Electronic Supplementary Information

Dynamic Sub-Wavelength Microparticle Patterning via Phase-Modulated Pulsing Coherent Surface Acoustic Wave Tweezers

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Section 1. The reflection coefficient of the chamber ceiling with different interlay material

Table S1. Material properties at T = 25 °C used in theoretical calculation.

Supplementary Figures.

Fig. S1. Time average acoustic pressure fields under phase-modulated pulsing coherent SAWs with PDMS chamber ceiling.

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Movie S1. Particle patterning with SSAWS under the chamber ceiling with glass interlayer.

Movie S2. Half spacing particle patterning with phase modulated pulsed saws along *x*-direction under the glass interlayer ceiling of PDMS chamber.

Movie S3. One-third spacing particle patterning with phase-modulated pulsed saws along *x*-direction under the glass interlayer ceiling of the PDMS chamber.

Section 1. The reflection coefficient of the chamber ceiling with different interlay material

For nonmaterial chamber ceiling conditions, the reflection coefficient is given by

$$R_{water-PDMS} = \frac{z_{PDMS} - z_{water}}{z_{PDMS} + z_{water}} = -0.1855 \tag{S1}$$

where the material's acoustic impedance is $z = \rho c$ for single material reflection, ρ and c are the density and acoustic velocity of the material respectively, which are listed in Table. S1. The reflected acoustic energy is R^2 times of input energy.

For multi-material chamber ceiling conditions, the reflection coefficient is given by [s1]

$$Z_n = z_1 \frac{Z_{n+1} - iz_{n+1}\tan(k_{n+1}d_{n+1})}{z_{n+1} - iZ_{n+1}\tan(k_{n+1}d_{n+1})} \tag{S2}$$

$$R_n = \frac{Z_n - z_n}{Z_n + z_n} \tag{S3}$$

where z and d are the impedance and thickness of each layer, the wave number $k_n = \omega_n / c_n$, the first boundary between the liquid and $LiNbO_3$ base is set as the R_0.

Table S1. Material properties at $T = 25$ °C used in theoretical calculations [s2]

Material	Acoustic Velocity m/s	Density kg/m³	Acoustic Impedance Pa·s/m	Reflection Coefficient as Interlay Material R
Water	1490	960	1.430	\
PDMS	1075	970	1.043	-0.1855
PMMA	2547	1190	3.031	0.3434
Glass	5845	2203	12.877	0.7936

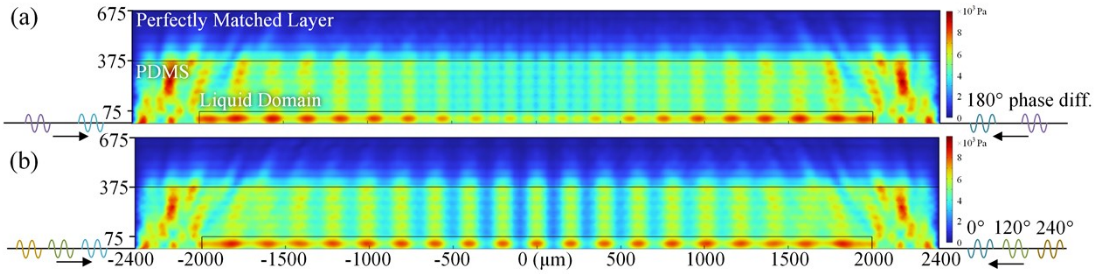

FIG. S1 Time average acoustic pressure fields under phase-modulated pulsing coherent SAWs with PDMS chamber which are highly affected by the TSAWs patterning form. 20 sinusoidal cycles in a single pulse with the pulse duty cycle of 1. (a) Pulsed signal with 180° phase-increment in each pulsation; The generated acoustic pressure nearing the PDMS boundary is dominated by the TSAWs patterning forms, while at the centre of the liquid domain remains half spacing. (b) Pulsed signal with 120° phase-increment in each pulsation; The spacing of pressure node remains the same with SSAWs.

