Electronic Supplementary Material (ESI) for Lab on a Chip.

Lab on a Chip

Electronic Supplementary Information

Graphene-Mediated Microfluidic Transport and Nebulization via High Frequency Rayleigh Wave Substrate Excitation

Kar M. Ang, Leslie Y. Yeo, Yew M. Hung, Ming K. Tan

a. Experimental setup for measuring the liquid spreading velocity

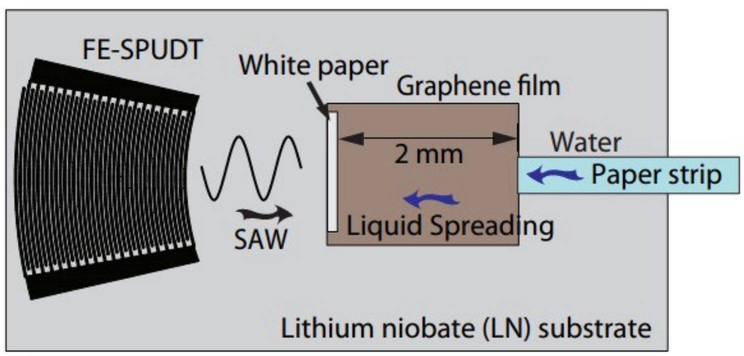

Figure S1: Sketch illustrating the top view of the experimental setup used to measure the liquid spreading velocity.

b. Justification for assuming negligible evaporation while measuring atomization rates

The total atomization rate was obtained by calculating the total mass loss of the liquid reservoir over the atomization period (60 seconds) and the rates were compared between the case with and without the presence of the graphene film. Hence, the calculated atomization rate is relatively accurate as long as the changes in the evaporation rates between both cases (with and without the graphene film) are negligible. Temperature measurements on the SAW substrate surface during atomization at various input powers (0.7, 1.0 and 1.15 W) were carried out using a thermal imager (TIM 160, Micro-Epsilon, Dorfbach, Germany) and the results are shown in Fig. S2. From the graph, we observe the temperature difference to be at most 2°C between the two cases after continuous atomization for 60 seconds. This suggests that the changes in the evaporation rates for both cases are insignificant and thus can be neglected in the estimation of the atomization rates. Furthermore, since the maximum substrate temperature is less than 45°C, we expect the evaporation rate over the atomization period of only 60 seconds to be considerably smaller than the atomization rate.

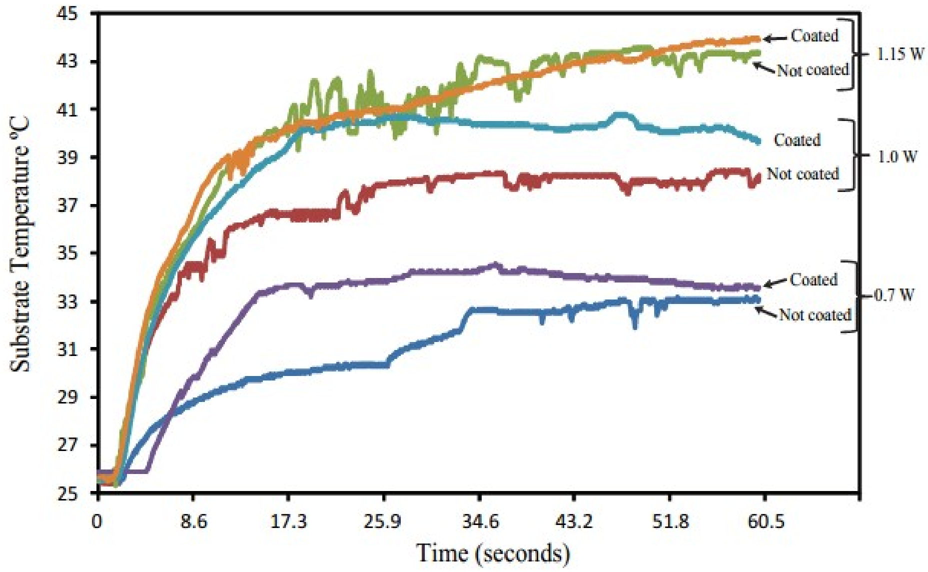

Figure S2: SAW substrate temperature (with and without the graphene film) during atomization at different input powers of 0.7, 1.0 and 1.15 W.

c. Measurement of the graphene film thickness

A field-emission scanning electron microscope (FE-SEM; SU8010, Hitachi GmbH, Krefeld, Germany) was used to measure the thickness of the graphene film deposited on the LN substrate. The sample substrate was initially coated with the graphene film and then placed on the vertical platform of the FE-SEM to obtain a side view of the graphene film. The graphene film thickness H_g can then be measured from the edge of the substrate to the edge of the coated film as shown in Fig. S3. We note here that the top surface of the coated graphene film was not perfectly even, and therefore the edge of the graphene film may not be clearly identified under the large magnification of the FE-SEM. To reduce measurement errors, several measurements were acquired across different samples. Some of the experimental images taken during the measurements are shown in Fig. S3.

