Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Electromagnetic and Acoustic Double-shielding Graphene-based Metastructures

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Methods:

Synthesis of graphene papers.

Graphene papers were prepared by combining freeze-dry and hot-pressing methods. First, the graphene aqueous with concentration of 20 mg/mL were put in a freezer (-20 ^{o}C) for 12 h until they have been entirely frozen into graphene monolith. Then, graphene monolith was dried by a vacuum freeze dryer for 36 h. Finally, the samples were directly compressed at 1200 ^{o}C for 2 h under static pressure of 25 MPa in a graphite furnace. The thickness of the graphene paper can be controlled by changing additive raw materials weight under the same pressing load during the heat-pressing process, resulting in different bulk density and thickness.

Fabrication process of electromagnetic and acoustic double-shielding graphene-based metastructures:

First, the square artificial honeycomb panel made of polymethyl methacrylate (PMMA) were fabricated by laser engraving. The side length of artificial honeycomb panel is 100 mm and the thickness is 2 mm. Moreover, the diameter of the holes in the honeycomb panels is 2 mm. Then, the graphene paper was fixed in the middle of the two honeycomb panels to assemble a sandwich structure, ensuring that each hole boundary fixed. The graphene paper in DSGM was divided into individual resonators in a planar array by the relatively rigid plastic frame. Notably, the plastic frame can be replaced with any material that has a much greater Young's modulus or rigidity relative to the film for use in special environments. The weight of the whole DSGM is 40 g, which translates to about 0.4 g/cm^2 in areal weight.

Characterization:

The morphology and structure were characterized by scanning electron microscope (SEM, model SU8000, Hitachi, Japan). Raman spectra were conducted with a Lab RAM HR800 from JY Horiba. X-ray diffraction (XRD) profiles were obtained using Cu Kα radiation (D/MAX-rA, Japan) to analyze diffraction patterns. The electrical properties of the samples were measured by a four-probe method by Keithley 2400. Mechanical tests were carried out by a single-column static instrument (Instron 5843) equipped with two flat-surface compression stages and a 10 N load cell. Poisson’s ratio for the graphene paper was obtained by measurement of transverse strain and axial strain using Force Transducer (DH3820) and Static Instrument (Instron 55298).

EMI shielding measurement process:

An Agilent Technologies N5227A vector network analyzer was used to measure the S-parameters of DSGM structures with different thickness graphene paper in the frequency range of 8-12 GHz. Likewise, we also measure the S-parameters of DSGM structures with 0.1 mm graphene paper from 2.6-26.5 GHz. The S-parameter is scattering parameter, the EMI shielding efficiency was calculated based on S-parameter. The test sample was cut into a rectangle with 22.8 mm × 10.2 mm (for X band) to fit an aluminum waveguide. After the sample was placed into the edge side of the waveguide, then we started the measurement. The electromagnetic radiation intensity data was collect by using electromagnetic field tester (LZT-1130) in the demonstration experiment.

Acoustic experimental details.

The acoustic properties were obtained by using a modified impedance tube for the measurements of the transmission coefficients. The experimental setup comprised of two square impedance tubes with the sample sandwiched in between. The speaker in the far end of the front tube generates a plane wave. The end of the back tube is blocked by a steel plate and terminated by one-meter long wedged spongy to reduce reflection. Two microphones (PCB model 377C10) are installed in the front tube to sense the incident and reflected waves. In the meanwhile, two microphones in the back tube, which was terminated with an anechoic sponge, are employed to measure the transmitted wave. The signals from the four sensors are sufficient to resolve the transmitted and reflected wave amplitudes, in conjunction with their phases. The side length of the square membrane is 100 mm. In a simple demonstration experiment, sound intensity was measured by digital sound level meter (AR824).

Theory and simulations:

The transmission coefficient and eigenmodes of the graphene paper were found by COMSOL multiphysics using the following parameters. In the simulations, the edges of the model are fixed. The mass density, Poisson's ratio and Young's modulus of the graphene paper were 1780 kg/m^3, 0.2 and $3.5*10^9$ Pa, respectively. The speed and mass density of air were 343 m/s and 1.29 kg/m^3, respectively.

