Measurement of acoustic resonance line shapes by microbead acoustophoresis in straight microchannels

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Introduction

Within the past five years there has been a significant increase in the number of novel applications of ultrasound standing waves for particle handling in microfluidic chips. In spite of this growing interest, detailed measurements of the resonance line shapes are lacking. We present such measurements based on tracking of individual polystyrene microbeads during acoustophoretic motion in straight water-filled microchannels in silicon/glass chips subject to piezo-induced ultrasonic pressure fields. From the measured line shapes we extract the corresponding Q factors and thus gain insight in the nature of the acoustic energy dissipation of such systems.

Experiment

We have fabricated microfluidic silicon/glass chips of different widths containing straight, 377-µm-wide channels, Fig. 1(a). In each experiment a chip was mounted on a piezoelectric transducer, and a dilute, aqueous suspension in the range from 0.01 g/mL to 0.05 g/mL of 5-µm-diameter polystyrene microbeads was injected into the microchannel, Fig. 1(b).

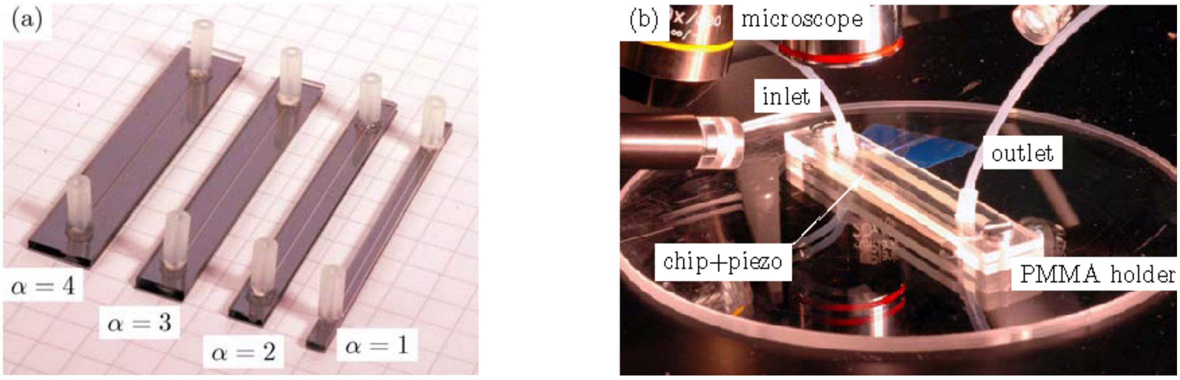

Fig. 1. (a) The silicon/glass chips containing straight channels of length $l = 40$ mm, width $w = 0.377$ mm, and height $h = 0.157$ mm. The channels are etched down into the silicon chip of thickness $h_{\mathrm{si}} = 0.35$ mm, and they are covered by a pyrex lid of thickness $h_{\mathrm{py}} = 1.13$ mm. The lengths of the chips are $L = 50$ mm and the widths are $W = 2.5$ mm ($\alpha = 1$), $W = 4.7$ mm ($\alpha = 2$), $W = 6.8$ mm ($\alpha = 3$), and $W = 9.0$ mm ($\alpha = 4$), respectively. (b) A photograph of the experimental setup with the chip and the PZT piezo crystal mounted under the microscope and the CCD camera. The piezo has the dimension 50.0 mm × 12.0 mm × 1.0 mm.

The acoustic energy density was measured by observing the transient, acoustophoretic motion of the microbeads. First, the driving frequency was tuned until observing a strong, resonant, acoustic focusing of the polystyrene microbeads towards the center of the channel. Then, the ultrasound field was turned off, and a fresh solution of microbeads was injected into the channel. When a homogeneous microbead distribution was observed, the flow was stopped. Finally, the ultrasound was turned back on, and the transient focusing of the microbeads towards the channel center was recorded by a CCD camera. Employing the free video analysis tool *Tracker 2.6* on the resulting movie, we determined the transverse position y for a number of particles on each frame, for which the time t is known. The resulting lists of (t,y)-coordinates can be extracted for all tracked microbead paths at any given driving frequency f and driving voltage U_{pp}.

