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Dependence of electromagnetic interference shielding ability of conductive polymer composite foams with hydrophobic properties on cellular structure

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Experimental Section

Raw materials

The PVDF (molecular weight 300 000 – 330 000 g/mol) was provided by Solvay. *N,N*-dimethylformamide (DMF) was supplied by Caledon Laboratories Ltd. *N,N*-dimethylformamide (DMF) was supplied by Caledon Laboratories Ltd. Multi-walled carbon nanotubes (MWCNT, NC7000^{TM}) (average outer diameter: 9.5 nm, average length: 1.5 microns, surface area: 250-300 m^2/g, carbon purity 90%) were supplied by Nanocyl^{TM}, Belgium and were fabricated by means of a Catalytic Chemical Vapor Deposition (CCVD) process. Carbon dioxide (CO_2) with purity of 99.98% was purchased from Linde gas. PVDF/MWCNT composite foams were prepared through a batch foaming system developed in-house (as shown in Figure S1).

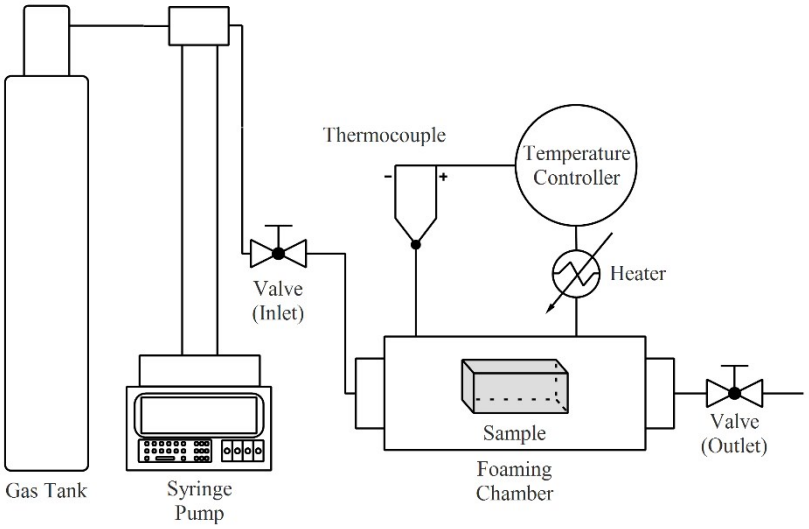

Figure S1. A home-made batch foaming equipment to fabricate PVDF/MWCNT composite foams.

Characterization

X-ray radiation diffraction (XRD), which was collected by a Rigaku Smart Lab (Tokyo, Japan) diffractometer using Cu Kα radiation (λ=0.15418 nm), was used to analyze the crystal structure. The characteristic vibrational modes were analyzed using Fourier Transform Infrared Spectroscopy (FTIR), which was performed on a Nicolet iS10 FTIR spectrometer (USA). To obtain the cell size and the void fraction, the samples were cryo-fractured and the microstructures were observed using a JEOL JSM-

6060 scanning electron microscope (SEM). The densities of the solid (ρ_s) and the foam (ρ_f) composites were studied based on the water-displacement method (ASTM D792-13). The void fraction (*VF*) was calculated as $VF = 1 - \rho_f/\rho_s$。[1] The electrical conductivity of carbon foams was investigated using an RTS-9 type double electric test four probe tester (China Guangzhou Four Probe Technology Co., Ltd.).

