

Supplementary Materials

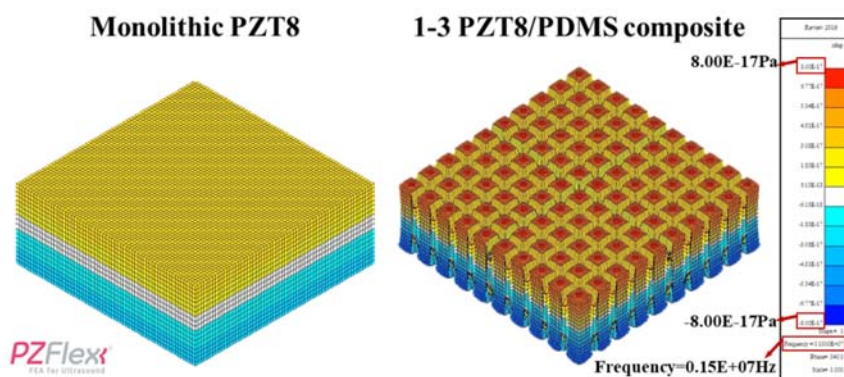


Fig.S1 The maximum vibration displacement of the monolithic and 1-3 composite elements. The resonant frequency of the piezoelectric material is 1.5MHz, and the normalized maximum acoustic pressure value is 8.00e-17 Pa.

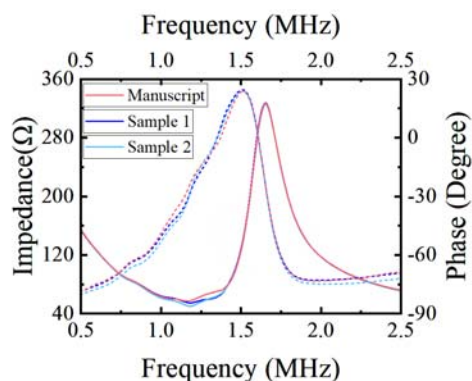


Fig.S2 The performance of three flexible transducers in the same batch. We used precision grinding machines and dicing machines to control the thickness and width of piezoelectric materials, so in the same batch, **three** flexible devices with high performance were prepared, and the results as shown in Table S2, which show that the three samples have a high consistency.

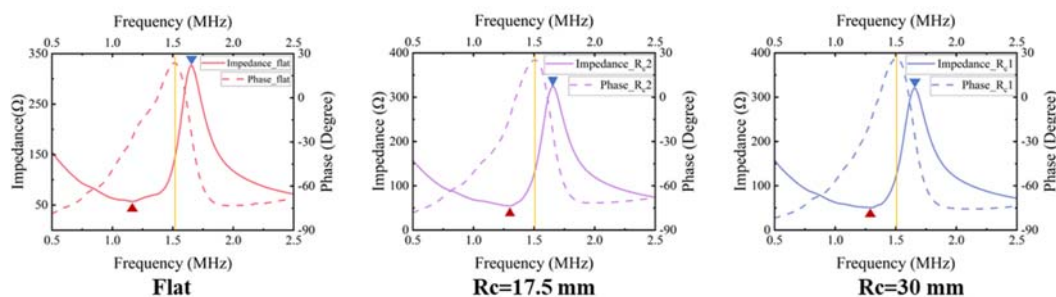
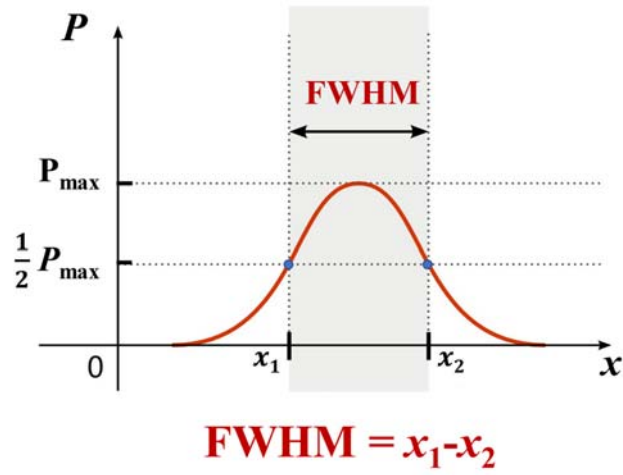
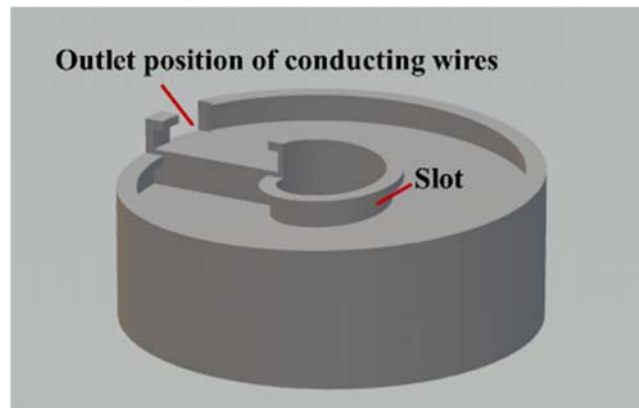