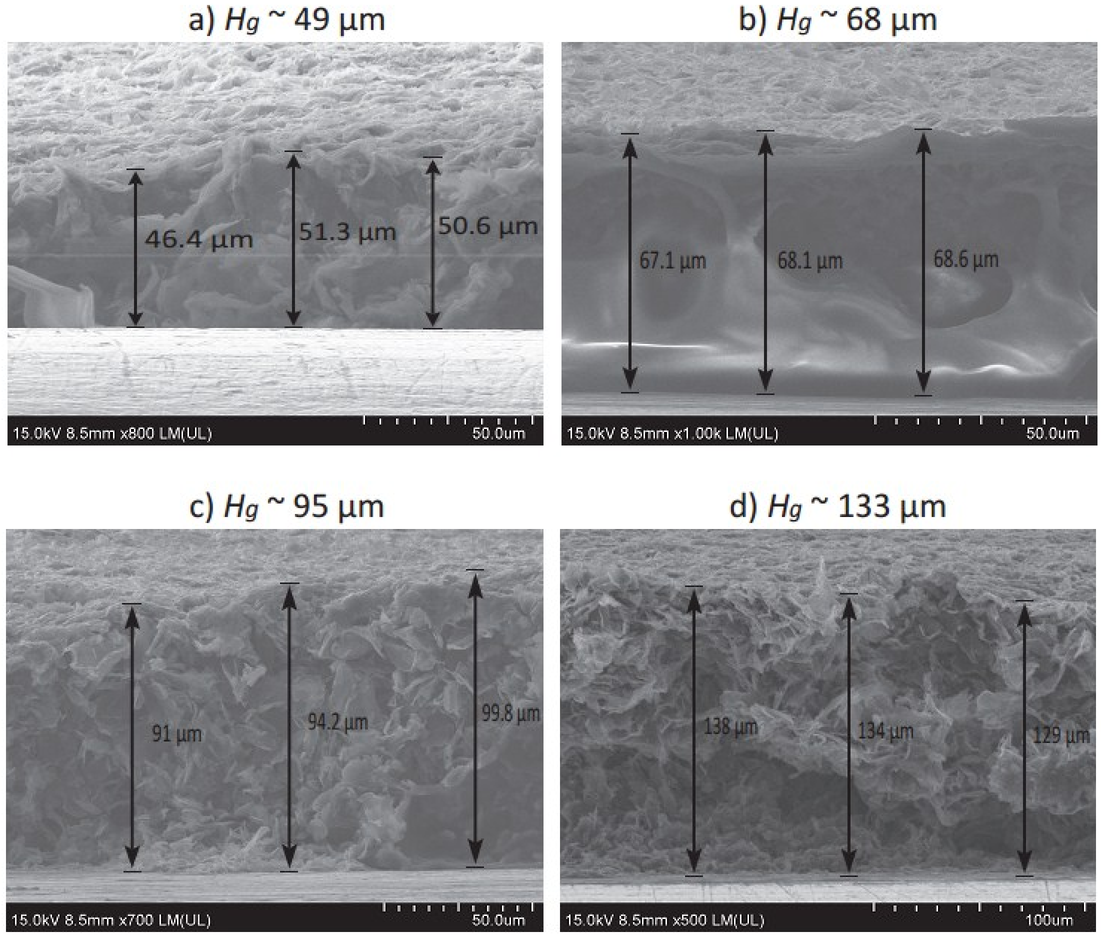

Figure S3: Experimental images taken during FE-SEM measurements with sample substrates coated with different volumes of graphene dispersions.

d. Measurement of the interstitial spacing between the layers of the graphene film

Figure S4 shows the measurement result using X-ray diffraction (D8 Discover, Bruker Corp., Madison, WI, USA) to estimate the interstitial spacing between each layer of the coated graphene film h_g. From the graph, peak counts were observed at $2\theta \approx 26.3°$, denoting the diffraction angle θ to be approximately 13.15°. The interstitial spacing h_g can then be calculated using Bragg's equation: $n\lambda = 2h_g \sin\theta$,[1] where n is an integer, λ the wavelength of the incident X-ray beam and θ the diffraction angle. With $n = 1$, $\lambda = 0.154$ nm (copper as the X-ray beam target material) and θ = 13.15°, $h_g \approx 3$Å = 3×10^{-10} m.