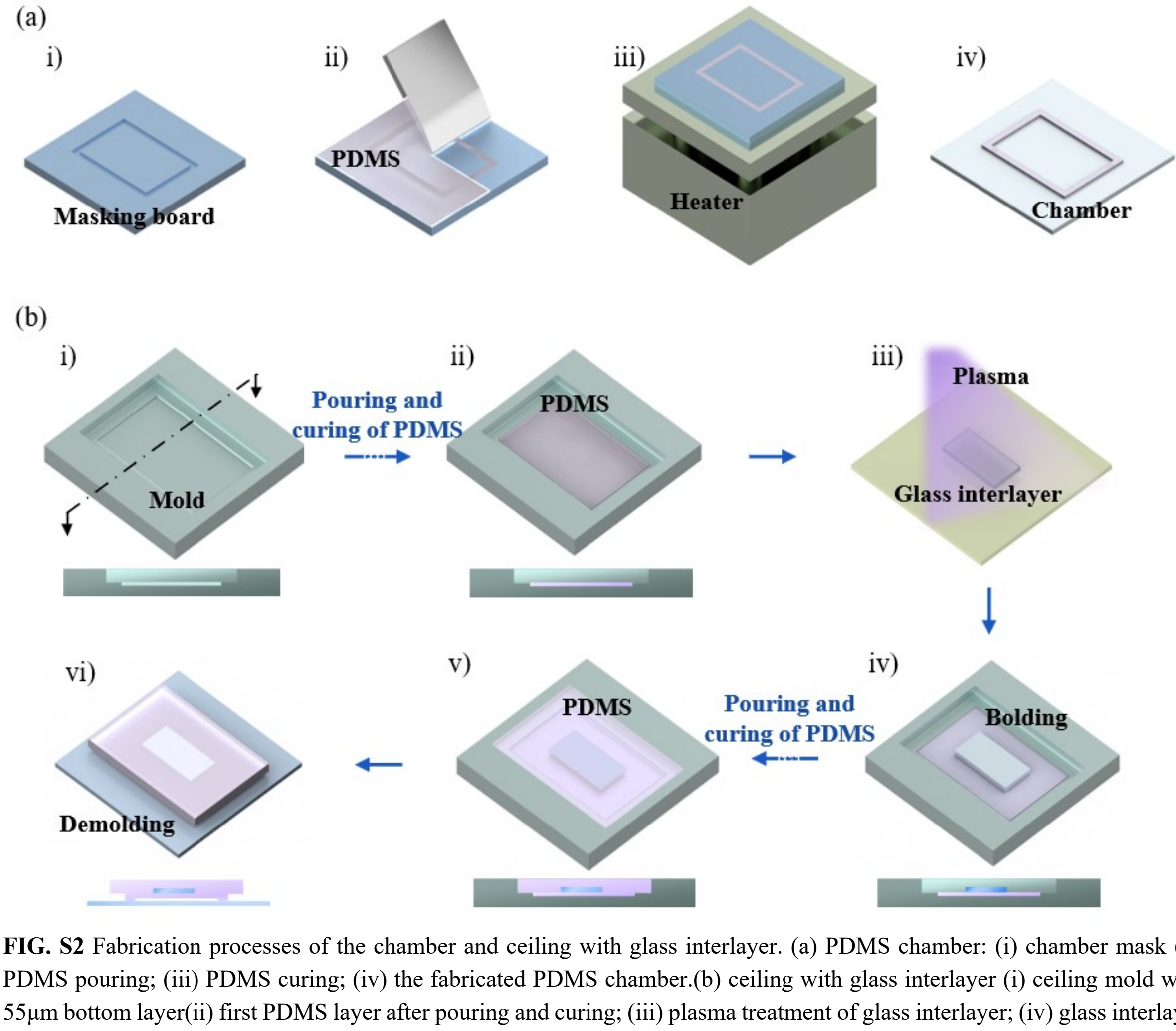

FIG. S2 Fabrication processes of the chamber and ceiling with glass interlayer. (a) PDMS chamber: (i) chamber mask (ii) PDMS pouring; (iii) PDMS curing; (iv) the fabricated PDMS chamber.(b) ceiling with glass interlayer (i) ceiling mold with 55μm bottom layer(ii) first PDMS layer after pouring and curing; (iii) plasma treatment of glass interlayer; (iv) glass interlayer bonded with the first PDMS layer; (v) second PDMS layer after pouring and curing; (vi) the fabricated ceiling.

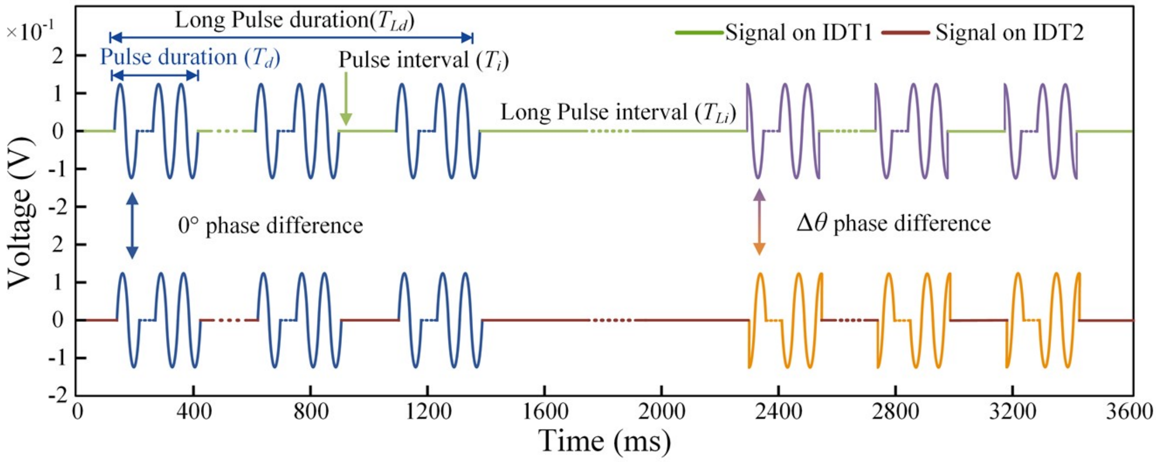

FIG. S3 Schematic diagram of the single period excitation signals on opposing IDTs with 100 μm finger width.