Fig. S3 The electrical and acoustic performance of the transducer with different

17 **curvatures.** The results show that the electrical impedance measurement results are
 18 similar under different curvature conditions, indicating that the flexible 1-3 composite
 19 material shows complete flexibility, high electrical and acoustic performance.
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21 Fig.S4 The explanation of the FWHM (full width at half maximum).
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24 Fig.S5 The drawing of 3D printed mold.
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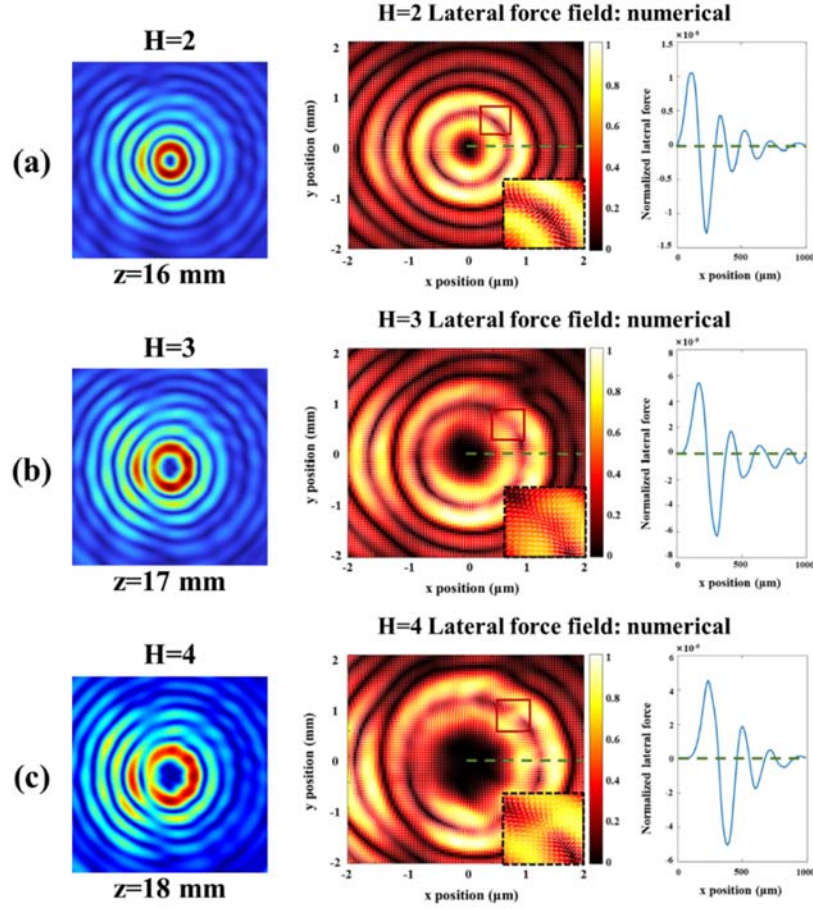


Fig.S6 Characterization of acoustic field and radiation force for the spiral FPCM transducer at different heights (H). (a) H=2, (b) H=3, (c) H=4. Left: Acoustic field amplitude distribution in the xy plane at the focal plane. Middle: Normalized magnitude and distribution of acoustic forces, with white arrows indicating the convergence of the force field toward the first ring. Right: Magnitude of the lateral force along the green dashed line indicated in the middle figure, revealing maximum radiation forces of 12.9 nN, 6.3 nN, and 5.0 nN, respectively. To be specific, the focal plane acoustic pressure magnitude in the xy-plane, the magnitude and distribution of the acoustic radiation force, and the magnitude of the lateral force along the green dashed line plotted in Fig(a). The inset depicts an enlarged view of the radiation force distribution within the red box, where white arrows indicate the radiation force field's propensity to push the particles towards the first outer ring. The particle's directional movement is influenced by the acoustic radiation force; when the force value is negative, the particle is compelled towards the center of the acoustic vortex, whereas a positive force value impels it outward.

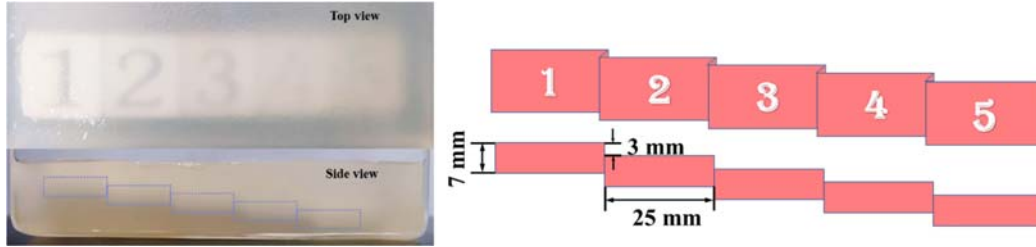


Fig.S7 The details of the phantom and the size of the digital plate. Left: the physical diagram of the digital plate in the imitation body, right: the spatial structure and size of the digital plate.



Fig.S8 Photograph of the microinjection pump system.

Table S1 The imaging resolution of the transducer with different curvatures

R_c	17.5	20	22.5	25	27.5	30
Lateral resolution (mm)	0.79	0.86	0.95	1.03	1.12	1.21
Axial resolution (mm)	4.45	5.82	7.70	9.65	11.74	14.01

Table S2 The performance and deviation of three flexible transducers

	f_r (MHz)	f_a (MHz)	k_t	f_c (MHz)	Z (MRayl)
Manuscript	1.1626	1.6537	0.7457	1.5137	139.9569
Sample 1	1.1835	1.6541	0.7339	1.5105	138.4495
Sample 2	1.1826	1.6532	0.7340	1.5128	138.4601
Standard deviations	0.0119	0.0005	0.0068	0.0016	0.8673

f_r is the resonant frequency, f_a is the anti-resonance, and the electrical coupling factor k_t is calculated by the formula, f_c is the center frequency as well as Z is the electrical impedance at the center frequency.