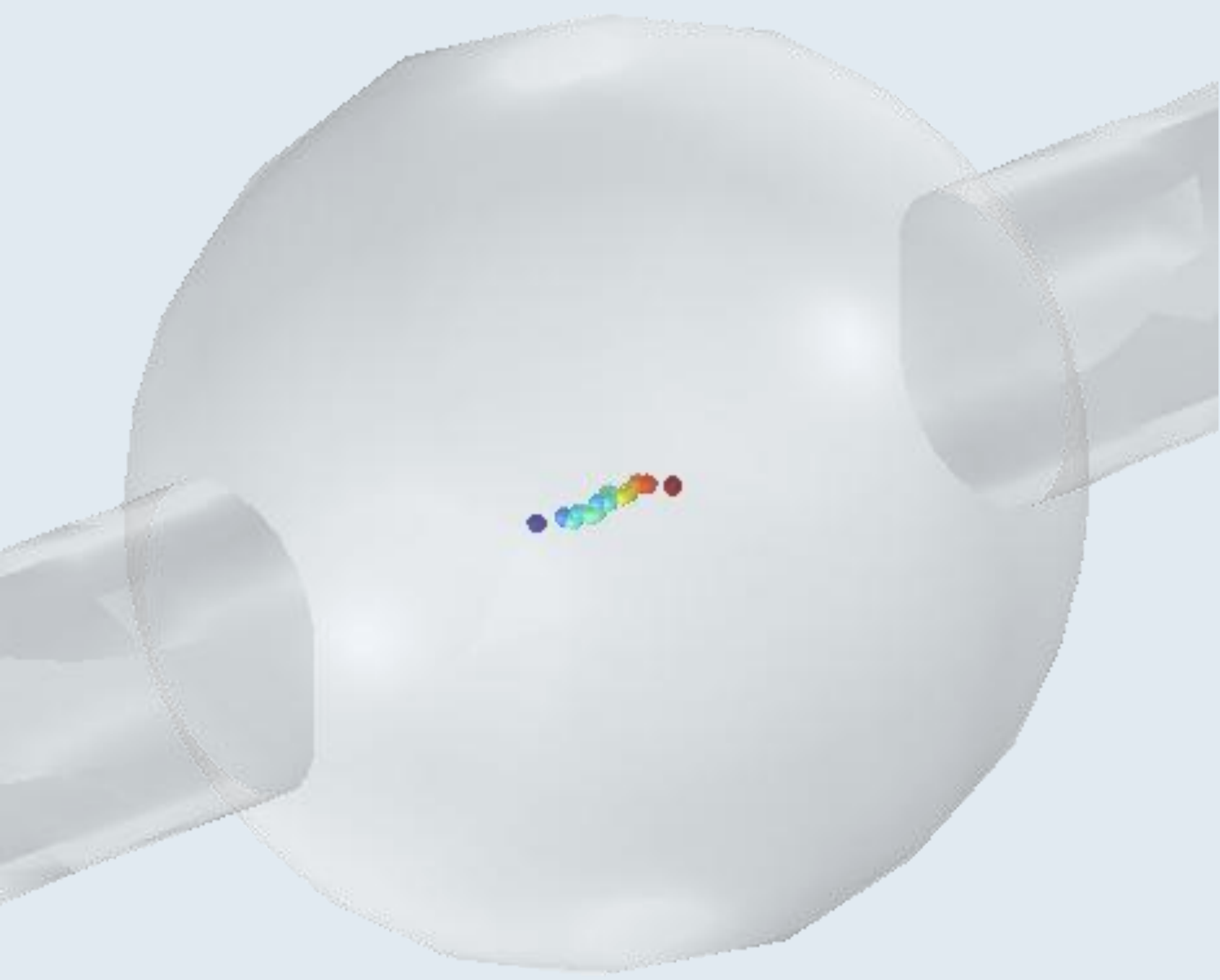




Numerical Investigation of a 100-Cavity Acoustofluidic Platform for Parallelized Acoustic Trapping

A coupled multiphysics model shows the potential of PZT, which can generate frequency-dependent acoustic fields in a 10×10 cavity array, enabling simulated 3D particle trapping.

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Introduction

Acoustic manipulation provides a label-free and contactless method for manipulation of cells and particles in microfluidic systems[1]. In acoustofluidic devices, particles can be concentrated inside the observation volumes while the fluidic network remains a possibility for sample loading, medium exchange, and microscopy[2]. Multi-well parallel acoustic trapping has also been developed for cell and spheroid studies[3]. On the other hand, the CellLEGO platform allows for the spherical trapping inside the cavities connected within the microfluidic network[4]. Scaling of

the platform to a 10×10 cavity array introduces a challenge in which the excitation of glass structure by one bonded piezoelectric transducer needs to generate usable local pressure fields in the array to maintain suitable operating conditions. Because both pressure magnitude and nodal-surface configuration vary with excitation frequency, complementary frequency-dependent fields may provide confinement in different spatial dimensions. This work therefore evaluates the coupled acoustic, particle, hydrodynamic, and thermal behavior of a prospective 100-cavity platform.

