The use of additive manufacturing to miniaturise a HIFU transducer

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Introduction

High Intensity Focussed Ultrasound (HIFU) transducers come in three main categories – bowl, acoustic lens and array – the latter being preferred for miniaturisation. While arrays excel at beam steering via phase delay between elements, they are complex to manufacture, requiring an electrical channel for each element [1]. This limits the capability of a bespoke miniaturized transducer for soft tissue ablation. This research proposes a single element transducer with an additively manufactured lens and housing, enabling bespoke devices and removing the requirement for complex wiring and driving solutions, hence allowing the device to be robotically delivered with ultrasonic b-mode imaging of the focal zone as feedback for control.

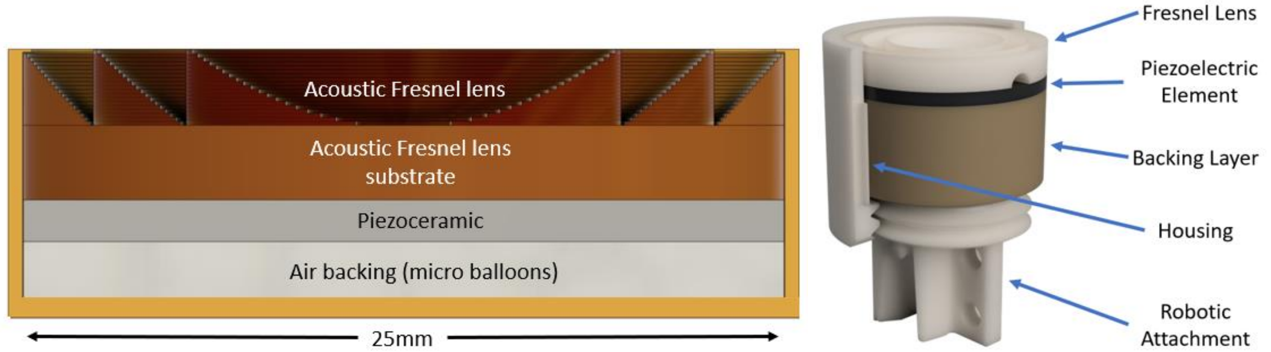

Fig. 1 left, a cross section schematic of the transducer design and right, a render of the design within the 3D printed housing and robotic pick up, showing scale.

Methods

By using additive manufacturing techniques, it is possible to rapidly produce bespoke, miniature HIFU devices. The Fresnel lens design allows the lens to be tailored to produce a more effective acoustic field. By changing the parameters in Eq. 1 and 2 [2], the focal length can be changed, which also effects the size and shape of the focal zone.

$$r_k = [\left(z + k\,\frac{\lambda}{N}\right)^2 - z^2]^{0.5} \tag{1}$$

$$h_k = \frac{1}{Nf(\left(\frac{1}{v_1}\right) - \left(\frac{1}{v_2}\right))} \tag{2}$$

where r_k is the radius of the kth step, z is the focal distance, λ is the wavelength of signal to be focussed by the lens and N is the phase number which controls how accurate the Fresnel lens approximates the equivalent bulk lens profile. Eq. 2 shows the height of the kth step where f is the frequency of signal to be focussed by the lens and v is the speed of sound in the lens and surrounding medium. To 3D print these features for a centre frequency of 1.5 MHz, the resolution of a suitable printer should be on the order of 100 µm. A cost-effective method is mSLA (mask stereolithography) such as the Elegoo Mars 2 Pro used in this study.

Results

A selection of commercial photopolymers was acoustically characterised and the lowest attenuation was chosen for prototype devices. The Strong-X photopolymer was found to have the lowest attenuation of 3 dB/MHz/cm. 12 devices where then manufactured using four different piezoelectric driving materials (PZ12, PZ54, PZ37 and PZ29 from CTS Ferroperm). The focal zone of each transducer was measured in a 3D acoustic scanning tank and compared to a finite element analysis (FEA) model. The acoustic field of each device was measured in two orthogonal planes in the direction of wave propagation, along with a transverse scan at the acoustic focus. To measure the acoustic field accurately a 200 µm diameter needle hydrophone was used (Precision Acoustics, UK). Due to the possibility of cavitation at the focus, the measurements were carried out at low power and low signal duty cycle. At the -6dB point in the focal zone the transverse dimension was found to be (1 ± 0.2) mm, as seen in Fig. 2.

