Supplementary Information (SI) for Lab on a Chip.

The Process and Fabrication of the Devices

The Solidly Mounted Resonators (SMRs) used in this paper were designed with a frequency of 2.56 GHz. The photomasks were designed using L-edit software. A total of six masks were used, as shown in Figure S1, corresponding to the six manufacturing steps detailed below. The complete fabrication process is as follows:

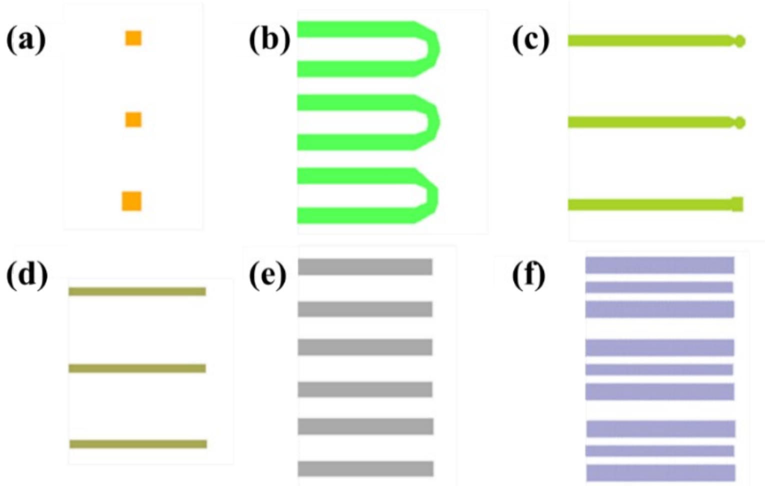

Figure S1. Mask layouts and their functions. (a) For etching the Bragg reflector (BR) layer; (b) For etching the bottom electrode (BE); (c) For etching the top electrode (TE); (d) For exposing the top electrode; (e) For exposing the bottom electrode; (f) For patterning the gold (Au) electrodes.

1. Fabrication and Etching of the BR Layer. Prior to device fabrication, the substrate requires cleaning. The silicon substrate was cleaned using a Piranha solution (a 7:3 mixture of concentrated sulfuric acid and hydrogen peroxide. The BR layer is composed of alternating silicon dioxide (SiO_2) and molybdenum (Mo) layers. This stack consists of five layers, which (listed from top to bottom) are 650 nm, 640 nm, 150 nm, 640 nm, and 650 nm, respectively. These layers were deposited on the silicon substrate via chemical vapor deposition (CVD) and reactive sputtering. The BR layer formed after subsequent etching is shown in Figure S2(a).
2. Fabrication and Etching of the BE Layer. A 150 nm Mo layer was deposited on the Bragg reflector layer using reactive sputtering. This layer was subsequently etched to form the BE pattern (Figure S2(b)).
3. Fabrication and Etching of the TE Layer. After the BE was formed, an 1100 nm thick AlN layer was sputtered directly onto the substrate as the piezoelectric (PZ) layer. Subsequently, a 170 nm Mo layer was deposited to serve as the TE layer. This TE layer was then etched to obtain the desired shape (Figure S2(c)).
4. Fabrication and Etching of the Passivation (PS) Layer. SiO_2 was deposited over the TE as a passivation layer, protecting both the top electrode and the AlN layer. This

layer was then etched to expose the TE layer for the subsequent metal deposition step (Figure S2(d)).

5. Etching and Exposure of the BE Layer. Similarly, to facilitate the subsequent metal deposition, a two-step etching process was performed to expose the bottom electrode (Figure S2(e)).
6. Gold Electrode Patterning. An 80 nm Au layer was patterned using a Lift-Off process to form the gold electrodes, which facilitate subsequent wire bonding (Figure S2(f)).

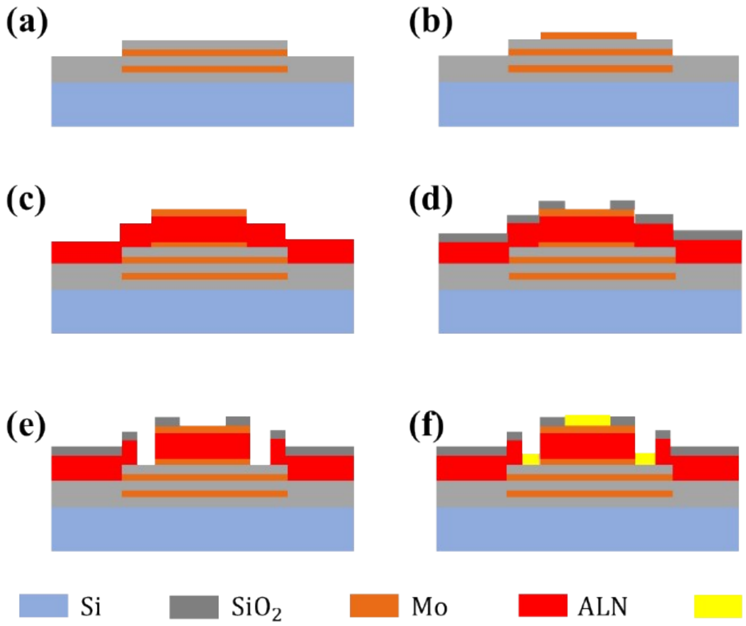

Figure S2. Schematic of the SMR device fabrication process.

The SMR is fabricated via the process described above are on a full wafer. The wafer must be diced along the alignment marks using a dicing saw. The resulting rectangular chips are indicated by the yellow dashed line in the figure. The image on the right shows a micrograph of an actual fabricated SMR, taken under high magnification. The diameter of the circular TE layer is 100 μm. The three electrodes (the central TE and the two BEs) are connected via gold wire bonds to a Printed Circuit Board (PCB) that is soldered with SMA connectors (Figure S3). The radio frequency (RF) electrical signal is transmitted through RF cables and the SMA connectors to be applied to the device.

