

Impact of Damping Effects on Piezoelectric Actuation Used in Acoustofluidic Cell Trapping

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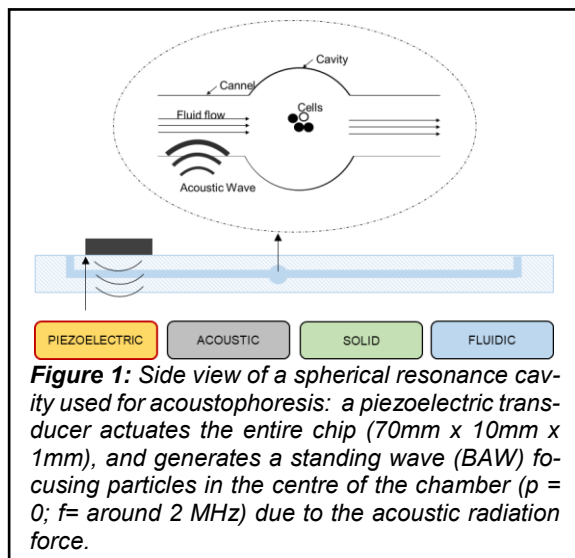
SUMMARY

Acoustic trapping is increasingly recognized as an effective and gentle non-contact method for manipulating cells and particles within microfluidic systems, which is crucial for advancing research in drug development and medical treatments. A critical factor in the successful assembly of an acoustic trapping system is the design of the acoustic resonator, which must ensure the alignment of the resonance frequency between the piezoelectric element and the fluid-filled cavities. This paper focuses on characterizing piezo electrical damping effects essential for optimizing and advancing the acoustophoretic microsystem.

KEYWORDS: piezoelectric actuation, damping effects, acoustofluidics, acoustophoresis

BACKGROUND

Acoustic trapping, also known as acoustic tweezers, represents a promising technique in biomedical engineering, enabling various functions such as capturing, separation, filtration, and agglomeration of cells [1]. Utilizing this technology, a measurement setup and a prototype (Figure 1) have been developed [2–4]. A crucial prerequi-

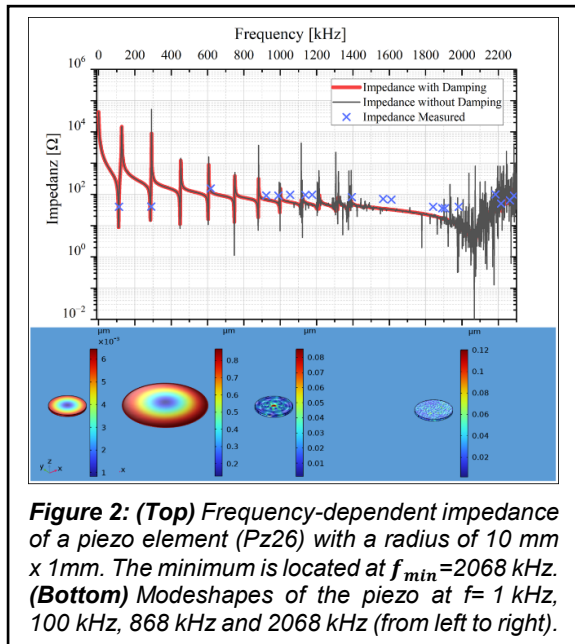


site for the propagation of Bulk Acoustic Waves (BAW) in both, the solid and the fluidic parts is the design and the positioning of the piezoelectric actuator. In acoustic trapping, the two phenomena decisive for successful operation are the acoustic radiation force (ARF) and the acoustic-streaming-induced drag force (ASF). The ARF is generated by pressure nodes and antinodes of standing acoustic waves, while the ASF results from the nonlinear attenuation of a

propagating acoustic wave in a viscous medium. These forces are primarily determined by the acoustic resonator in combination with the generated BAWs and must be strong enough to counteract the velocity of the liquid medium. In this context, the impedance of the piezo and the deflection play a pivotal role. Preliminary studies revealed a zero-pressure node within the cavity at around 2 MHz, and the cell trapping conditions have been empirically met by sweeping the actuation frequency at the piezo within a certain range since neither the frequency characteristics nor the damping of the piezo material have been known precisely enough. However, operating the piezo at the dedicated and optimized operating frequency would be more energy-efficient and reduce system heating, which is particularly important if the device is extended to an extensive array system and/or applied in long-term studies like tumor cell interaction. Developing a second generation of cell trapping devices, specifically in an array configuration for parallelization of cell investigations and, hence, geometry and size changes in the system, necessitates dedicated characterization of the applied piezo element to ensure efficient wave transmission.

RESULTS

In the first step, the unmounted piezoelectric actuator was excited by applying a voltage ($V_{pp} = 10 \text{ V}$), with the system being in a vacuum and at a constant temperature, and its impedance was simulated and measured (Figure 1). In the second step, we introduced damping by applying an isotropic loss factor from the COMSOL material database. In theory, the minimum impedance of the piezo (Figure 2) occurs at the same frequency as the maximum deflection of



the piezo (**Figure 3 (A)**) shows that this is not the case when damping is considered. The maximum amplitude of the piezo is shifted to lower frequencies (110 kHz), and the maximum deflection decreases by a factor of 150. Next, we additionally took into account the gluing process (see **Figure 3 (B)**). As a result, the maximum impedance is shifted again to lower frequencies (blue), and the deflection decreases by 11% of the original deflection (red). Laservibrometer measurements show the most significant deflection at 6 kHz and 110 kHz for both the freely vibrating and glued disc, which compares well with the simulations.

CONCLUSION AND OUTLOOK

We characterized a piezoelectric actuator used in acoustophoretic devices for cell trapping by simulations and measurement to quantify the impact of material damping and of the glue used for mounting on the impedance of the piezo and the displacement induced by it. Both parameters are crucial for the design of the chips to get an optimized energy transfer and ensure frequency matching. It revealed that considering material damping, the maximum deflection is shifted to lower frequencies and – in contrast to theoretical expectations – does not coincide with the minimum impedance. Measurements by a Laservibrometer confirmed this trend. The outcome of this study will go into the design of more advanced cell trapping devices, e.g., the parallelization of cell investigations in arrays or the mixing of different liquid media.

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