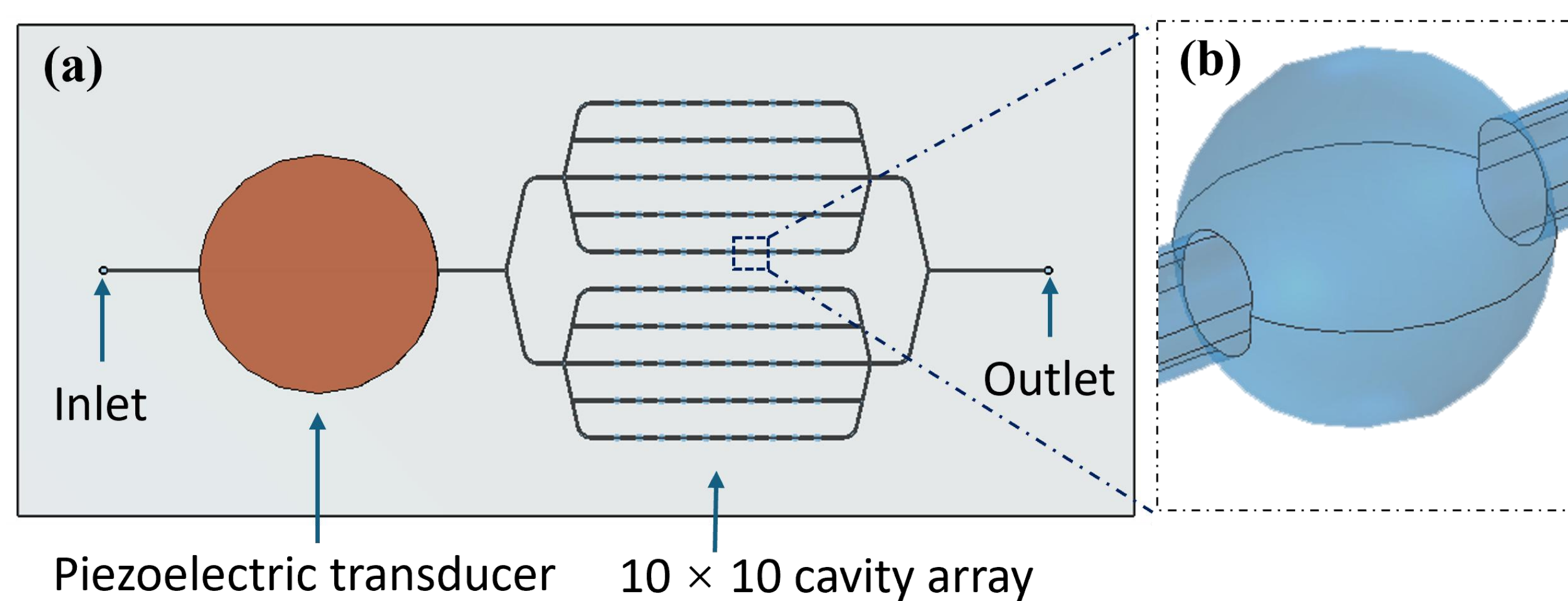


FIGURE 1. Device geometry of the prospective 100-cavity acoustofluidic platform. (a) Whole-device architecture. (b) Enlarged geometry of a representative cavity and connecting channels.

Methodology

A 3D model was generated using COMSOL Multiphysics® 6.3, consisting of a D263 glass chip having 100 spherical cavities on a 10×10 array connected through a microfluidic network filled with water. A Pz26 disc having a diameter of 16 mm was attached to the glass. The Electrostatics, Solid Mechanics, and Pressure Acoustics physics interfaces were coupled through the Acoustic-Structure Boundary and Piezoelectricity Multiphysics couplings to calculate the electrical, mechanical, and acoustic properties of the entire system. A frequency domain simulation was carried out between 1.75 to 2.00 MHz with 0.025 MHz steps, assuming 15 V input excitation. In the case of particle tracing, 18 particles having a diameter of $15 \mu\text{m}$ were introduced into a representative cavity. Several acoustic field solutions were applied. Thus, Acoustic radiation force and Stokes drag were considered. Flow and thermal analysis were separately studied at $0.08 \mu\text{L min}^{-1}$ and heating.