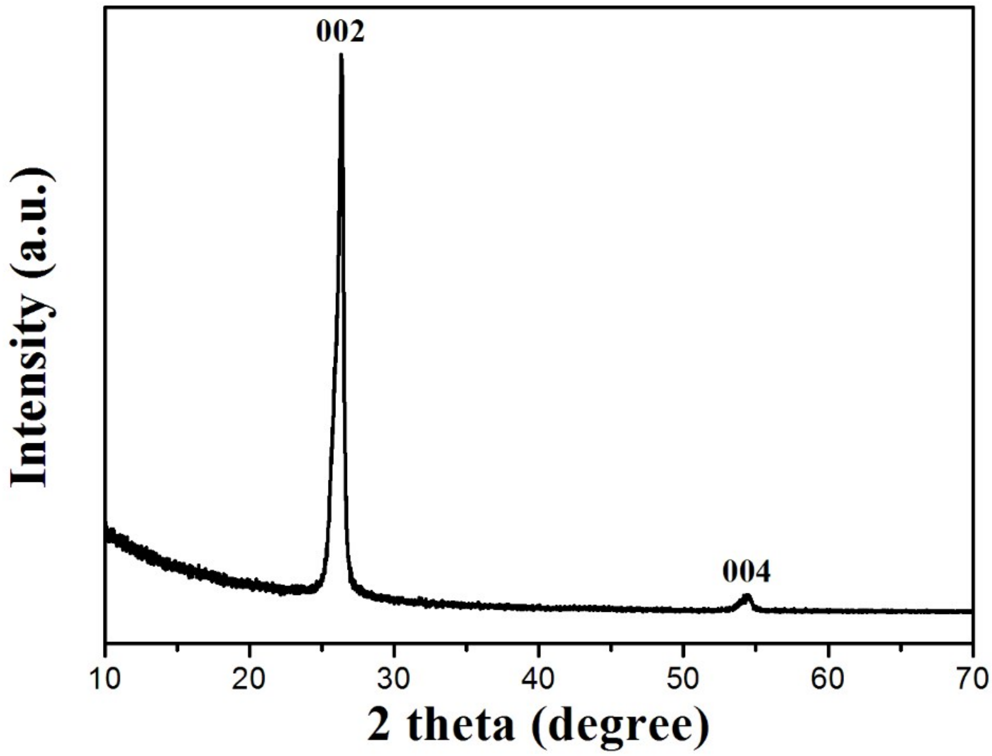

Fig. S1 XRD patterns of graphene paper.

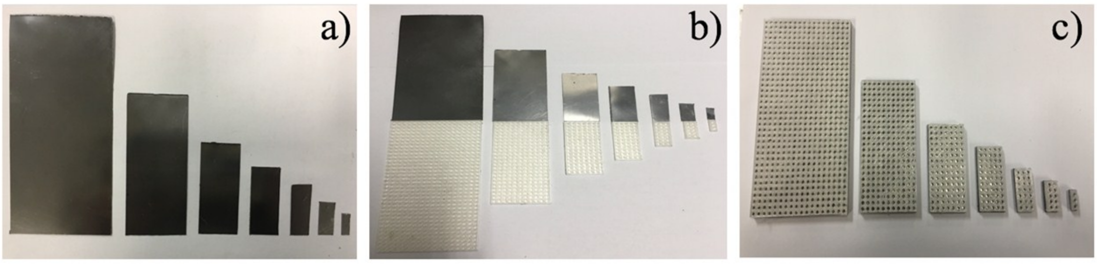

Fig. S2 a) Different sizes of graphene paper, b) The process for preparing EMI shielding samples and c) The photographs of sandwich structure DSGM.