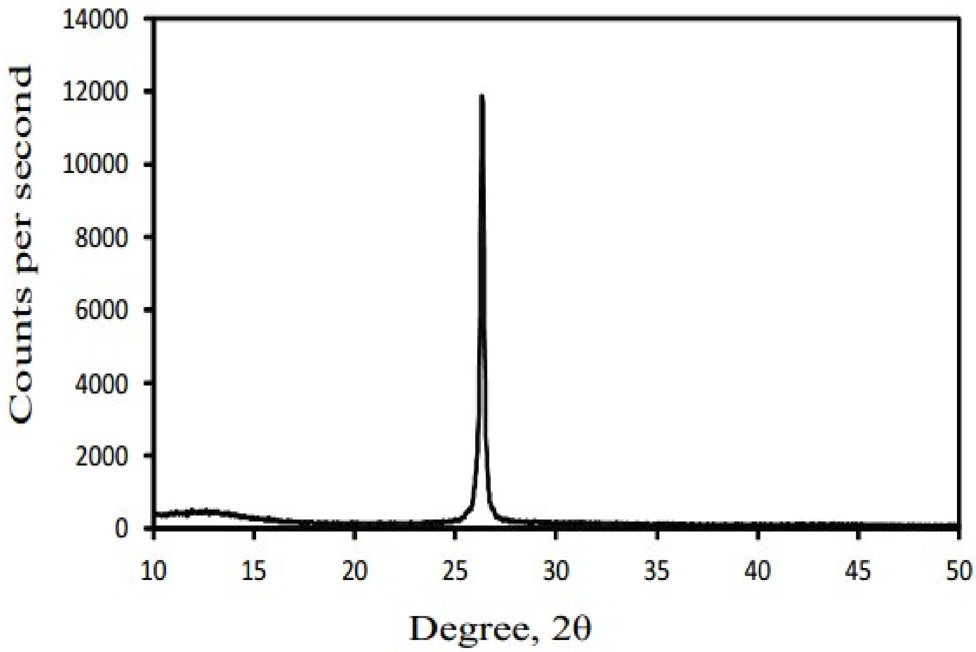

Figure S4: X-ray diffraction measurement showing the peak count occurring at $2\theta \approx 26.3°$, i.e., $\theta \approx 13.15°$.

e. Acoustic streaming velocity measurements

To estimate the acoustic streaming velocity u_{dc}, 6 μm diameter fluorescent polystyrene sphere particles (Polysciences, Warrington, PA, USA) were suspended in a 5 μl deionized water droplet at a concentration of approximately 5% and placed atop the graphene coated SAW device. At a fixed input power to the SAW device, the droplet rotation as a consequence of the acoustic streaming was recorded at a speed of 300 frames/s using a high speed camera (Phantom M310, Vision Research, Wayne, NJ, USA) connected to an optical microscope (Eclipse Ci-E, Nikon, Japan) coupled with fluorescent illumination (Intensilight C-HGFIE, Nikon, Shinjuku, Japan). The velocities of the illuminated fluorescent particles in the droplet were estimated using the supplied camera software (Phantom PCC 2.2, Vision Research, Wayne, NJ, USA), which can be approximated as the acoustic streaming velocity u_{dc}. The experiments were repeated for various SAW devices coated with different thicknesses of the graphene film.

f. Measurements of the liquid layer contact angle, height and length

The liquid layer's contact angle and its characteristic height H_f and length L_f were measured based on the high speed images taken during atomization by using a high speed camera (Phantom M310, Vision Research, Wayne, NJ, USA) and its supplied software (Phantom PCC 2.2, Vision Research, Wayne, NJ, USA), as indicated in the experimental image shown in Fig. S5. Prior to the measurements, calibration was done in each experiment using a scale bar with a precision of 0.1 mm.

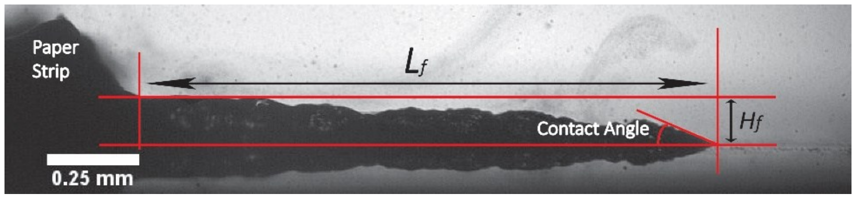

Figure S5: Experimental image taken during atomization showing the measurements of the contact angle and characteristic length L_f and height H_f of the thin liquid layer.

Reference

1. W. H. Bragg and W. L. Bragg. *Proc. R. Soc. Lond. Ser. A*, 1913, **88**, 428–438.