The EMI SE (SE_T) was tested in a frequency range of 26.5 - 40 GHz (Ka-band) at room temperature using a vector network analyzer (VNA, Agilent N5234A). The VNA was calibrated before the S scattering parameters were measured. Samples were cut into ~7.1 mm × 3.5 mm (length × width) pieces to perfectly fit the waveguide holders. The EMI SE (SE_T), the ability of the material to shield an electronic device from electromagnetic radiation, was obtained from the following equation: [2-5]

$$SE_T(\mathrm{dB}) = 10\log_{10}\left(\frac{P_I}{P_T}\right) \quad (1)$$

where P_I is the incident power and P_T is the transmitted power. Popularly, electromagnetic waves are dissipated by three mechanisms: absorption (SE_A), reflection (SE_R) and multiple reflections (SE_M). The SE_M is omitted when EMI SE is above 15 dB, that is, SE_T can be simplified as:

$$SE_T = SE_R + SE_A \quad (2)$$

In the two-port vector network analyzer, SE_T can be determined through the calculation of reflectance (R), transmittance (T) and absorbance (A) coefficients, which can be deduced from scattering parameters (S_{11}, S_{12}, S_{21}, S_{22}) as follows:

$$R = |S_{11}|^2 = |S_{22}|^2 \quad (3)$$

$$T = |S_{21}|^2 = |S_{12}|^2 \quad (4)$$

$$SE_R = -10\log_{10}(1 - R) \quad (5)$$

$$SE_A = -10\log_{10}\left(\frac{T}{1 - R}\right) \quad (6)$$

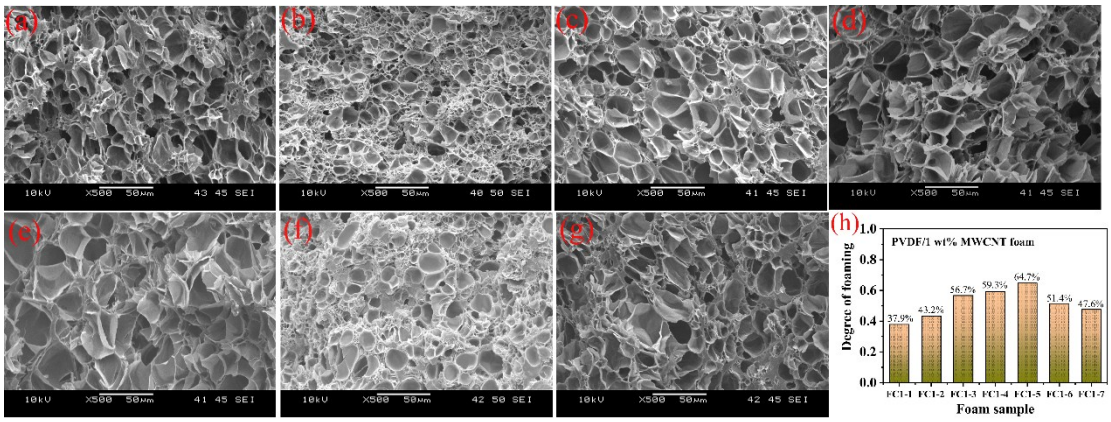

Figure S2. SEM images of cryo-fractured FC1 nanocomposite foams: (a) FC1-1, (b) FC1-2, (c) FC1-3, (d) FC1-4, (e) FC1-5, (f) FC1-6 and (g) FC1-7 samples. (h) Various FC1 foams' degree of foaming.