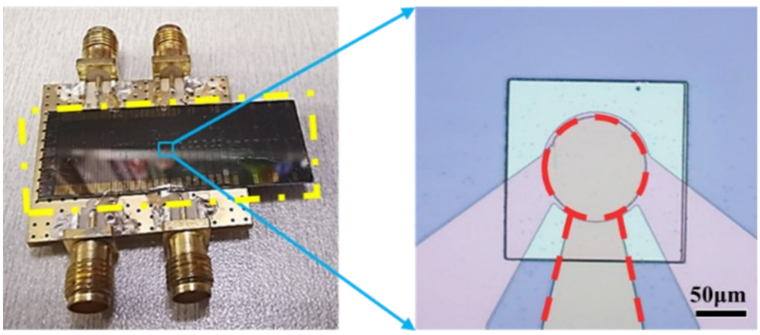

Figure S3. Photograph of the fabricated SMR device and substrate. In the right-hand image, the TE layer is highlighted with a red dashed line.

Construction of the Multiphysics Model

As shown in Figure S4, the geometry construction and material settings are as follows: The device was designed as a circular resonator with a resonant frequency of 2.56 GHz and a radius of 50μm. A three-dimensional (3D) resonator model was constructed based on the axis of rotational symmetry r=0. The structure comprises: a silicon (Si) substrate, a Mo/ SiO_2 Bragg reflector (BR), Mo electrode layers, a c-axis-oriented AlN piezoelectric layer, and a liquid/air layer.

Below is the specific model construction process:

1. Geometry Construction and Material Settings: The device was designed as a circular resonator with a resonant frequency of 2.560 GHz and a radius of 50μm. Using r=0 as the geometric center of rotation, the substrate for the solid-assembly resonator was constructed, with the material set as silicon. The BR employs a stacked structure of alternating Mo/SiO_2 layers. The electrode material was set to Mo, the piezoelectric layer material to AlN, and the liquid layer material to paraffin oil. The top fluid layer was set as air.
2. Multiphysics Settings: The acoustofluidic effect of the device involves the coupling of three multiphysics fields in the physical model, which are: (1) Piezoelectric Effect: This involves the coupling of Solid Mechanics and Electrostatics. All materials, excluding the liquid, were defined within the solid mechanics domain. Piezoelectric coupling was applied at the interfaces of the AlN layer. The electrode sections on both sides of the AlN layer were selected for the "Electric Field," with one side set to "Ground" and the other set to a "Terminal." In the multiphysics coupling node, the AlN layer was selected and set to "Piezoelectric Effect" to simulate the resonator's driven state upon voltage application. (2) Acoustic-Structure Boundary Coupling: This involves the coupling of Solid Mechanics and Pressure Acoustics. The liquid and air layers were defined as the Pressure Acoustics domain to simulate the propagation of acoustic waves. As the acoustic waves transmit from the solid interface into the liquid, the boundary between the liquid and the solid was set as an "Acoustic-Structure Boundary." This allows the acoustic waves generated by the device to couple into the liquid interior through this boundary condition. (3) Acoustofluidic Coupling: This involves the coupling of Pressure Acoustics and Fluid Dynamics. The liquid and air layers were selected as the domains for "Laminar Flow" and "Level Set." The effect of the acoustic waves was coupled into the fluid in the form of a "Volume Force."
3. Mesh Construction and Solving: The mesh construction must satisfy the basic sampling theorem, requiring at least 5 mesh elements per acoustic wavelength. In this simulation, 12 elements per wavelength were used. Concurrently, for the "Level Set" function, the material properties on either side of the liquid-air interface and the boundary itself change continuously during the solution process, which can affect convergence. Therefore, the mesh in this region was made as dense as computationally permissible to ensure the convergence of the results.

   The solution was configured in two stages: (1) Steady-State Solution: Since the resonator exhibits steady-state vibration, the solver was set to the "Frequency Domain." The frequency was set to 2.560 GHz, and the piezoelectric effect was solved to obtain the device's vibration characteristics. Subsequently, these vibration results were passed through the "Acoustic-Structure Boundary" interface to solve for the acoustic wave propagation in the liquid. The resulting acoustofluidic forces on the fluid were then calculated and used as the initial values for the level set function. (2) Transient Solution: After obtaining the initial values for the level set function, a "Transient" solver was employed to compute the real-time deformation of the liquid and air layers, thereby yielding the dynamic simulation results.

(a)

Layer	material	height
Air	Air	4μm
Liquid	light liquid paraffin	1.2μm
TE	Mo	0.17μm
PZ	AlN	1.1μm
BE	Mo	0.15μm
BR1	SiO_2	0.65μm
BR2	Mo	0.64μm
BR3	SiO_2	0.15μm
BR4	Mo	0.64μm
BR5	SiO_2	0.65μm
SI	Silicon	10μm
Power		100mW

(b)

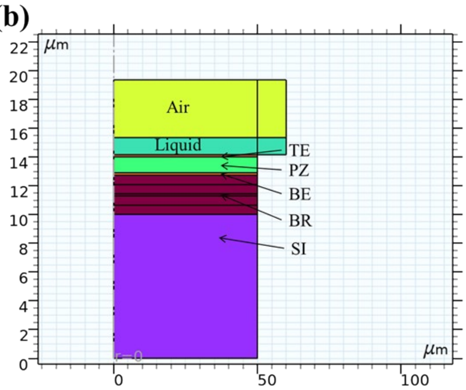

Figure S4. Schematic diagram of the simulation structure and parameter settings.