Flexible multi-focal optoacoustic lenses for axial scan with short pressure pulses

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Background, Motivation and Objective

Laser-Generated Focused Ultrasound (LGFU) employing an optoacoustic lens, made of carbon nanotube (CNT)-polydimethylsiloxane (PDMS) composite film, has attained a great attention due to its characteristics of short temporal pulse widths (tens of ns), broadband frequency spectrum (>30 MHz), and high-pressure amplitude output. Most of the optoacoustic lenses developed so far are of solid-based substrate with fixed focal dimensions. Recently, array-based piezoelectric acoustic lenses have been introduced with changeable focal lengths but are costly with complex designs. The use of liquid-based lenses combined with piezoelectric transducers has been limited to imaging applications, which are not compatible with LGFU systems. In our work, we demonstrate novel LGFU lenses whose focal lengths can be flexibly controlled. We expect that this can be utilized for a wide range of biomedical ultrasound applications (imaging, therapy, lithotripsy, etc) and non-destructive evaluations.

Statement of Contribution/Methods

Cylindrical lens molds of different dimensions were designed and printed through a 3D printer. A flexible substrate (thickness: 1~1.5mm) for lenses was prepared on one side of cylinder by using PDMS. Then, CNT-PDMS composite was coated on the inner side of the substrate which acts as an acoustic source. The lens was irradiated by a laser beam having pulse width of 6 ns and energy of 132 mJ/pulse. A petri dish slide was attached on the other side of structure to create an empty volume which was then filled with a silicone gel (~30 ml) through a small hole (diameter: 2.5 mm) by using syringe injection. Once the vacant region was filled with the gel, additional gel injection can lead to changes in the curvature of flexible substrate. The consecutive four focal spots (after each ~1 ml injection) were characterized in terms of spot sizes, acoustic frequency, and injected gel amount. Finally, the lens was applied to axially scan and characterize an ex vivo blood vessel model.

Results/Discussion

Multiple focal lengths were successfully obtained from a single LGFU-based lens by controlling gel injection. A gradual injected amount of gel (1, 2 and 3 ml) deepened the lens curvature and thus shortened the respective focal lengths from 59.8 mm to 53.4, 47.3 and 43.9 mm (lateral and axial spot sizes: 478 to 327 μm and 7.56 to 4.53 mm, respectively). Temporal pulse widths of 30, 20, 15, and 10 ns (FWHM of positive waveform) were obtained due to focal length variation, which indicates a high-resolution axial scanning capability. We demonstrated that the change in focal length per gel amount was decreased towards shorter focal lengths because of limited substrate flexibility. An approximately linear relation was also observed between focal lengths and their spot sizes. Moreover, the stretch and release of CNT-PDMS composite film due to gel amount variation slightly affected the thickness of CNT-PDMS, the acoustic frequency and the bandwidth, which are discussed in detail.