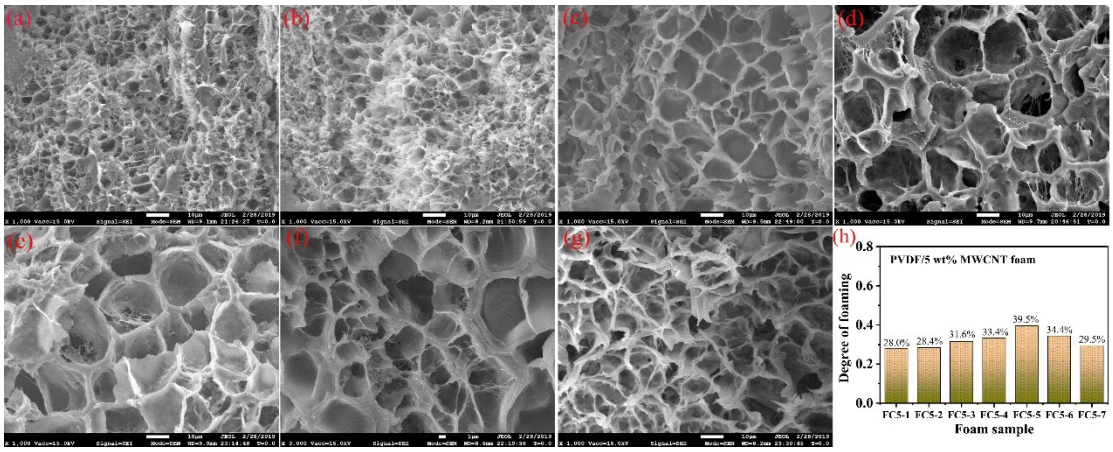

Figure S3. SEM images of cryo-fractured FC5 nanocomposite foams: (a) FC5-1, (b) FC5-2, (c) FC5-3, (d) FC5-4, (e) FC5-5, (f) FC5-6 and (g) FC5-7 samples. (h) Various FC5 foams' degree of foaming.

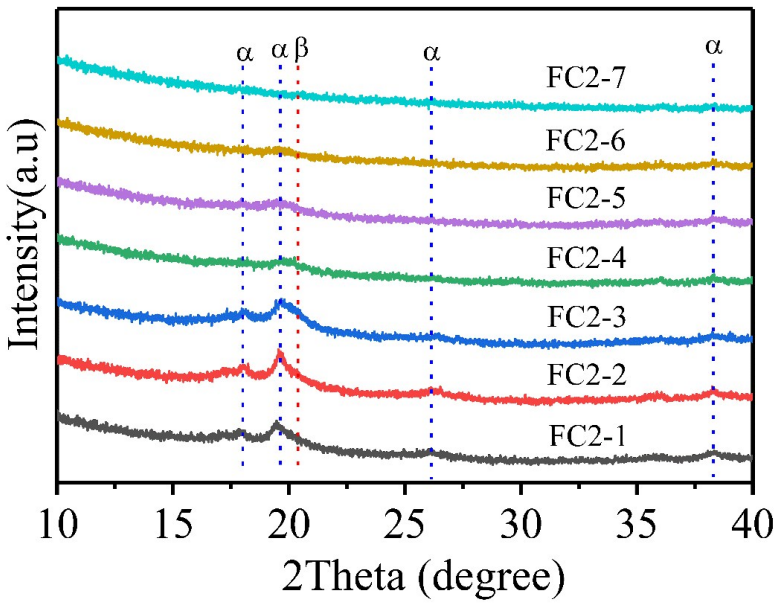

Figure S4. XRD patterns of FC2 nanocomposite foams prepared at different impregnation temperatures.