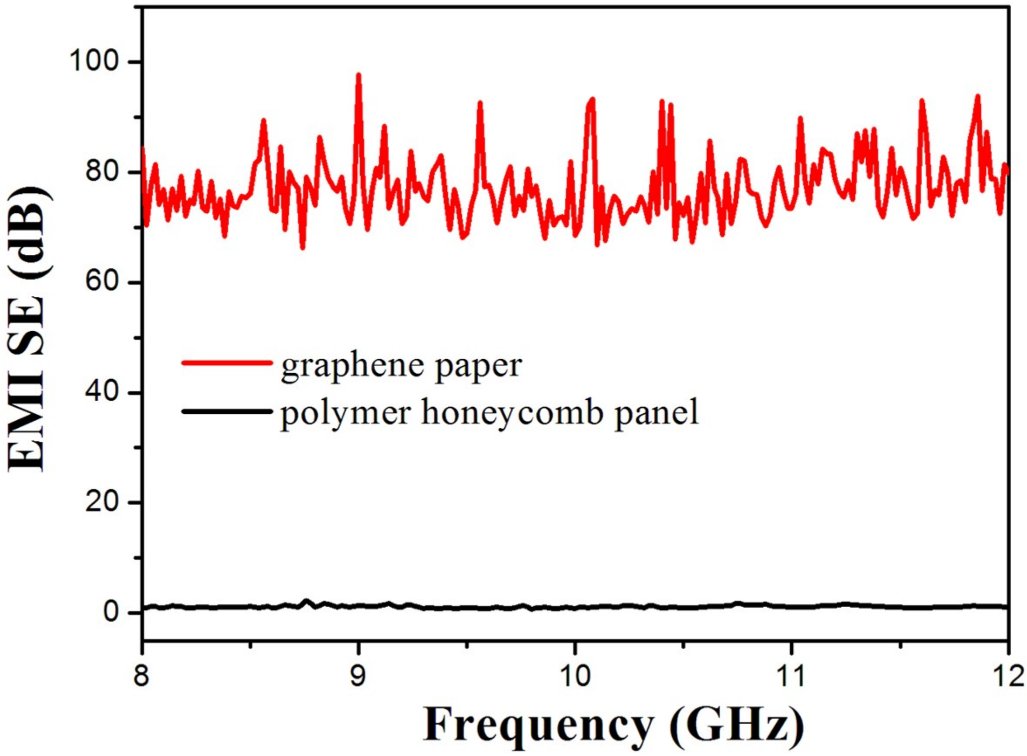

Fig. S3. The EMI SE of only graphene paper (0.10 mm) and only polymer honeycomb panel in the 8-12 GHz.

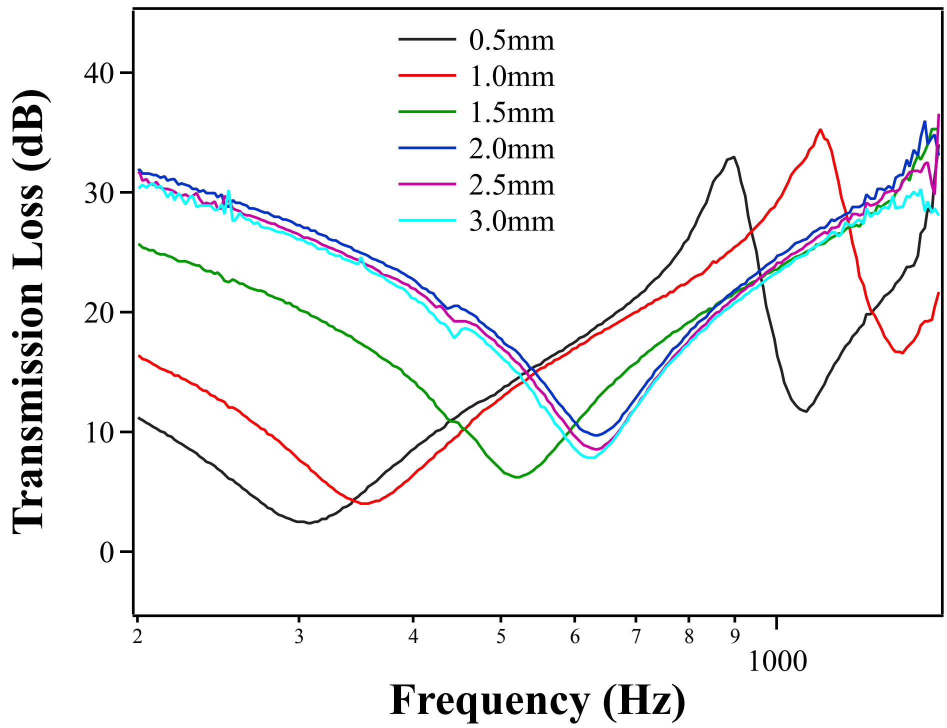

Fig. S4. The transmission loss of DSGMs with different hole size honeycomb panels.