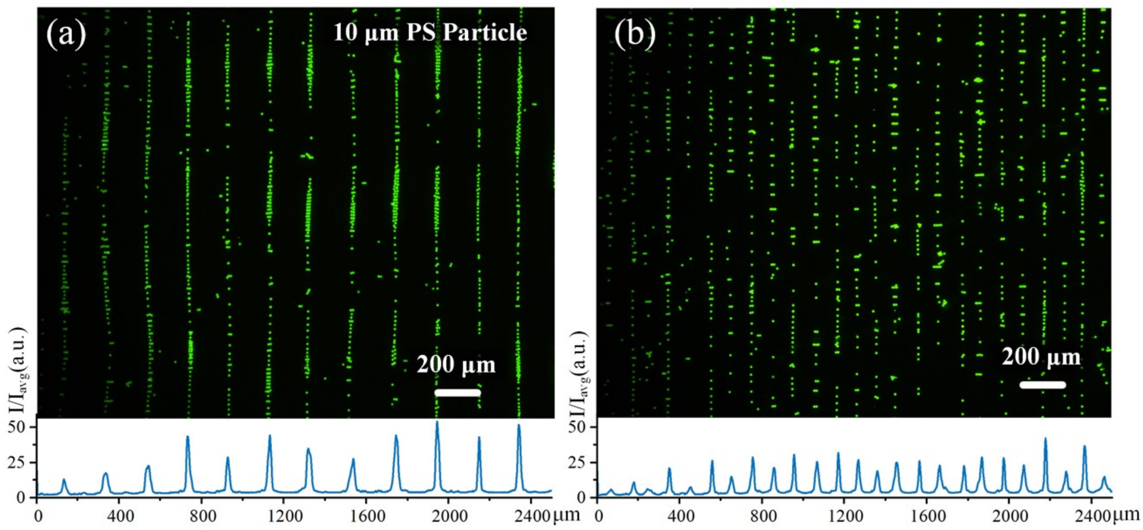

FIG. S4 Patterning results of half-spacing particle patterning under phase modulated pulsing coherent SAWs with 0° and 180° phase difference and 400 μm wavelength under glass interlayer. The fluorescence intensity averaged across the height of the frame is followed below. (a) PS particles patterned under conventional SSAWs with average peak-to-peak distances of 200.6 μm. (b) half-spacing patterning with average peak-to-peak distances of 99.8 μm.

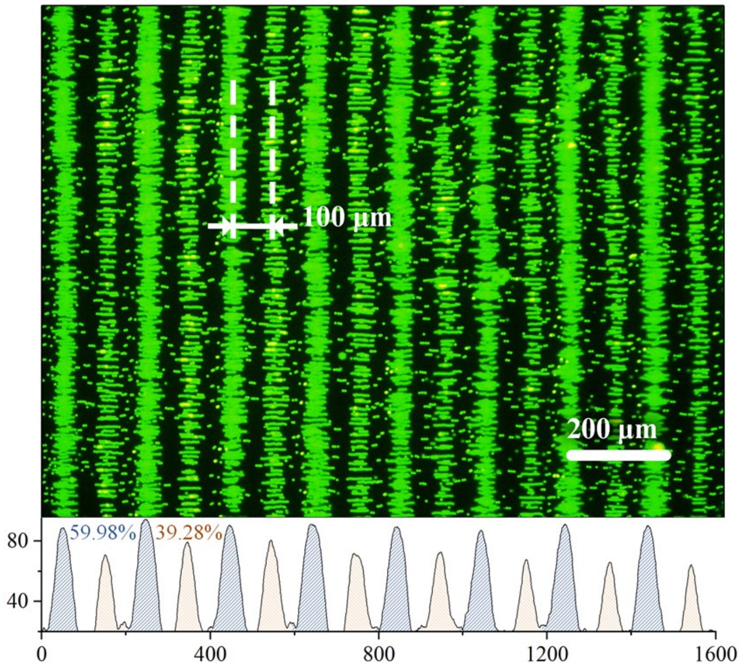

FIG. S5 Patterning results of half-spacing uneven particle patterning under phase modulated pulsing coherent SAWs with 0° and 180° phase difference and 400 μm wavelength under glass interlayer. The fluorescence intensity averaged across the height of the frame is followed below. The areas under the odd and even peaks are 59.98% and 39.28% of the total area, respectively, indicating that the area under the odd peaks is 52.70% greater than that under the even peaks.

Reference

S1. I. P. Dunn and W. A. Davern, *Applied Acoustics*, 1986, **19**, 321-334.

S2. S. Sachs, M. Baloochi, C. Cierpka and J. König, *Lab Chip*, 2022, **22**, 2011-2027.