Results

Using the standard theory for acoustophoresis we have obtained an analytical expression for the particle path $y(t)$ containing the acoustic energy density E_{ac} as an unknown parameter [1]. This expression is fitted to the measured data points (t,y), and E_{ac} is extracted. In Fig. 2(a) we have plotted E_{ac} versus the driving frequency f and fitted the obtained resonance peaks by the sum of two Lorentzian line shapes. The two observed peaks, differing Δf = 9.4 kHz in resonance frequency, correspond to two resonances. The high-f resonance has one more axial pressure node than the low-f resonance as illustrated by the pressure field simulation in Fig. 2(b). From the Lorentzian line shapes we obtain the Q factors of the resonance peaks to be 209 and 577, respectively. In the case of having only viscous dissipation we expect the Q factors to be $Q \approx 10^4$, which implies that the observed resonance widths are mainly due to the acoustic coupling to the surroundings.

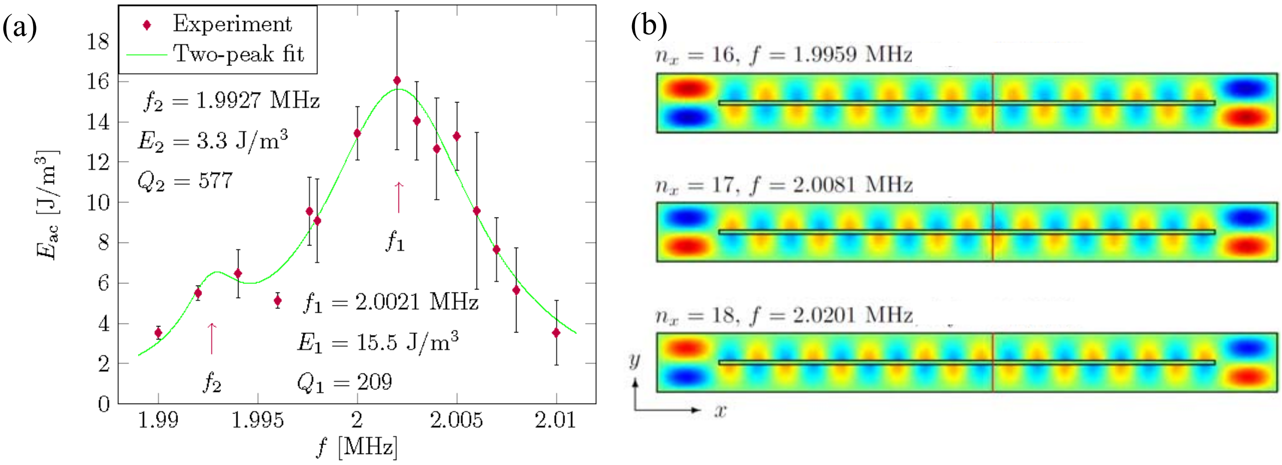

Fig. 2. (a) Measured acoustic energy density E_{ac} versus applied frequency f on the piezo transducer (points) for $\alpha = 2$. A sum of two Lorentzian peaks (full line) fits the data reasonably well. (b) Top-view colorplots of the pressure (blue negative, red positive) for three ultrasound resonances calculated in a simplified 2D model [2]. For each resonance is shown the number of n_x of pressure nodes in the axial direction and the resonance frequency f. The two resonances are separated by $\Delta f \approx 12$ kHz.

Conclusion

We have measured the acoustophoretic motion of microbeads in dilute, aqueous solutions in straight, water-filled channels in silicon/glass chips subject to piezo-induced ultrasound standing waves. For a given driving frequency and voltage amplitude of the piezo transducer, microbead paths have been recorded by a CCD camera and fitted to a theoretical curve. From the curve fit we have obtained the acoustic energy density. Furthermore, by plotting the energy densities as a function of the applied ultrasound frequency, we obtained Lorentzian line shapes, from which we can determine precise values of the resonance frequency and the Q factor for each acoustic resonance. This novel technique opens up for a detailed, *in-situ* study of microchannel acoustophoresis and its energy-loss mechanisms [3].

References

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