PATTERNED MICROCLEANSING AND PARTICLE RECOVERY WITH OPEN ACOUSTIC MICROFLUIDICS

Arlene Doria, Nicholas E. Martin and Abraham P. Lee
Department of Biomedical Engineering, University of California - Irvine, USA

ABSTRACT

The application of ultrasonic energy to a bath of solution is a well-established technique for improving the efficacy of cleansers and solvents, and this communication presents a technique for further improvement upon this method. Hydrophobic PDMS devices have been made with 2D arrays of cavities that naturally trap an air bubble when covered with aqueous solution. A piezoelectric transducer is used to transmit ultrasonic energy to the 2D array that oscillates the air-liquid interface above each cavity. These oscillations create micro-vortices that gently remove and trap particles and debris from adjacent surfaces, including proteins from soiled contact lenses.

KEYWORDS

acoustic, ultrasound, particles, beads, trapping

INTRODUCTION

The use of ultrasound to activate cavitation microstreaming on two dimensional bubble arrays have been used in bioengineering applications for mixing and hybridization [1][2]. The use of these arrays to loosen and trap particles from soiled surfaces may be a useful application for microvolume cleansing of delicate components. Ultrasonic baths have long been used for industrial cleaning and chemical processing. Baths requires agitation or microbubble generation that can be actuated with ultrasound. The precise location of microbubbles is not well controlled and baths require liquid volumes that exceed microliter scales. The large volume of solution required for ultrasonic baths makes the recovery of removed particles nearly impossible. Furthermore, many sonication methods that require agitation may not be suitable for delicate surfaces. Herein, we describe acoustically actuated bubble arrays we term air-liquid cavity acoustic transducers (ALCATs) for microcleansing and particle recovery using microliter volumes.

ALCATs are air cavities that form naturally in properly designed hydrophobic devices filled with aqueous liquids. When activated by an acoustic source, the air-liquid interfaces above these cavities will oscillate and create stable cavitation streaming within a localized region of the surrounding liquid. ALCATs have been shown to be useful for several biological applications [3], and in this embodiment will serve to dislodge particles from a desired surface via the micro-vortices

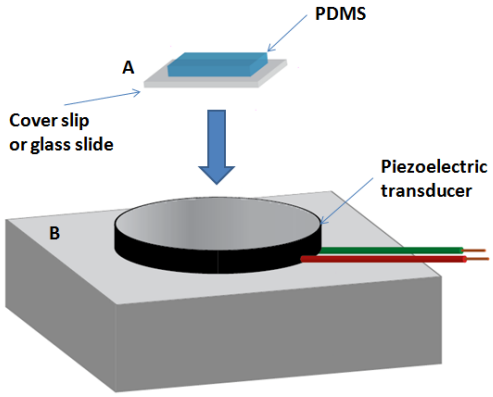
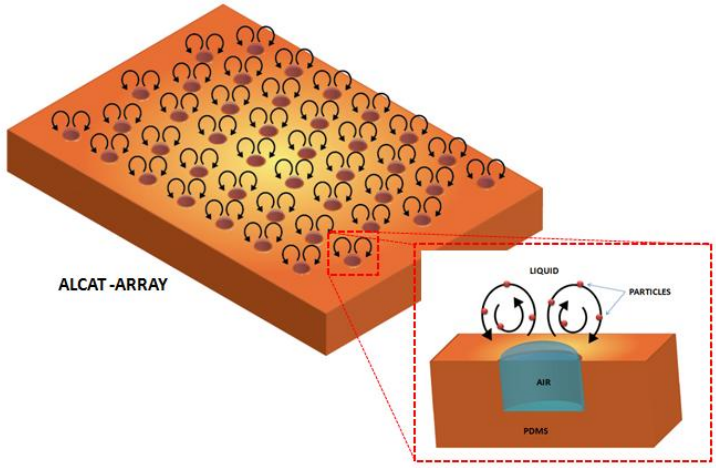


Figure 1. Experimental setup. A passive PDMS on glass chip (A) is placed on a piezoelectric transducer (B). No external tubing or syringe pumps are required.



