Sub-Wavelength Ultrasonic Lipid Manipulation Utilising Embossed Plastic Channels

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Abstract: A simple embossing technique has been demonstrated to produce fluidic channels in PMMA. These channels have been designed to allow ultrasonic suspension of lipids in water, and it is verified that sub-wavelength PMMA channels are acoustically active and capable of manipulating lipids.

1 Introduction: There is significant interest in separating the different constituents of complex biological fluids continuously. For example, lipid separation from blood, or milk. The use of acoustic radiation forces, generated by ultrasonic standing waves has been demonstrated to allow lipids to be manipulated[1], but this has been achieved by complex construction using acoustically hard materials such as glass and silicon. Previous work on multilayer resonant structures has demonstrated that the acoustic conditions can be modelled accurately [3] but that the necessary acoustic conditions are very sensitive to layer thicknesses. More recent work at the University of Southampton [4] has demonstrated that particles can be driven to a surface by using sub-wavelength reflectors, and that such systems are much less susceptible to thickness variations. In addition, as the acoustic paths are short, it is possible to use acoustically lossy plastics as the construction material. Recent work [5] at The University of Western Australia has demonstrated the construction of PMMA channels by embossing, using a stamp created by PCB techniques, offering a rapid and cost-effective way to produce microfluidic systems. Lipids in biological fluids are acoustically soft particles and behave differently from most particles in that they will concentrate at antinodes rather than nodes, and the purpose of this work is to show that it is possible to produce robust designs that allow lipids to be concentrated near the centre of a channel. This allows less clogging of the channel due to the lipids sticking on the channel walls, necessary for flow-through separation.

2 Theory: Acoustic radiation forces are a second order effect, and are due to discontinuities in the sound field. The discontinuity (particle) will experience a force due to the scattering and will move in the direction of the force. Theory developed in [2] for compressible material in a fluid shows that the time-averaged acoustic radiation force on a spherical particle of radius a, at position x within a one dimensional standing wave of acoustic energy density ε is given by:

$$F(x) = 4\pi k \varepsilon a^3 \,\Phi(\beta,\rho)\sin(2kx) \tag{1}$$

$$\Phi(\beta,\rho) = \frac{\rho_p + \frac{2}{3}(\rho_p - \rho_f)}{2\rho_p + \rho_f} - \frac{\beta_p}{3\beta_f} \tag{2}$$

where β and ρ are the compressibility and the mass density of the fluid and the particle, indicated by subscripts f and p respectively. The wave number, k is equal to $2\pi/\lambda$ where λ is the wavelength and the compressibility is related to the speed of sound, c, by $\beta=1/\rho c^2$.
The practical result of this is that particles will move to either the node or antinode of the standing wave, dependent of the value of Φ.

3 Modelling: Construction of a stamp using PCB techniques results in the copper track being used to define the fluidic channel. The copper is 70um thick and so in principle, a double layer structure can result in a channel height of about 140um. A multilayer structure was modelled using Matlab to determine the performance of the device, using a 250um thick PMMA imprinted with a 70um channel (resulting 180um reflector layer), aligned and sealed to a 1.43mm carrier layer having a mirror image 70um channel.

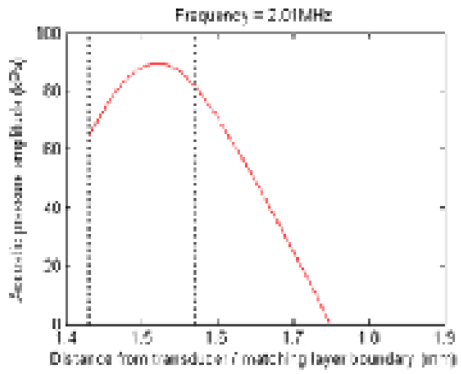

Figure 1 Pressure profile within device. Fluid layer is between the dotted lines.

This clearly shows the pressure antinode within the fluid layer, where lipids will concentrate.

4 Construction: The embossing/bonding technique developed uses a double sided PCB as an embossing mould. Silicone lubricant is used as a mould release, and the 1.5mm and the 250um thick PMMA blanks are placed either side of the PCB to make a sandwich. This is then placed in a hot press and pressed at 125 °C at a force of 1500kg for 30 minutes. This embosses the channels into the PMMA. Bonding of the two halves is then achieved by solvent bonding with a 33/66% mix of acetone and ethanol at room temperature. Vinyl tubing was epoxied in place to allow fluid ports.

5: Experiment

Good results were achieved at 2.05MHz with an amplitude of 25V pk/pk. The plastic assembly was acoustically very active and milk was visibly separated into agglomerations. Further trials with a vegetable oil/water/detergent mix allowed verification that the oil fraction is suspended in the fluid layer by the acoustic field. This is shown in fig 2a which shows a group of small oil droplets floating against the top surface. The surface is the focal plane, and figure 2b shows the same group now floating below the surface under the influence of the acoustic field.

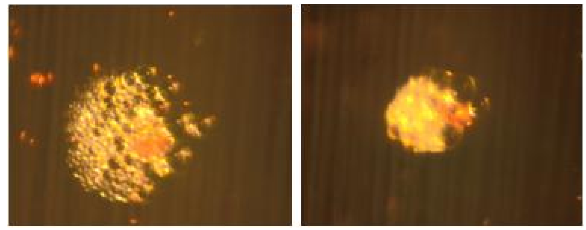

Figure 2 (a) Oil droplets floating on surface (red particles are surface markers) and 2(b) same droplets suspended below surface

5 Conclusion: This work reports a simple, rapid prototyping technique for making channels and demonstrates fluid fractionation under static flow conditions. It also shows that lipid manipulation is possible in sub wavelength structures constructed from PMMA. Refinements are underway to prototype a flow through device.

Acknowledgements

This work has been supported by the World University Network

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