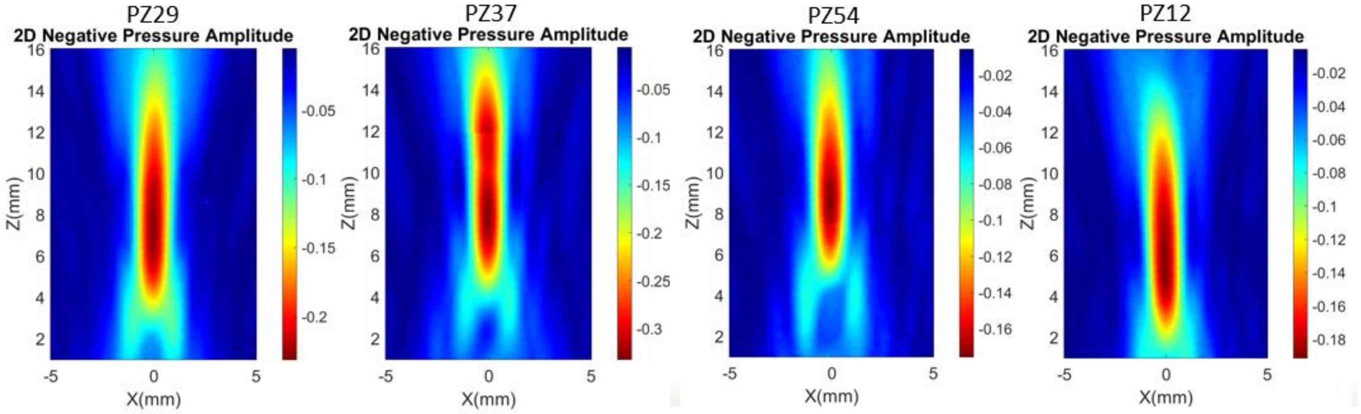

Fig. 2 The acoustic fields of the additively manufactured HIFU devices grouped by the piezoelectric material used as the active element. The position of the transducer is -22mm in Z and centred with respect to the X axis.

The maximum acoustic power was then measured in a radiation force balance and the devices driven to 1 Vpp input to the power amplifier. The results in Fig. 3 show that the porous piezoelectric ceramic material (PZ37) performed well in the device, suggesting that the better acoustic impedance match plays a significant role. The lead-free piezoceramic (PZ12) could be driven at higher amplitudes without failure, to achieve a large acoustic power output. However, this also shows that PZ12 results in a less efficient device than PZ37, requiring up to 100 V higher driving signal to achieve the same acoustic power output.

Conclusions

A HIFU device was miniaturised with the use of a cost effective additive manufacturing technique. Of the piezoelectric materials used, a porous piezoceramic, PZ37, performed well, indicating the acoustic impedance of the active material in such a configuration plays a dominant role in performance. The lead free material (PZ12) performed significantly better than figures of merit and material properties suggested and will be included in further investigations.

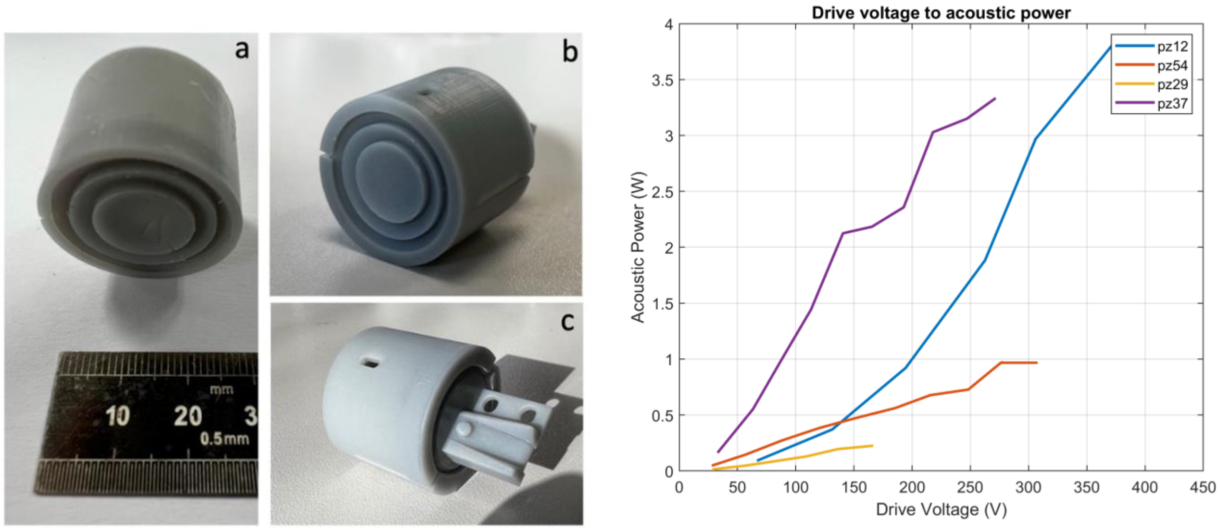

Fig. 3 a)-c) a Fresnel lens based HIFU device additively manufactured from photopolymer Strong-X. The graph showing the acoustic power output from each type of device in a radiation force balance.

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