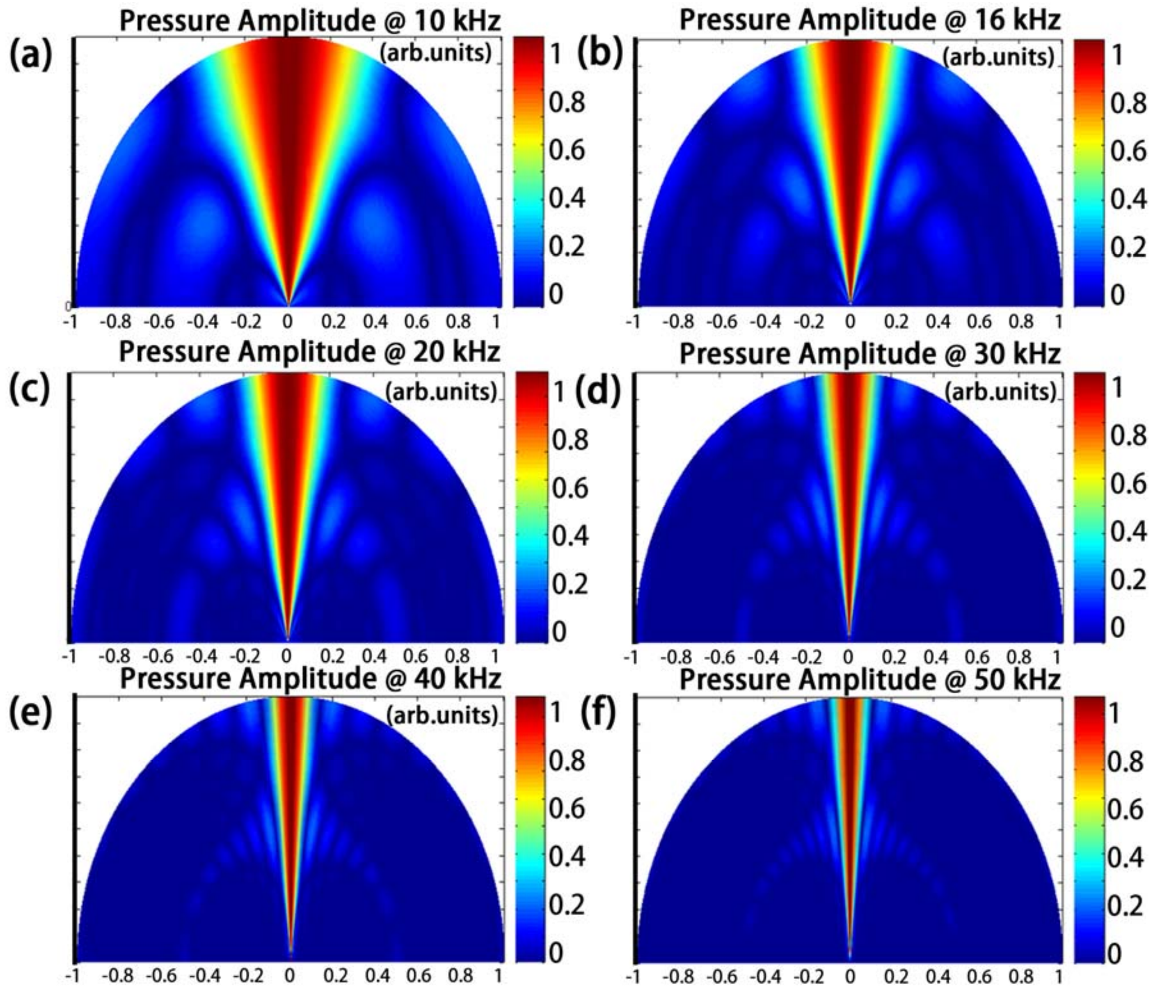

Figure S3. Simulation results of sound directivity of the G-SEDs at different sound frequency (a) 10 kHz (b) 16 kHz , (c) 20 kHz, (d) 30 kHz, (e) 40 kHz, (f) 50 kHz. It is noticed that the main intensity area is decreased with the increase of the sound frequency.

SUPPLEMENTARY METHODS

Large-scale multi-layer and single-layer graphene films (Graphene Supermarkert, Inc.) were synthesized by using chemical vapour deposition on thin nickel layers and copper layers, respectively. The surface morphology was observed by SEM (DI-3100).

Structure characteristics of the graphene films were analyzed from Raman spectrum obtained by the Raman spectroscopy with a Renishaw R-1000 system using wavelength of 514.5 nm. The thickness and surface roughness of the films were measured using a surface profiler (Dektak150, Veeko). Sheet resistance was measured by the automatic four point probe meter (MODEL 280SI, Four Dimensions, Inc.).

We manually transferred the graphene on the anodic aluminum oxide substrate, and contacted pads using low-resistivity sliver ink. Then attached to PCB board which was used to improve the mechanical strength and establish electrical connection, thus graphene based sound-emitting devices (G-SEDs) were fabricated. The G-SEDs device was baked at 80 °C for 10 minutes.

The acoustic platform for testing graphene sound source contains a signal generator, a standard microphone and a dynamic singal analyzer. The 1/4 inch standard microphone (Earthworks M50), which had a very flat frequency response reaching up to 50 kHz and a 31 mV/Pa high sensitivity, was used to measure the sound intensity of the G-SEDs. The signal analyzer (Agilent 35670A) was used to make fast Fourier transform analysis and record the value of SPL. Our samples were measured in a soundproof box. The box size is $1\times0.5\times0.5$ m^3. In order to avoid the effects of reflections, the box was filled with sound-absorbing sponges.

SUPPLEMENTARY DISCUSSIONS

Considering the G-SEDs as a point sound source in far-field, the theoretical half-space directivity $D(\theta,\varphi)$ can be written blew.

$$D(\theta,\varphi) = \sin c(\frac{k_0 L_x}{2}\sin\theta\cos\varphi)\sin c(\frac{k_0 L_y}{2}\sin\theta\sin\varphi) \quad \text{(S1)}$$

Where the θ and φ are the angles of a spherical coordinate system. $k_0 = 2\pi / \lambda_0$ is the isentropic wave-number. The sound source device places in the origin of the system. L_x and L_y are sound source length and width, respectively.

Fig. S3 shows the simulation results of sound radiation for G-SEDs in far-field. The on-axis direction has the largest sound intensity, the sound intensity decreases with the angle. It can be explained by the sound interference.[7] When sound frequency is 10 kHz, the main intensity area focuses on axis ±20 angles as shown in fig. S3(a). When frequency is 16 kHz, the main intensity area focuses on axis ±10 angles as shown in fig. S3(b). Seeing from Fig. S3(a)~(f), it is noticed that the main intensity area is decreased with the increase of the sound frequency.