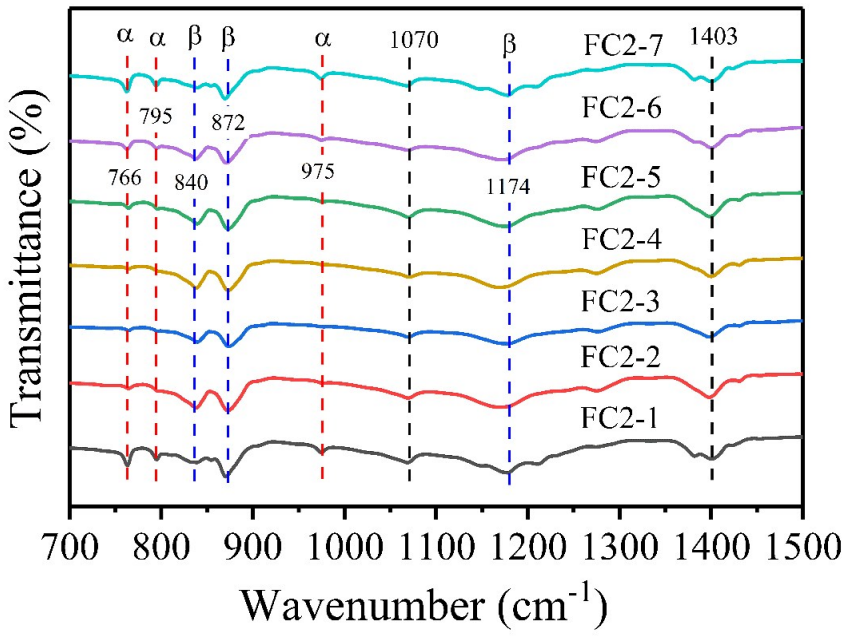

Figure S5. FT-IR spectra of FC2 nanocomposite foams nanocomposite foams prepared at different impregnation temperatures.

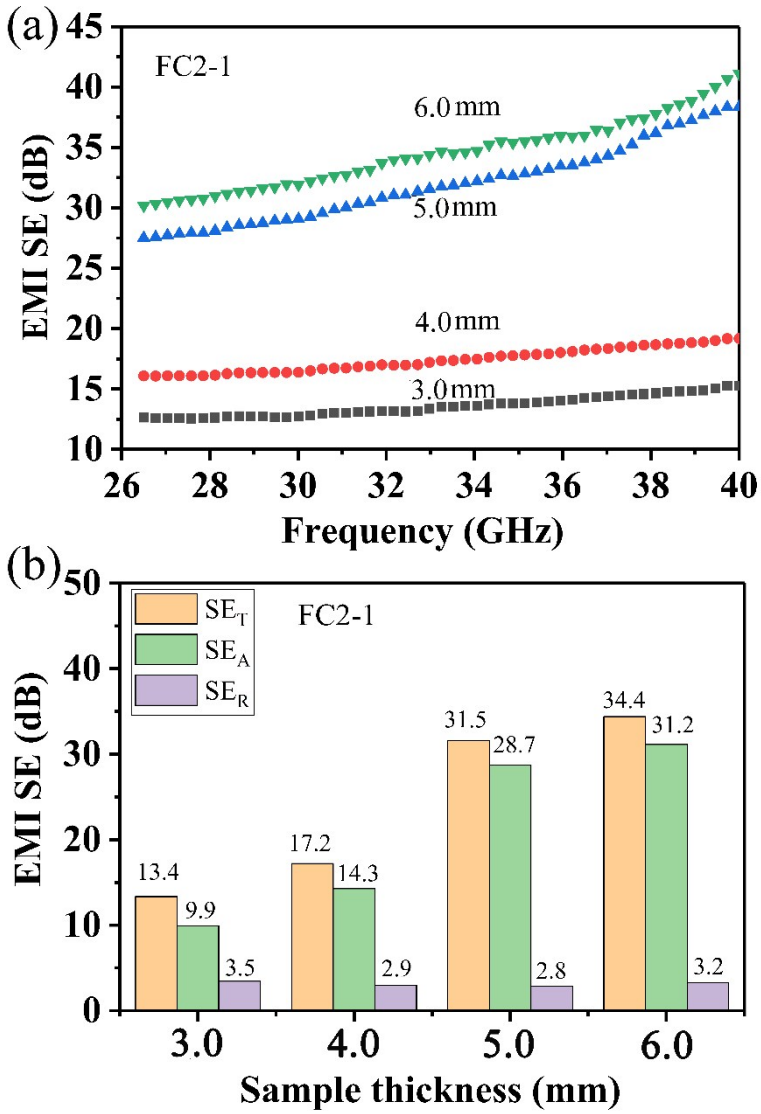

Figure S6. (a) EMI SE in the Ka-band (26.5-40 GHz) of the FC2-1 foam (28.0 % degree of foaming) at different thicknesses; (b) average SE_T, SE_R, and SE_A values of the FC2-1 foam (28.0 % degree of foaming) at different thicknesses.

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