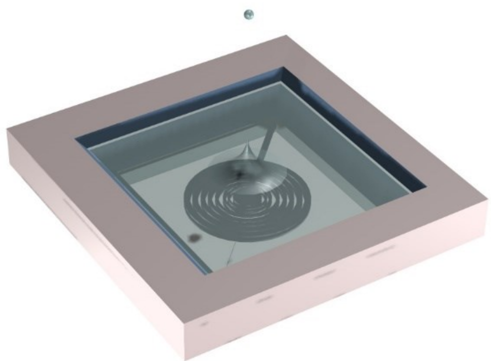
Self-Focusing Acoustic Transducer (SFAT)



Self-Focusing Acoustic Transducers (SFAT) consist of concentric, annular piezoelectric (ZnO) transducers. Constructive interference of acoustic waves generated by these half-wave band sources leads to a large acoustic pressure perpendicular to the plane of the SFAT. If immersed in liquid, the acoustic pressure will eject droplets. Benefits of this novel ejector device include: no nozzle, no acoustic lens, and low temperature increase of the ejected liquid. This makes for a simple system that is well suited for liquids containing suspended particles or with high temperature sensitivity.

When the SFAT (shown in Fig. 1) is driven by a burst of RF signal, it generates acoustic waves that propagate in the liquid toward the liquid/air interface. The spacing of the electrodes is such that the distance between each ring and the focal point at the fluid surface differs by an integer number of wavelengths. Since this planar design borrows its concept from the optical Fresnel lens, we say that this configuration is made up of Fresnel Half-Wave-Band (FHWB) sources. With *n* number of FHWBs, the acoustic intensity at the focal point is $4n^2$ times the intensity at the transducer.

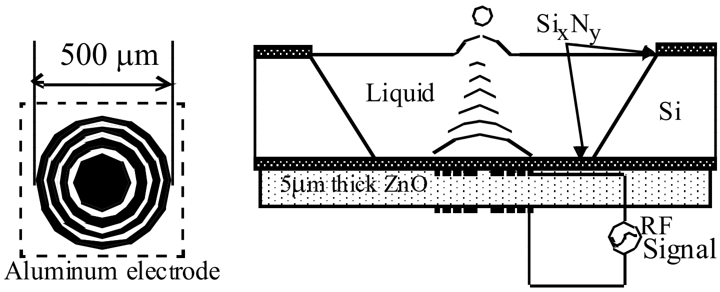


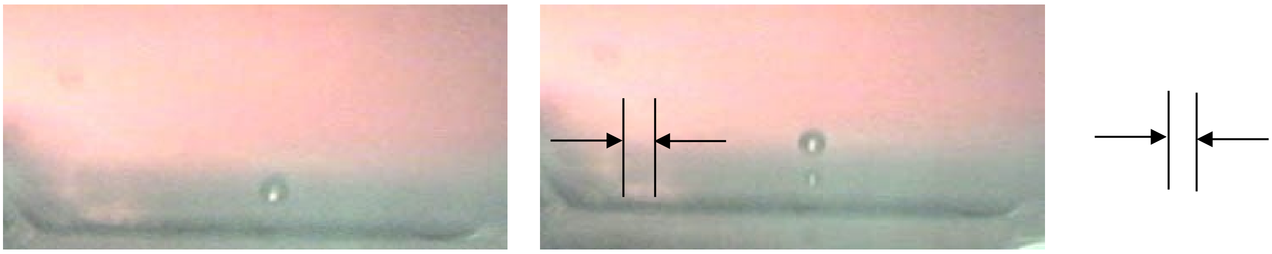
Fig. 1: (a) Top view of the electrode pattern showing the spacing of annular transducers. (b) Cross-sectional view of the liquid ejector microfabricated on a silicon wafer. The liquid ejection is produced by an acoustic beam focused on the liquid-air interface through constructive interference.

The versatile self-focusing acoustic-wave transducers can typically be fabricated with the following 4-mask process. After depositing and patterning 0.5-0.8 μm thick low-stress silicon nitride, we remove silicon with KOH to form 1.5 x 1.5 mm^2 membranes, on which 0.5 μm thick

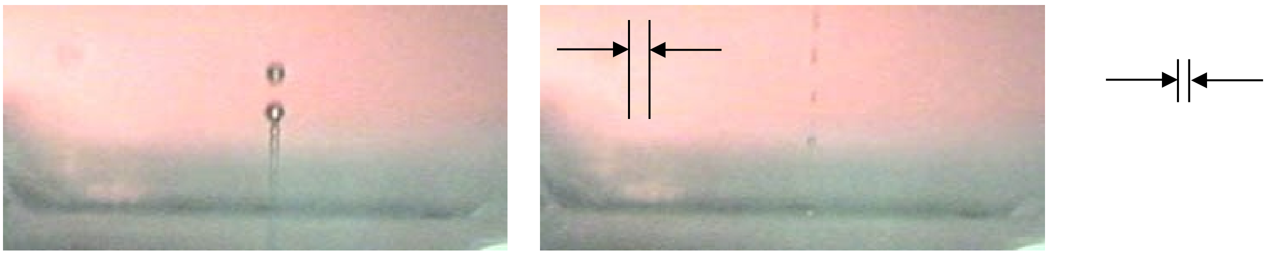
Al is evaporated and patterned for an annular bottom electrode. Then a 3-10 μm thick ZnO film is deposited, followed by 0.5 μm thick Al evaporation and delineation for a top electrode. The segmented electrodes and the ZnO film act as the half-wave band sources.

In the demonstrated devices, two factors determine the size of the ejected droplet: frequency and duration (width) of the RF pulse used to drive the transducer. We have fabricated and tested three versions of the ring SFATs having three different thicknesses of ZnO film and thus operating at 300, 600 and 900 MHz. The SFAT with higher operating frequency ejects smaller liquid droplets and also requires thinner ZnO film, which eases the fabrication. However, it requires higher electrical power for liquid ejection because acoustic-wave propagation loss in liquid is proportional to the square of the frequency. Among the three SFATs, the 600 MHz SFAT (with 5 mm thick ZnO film) offers the best compromise between droplet size and power consumption. The droplet size decreases with decreasing pulse width, and with the 600 MHz ejector, ~5 μm droplets are observed when the SFAT is driven by pulses of 5 μsec width. Larger droplets (up to ~100 μm) are observed with longer pulses, and the droplet velocity is measured to be 2-3 m/s, depending on conditions.

Photographs of the ejector in operation are shown in Figure 2. Here we can also see the dependence of droplet dynamics on the level of the liquid with respect to the focal point of the SFAT. Unless the liquid level is actively maintained, it will decrease as liquid is ejected from the reservoir. Initially the level is above the focal point, and performance is low (large, non-uniform drops). The liquid level then falls to coincide with the focal point, and the ejection characteristics are optimal (small, uniform drops and stabile operation).



(a) 80μ m (b) 60μm



(c) 30μm (d) 15μm

Fig.2: Snapshots showing the time evolution of the liquid ejection process produced by our 600 MHz SFAT with an RF pulse width of 30 μsec. (a) Large droplets with low velocity characterize the beginning of the ejection run. (b) Smaller droplets are ejected as the liquid level falls. (c) As water level drops further, droplets become much smaller and uniform in size. The velocity increases dramatically so the tiny droplet collides with the larger one ejected just before it. (d) Minimum droplet size is achieved when the liquid level is exactly at the focal plane. Ejection stabilizes for tens of seconds.