Nanoparticle Sorting in Microfluidic Channels

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Abstract:

A device capable of detecting, characterizing and sorting nanoparticles and important biological targets would be an invaluable tool both for public health monitoring and for biomedical research. We describe the development of a microfluidic device that should permit the high-throughput sorting of nanoparticles, potentially able to sort hundreds to thousands of particles per second.

Introduction:

The ability to manipulate biologically relevant nanoparticles such as viruses, proteins, and synthetic nanoparticles would be a boon for medical research. Examples of the utility of such a device include aggregating rare particle types or efficiently imaging representative particles in a diverse mixture. Current methods of sorting particles are impractical for use in processing polydisperse samples. We describe the development of a microfluidic device that should permit high-throughput nanoparticle sorting. The device consists of a microchannel, an optical sensor, and a fluid actuator. Sorting is accomplished by driving fluid on-demand using a piezoelectric transducer (PT), actuated by an optical sensor sensitive to particles passing through the microchannels. We have performed a systematic study of PT actuation using a laser vibrometer, and have explored various means of coupling the PT and the microfluidic device. Through this study, we have developed an improved method for mounting the PTs to the microfluidic device that we expect will demonstrate more effective fluid actuation.

Experimental Procedure:

Device Fabrication. The device's microchannels were cast in the transparent elastic polymer polydimethylsiloxane (PDMS). The mold used to cast the PDMS consists of patterned SU-8 photoresist. PDMS was spun onto the mold, then cured on a hotplate for 10-15 minutes at 140°C. We coupled the PTs to the microchannels by embedding them in a second layer of PDMS, which was cured for 20-40 minutes at 140°C. Each of the two PTs was placed over a reservoir which directed fluid perpendicular to the direction of particle flow (see Figure 1). Once the PDMS had hardened, we peeled it from the mold and cored ports for fluid injection using a biopsy punch. We prepared the PDMS for bonding by exposing it to UV ozone, and then we bonded it to a glass substrate and cured it for 3-5 hours at 140°C. Fluid and florescent polystyrene nanoparticles were injected into the microchannels from pressurized reservoirs connected to flexible tubing inserted into the ports. Both PTs were connected to a function generator. Particles were forced through a fluid restriction and detected by an optical sensor, which signaled the function generator to actuate the PTs to direct the particle as desired.

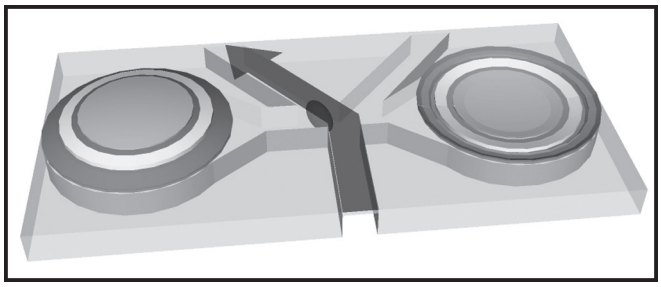

Figure 1: Particle actuation.

Device Characterization. Piezoelectric materials deform mechanically in response to applied voltage. We induced sinusoidal vibration in the PTs using a function generator with frequencies in the kilohertz range. We characterized these PTs and the PDMS that formed our device's channels using a laser vibrometer. This tool measures the vibration of a reflective surface by measuring the phase shift difference between the reflected laser beam and a reference beam.

Results and Conclusions:

We performed a variety of vibrometry experiments to determine the behavior of the device as driving voltage, frequency, and measurement location were varied.

We measured the resonance characteristics of the PTs by applying a fixed voltage to the PTs while modulating the driving frequency from 1-50 kHz. At each frequency, we found the peak-to-peak displacement of the PT as measured by the vibrometer. The resulting curve showed that the PTs act as harmonic oscillators with resonance frequencies close to 7 kHz, in accordance with the manufacturer's specifications. We performed these experiments on several PTs in three distinct environments: 1. The PT was glued onto a hollow metal cylinder. This showed the clearest resonant peak and two harmonics; 2. The PT was embedded in PDMS; and 3. The PT was embedded in PDMS and bonded to glass. In addition, the microchannels were filled with DI water. The results are summarized in Figure 2.

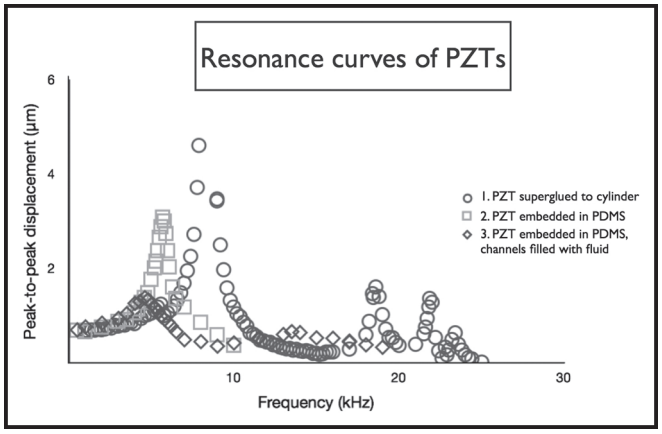

Figure 2: Resonance curves of PTs.

Because PDMS is an elastomer, we examined the possibility of vibrations propagating through it. We tested this by determining that the PTs were coupled together by PDMS vibrations: that is, we found that each PT could drive the respective other. When one PT was driven by the function generator, we found that the other PT showed a resonance curve similar to (though smaller than) that of the driving PT.

We examined the PDMS vibration further by measuring the PDMS itself. We applied a layer of silver paint to a sample to make it reflective and measured the peak-to- peak displacement of the PDMS as we moved the vibrometer beam away from the edge of the driving PT. The results, summarized in Figure 3, showed a standing wave in the PDMS whose amplitude was reduced when the sample was made of stiffer PDMS.

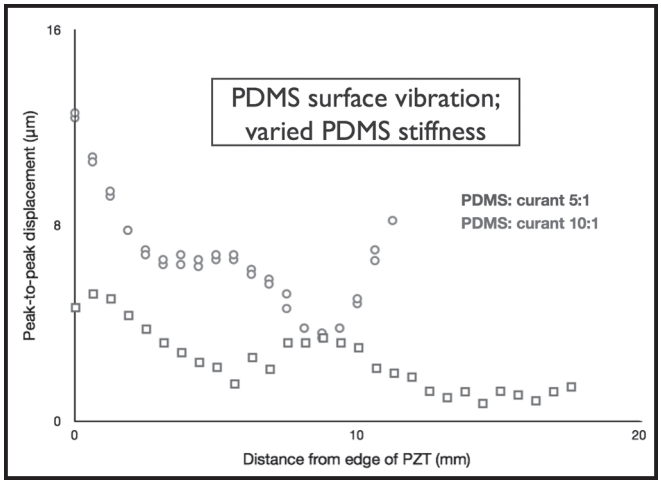

Figure 3: Standing waves in PDMS.

In light of these data, we desired a way to isolate the PT vibration from the PDMS so that fluid actuation would be discrete and well-controlled. This was accomplished by machining brass funnels on which the PTs could be mounted, the stems of which could be inserted into ports in the PDMS. Vibrometry measurements showed that this modification successfully isolated the PT vibrations from the PDMS: we repeated both experiments testing for PDMS vibration without finding a signal in any case.

Future Work:

Future direction for this project includes further calibrating the device to allow for well-controlled particle actuation. Once the device works predictably with the polystyrene nanoparticles, biological samples could begin to be processed.

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