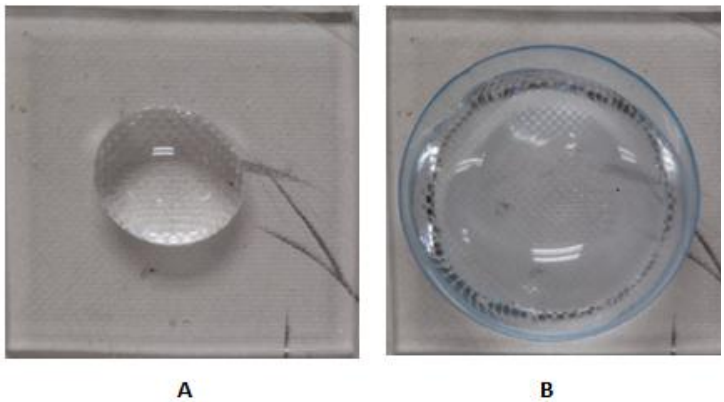


Figure 2. Open microfluidic chips for particle recovery and microcleansing. Only a 100 uL of saline (A) is required to remove particles on surfaces as delicate as a contact lens (B).

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generated at the air-liquid interface. For our device, a high density bubble array was fabricated using standard soft lithography techniques. Fluid and particle manipulation can be accomplished on a passive, disposable chip that is placed on top of an external acoustic transducer (in this case an electrically driven piezoelectric transducer) with a coupling medium (Fig. 1). There is no need for a pump or external tubing.

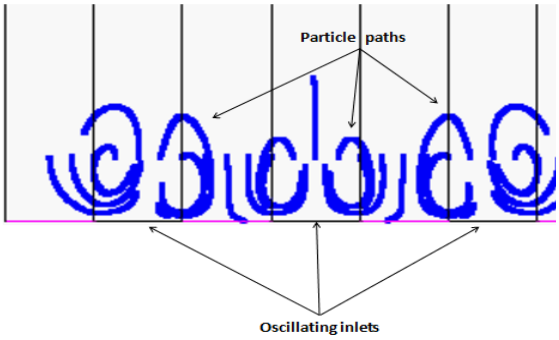

Figure 3. Computational Fluid Dynamic Simulation of particle paths in the presence of activated ALCATs.

EXPERIMENT

Here, ALCATs are formed by pipetting microliter volumes onto cavity arrays that trap air bubbles. (Fig. 1 and 2A). In our model, a fragile, soiled contact lens (Fig. 2B) is placed on the chip with nearly conformal contact to the array. Computational fluid dynamic simulations were performed to show particles trapping in the presence of these vortices (Fig. 3). In these simulations, the air-liquid interface is modeled as an oscillating inlet/outlet. This approximation has been verified by analyzing the behavior of the air-liquid interface with a high-speed camera (Phantom v310, Vision Research) and inverted microscope (Eclipse TE2000-S, Nikon). Fig. 5 shows various debris types (beads, eyeshadow, salt/proteins) circulating in dynamic micro-vortices near localized regions of the ALCAT array. In some videos, the combined actuation of all the bubbles was enough to oscillate the liquid solution as observed under a microscope. Fig. 4 presents quantitative data which supports the claim that an activated ALCAT array can successfully remove protein debris from a delicate surface. A contact lens was incubated in fetal bovine serum albumin for 6 days at 37°C in 5% CO_2. The contact lens was rinsed in DI water and N_2-dried then placed in 100uL of saline solution on an ALCAT chip. The air-liquid interfaces of the ALCAT array were activated by a piezoelectric transducer at a frequency of 44 kHz. The solution was sampled every 3 minutes and measured for 280nm absorbance using a Beckman Coulter DU730 Spectrophotometer. UV280 absorption roughly represents amount of proteins in solution due the strong absorption of aromatic rings in amino acids at 280nm. An upward trend in absorbance over time is seen (Fig. 5), indicating that more protein is being dislocated from the surface of the lens as time goes on.