Results

Under a frequency of 1.75 MHz, the magnitude of the electric field covered the active PZT disk and had variable values across the transducer. The displacement field was spread from the PZT to the glass chip. Sequential application of complementary acoustic fields generated by mechanical vibration progressively contracted the particles, producing a compact central cluster by 0.12 s.

At $0.08 \mu\text{L min}^{-1}$, shear rates in the cavity-array region remained approximately $0.006\text{--}0.016 \text{ s}^{-1}$, below those in narrow upstream channels. In contrast to the uncooled condition where the device temperature reached 417 K after 30 minutes of operation, effective convective cooling limited the maximum temperature to approximately 312 K over the same duration.

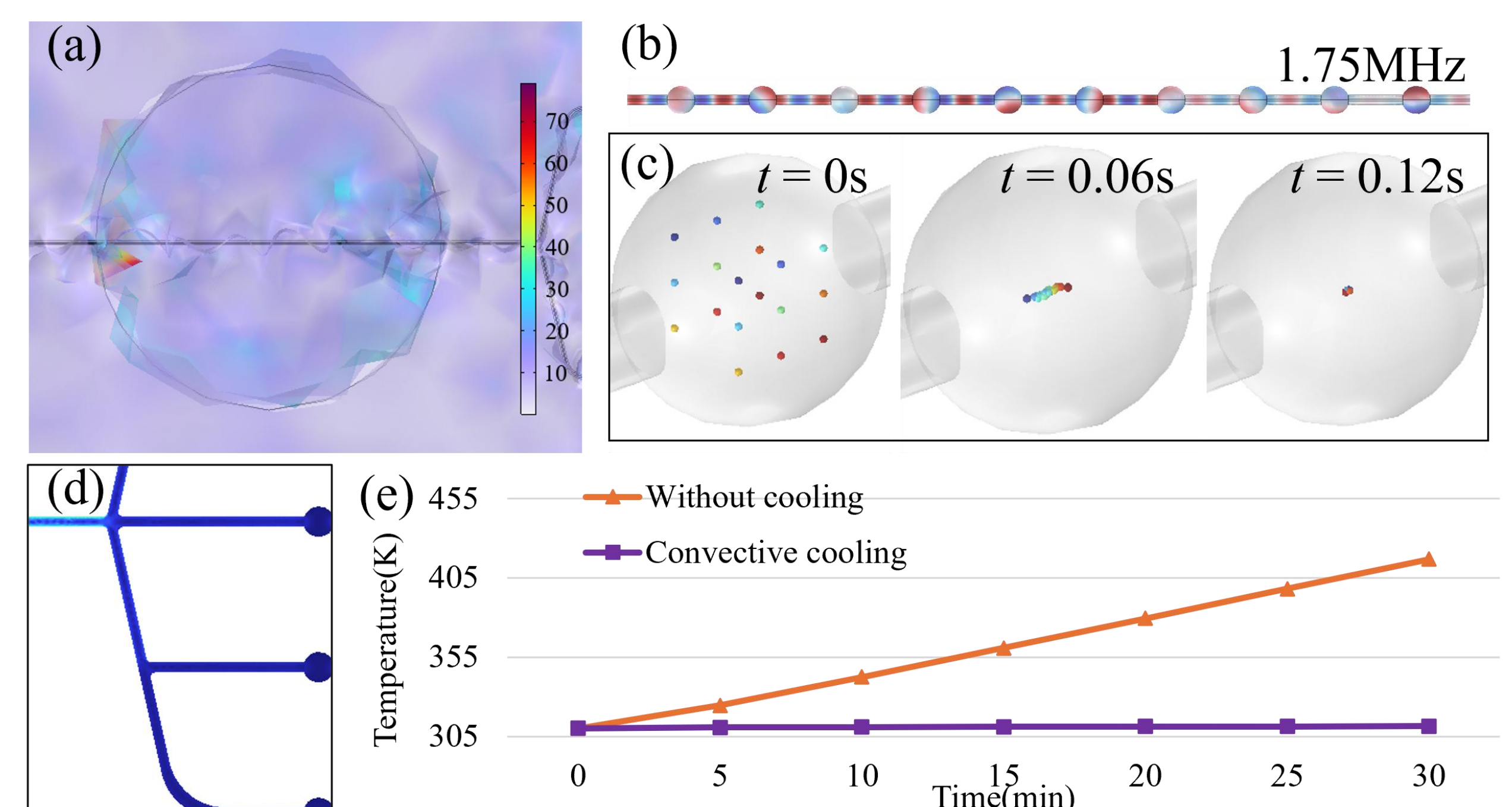


FIGURE 2. (a) Electric-field magnitude in the PZT. (b) Total acoustic pressure of channel and cavities at 1.75MHz. (c) particle trapping. (d) Shear-rate distribution in the cavity region. (e) Mean temperature of two monitoring points located in the cavities nearest the PZT.

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