This novel method of microcleansing may serve as a niche for removing particles off delicate, soiled surfaces and recovering those particles if necessary in small microliter volumes without the need to agitate the surface to be cleaned. Additionally, ALCAT arrays made with soft elastomers such as polydimethylsiloxane can be made to have conformal contact to a variety of geometric shapes. ALCAT microstructures can be fabricated in only a single layer and are therefore very amenable to conventional manufacturing processes.

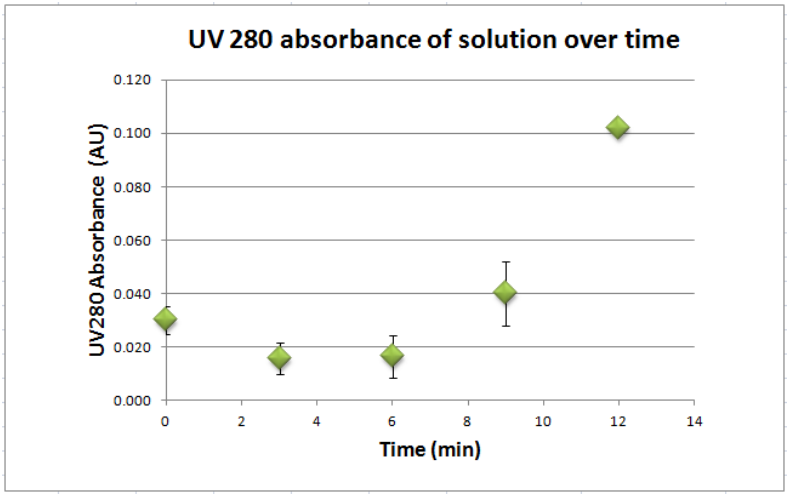

Figure 4. UV280nm absorbance of the solution used for cleaning the protein incubated lens shows a general increase over time of cleansing.

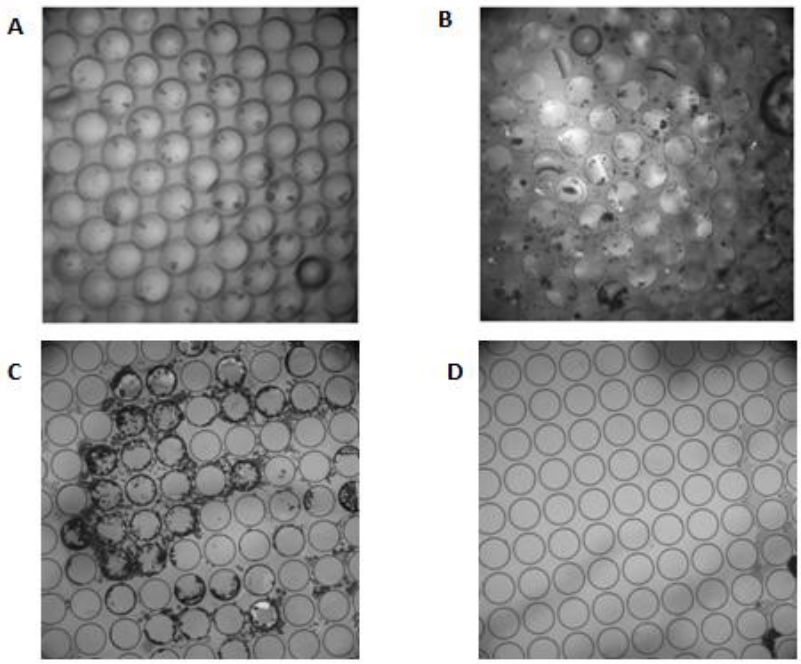

Figure 5. Snapshots of swirling particles trapped in microvortices. 5um polystyrene beads (A), eyeshadow particles (B), salts/protein (C) are trapped after exposure to a soiled surface of the contact lens. Areas adjacent to the surface did not appear to have particles (D).

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CONTACT

Arlene Doria (arlened@uci.edu)
Abraham P. Lee (aplee@uci.edu)
Website: biomint.eng.uci.edu