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Lithography of Aluminum Coated PVDF Annular Array for Photoacoustic Endoscopy

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Abstract. Focused transducers are frequently used in photoacoustic endoscopy (PAE) to ensure high acoustic resolution beyond the depth of optical diffraction. Although most transducers in PAE are ceramic and focus-fixed, we here propose the polyvinylidine fluoride (PVDF) based annular array to reduce the fabrication cost, and to allow dynamic focusing for increased depth of field. In this work, a method of direct lithography on the aluminum coated PVDF films was used for the annular array fabrication. The PVDF annular array was built with a 110 μm thick aluminum coated PVDF film, which contained three independent rings of equal width within a 5.5 mm aperture size. Phantom experiments were conducted for field test, and a simple linear model was used to compare the acquired results in the acoustic field test. The device was used for demonstration in PAE application. Potential applications of the proposed method include the PAE imaging of several large human organs and lumens such as the gastrointestinal tract and the cervical canal.

AMS subject classifications: 65C20, 65D30, 68U20

Key words: Polyvinylidine fluoride, annular array, photoacoustic endoscopy, mask-and-etch method.

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1 Introduction

Photoacoustic endoscopy (PAE) is one of the most important methods in the fast developing technology of photoacoustics, in which a focused transducer is generally used for

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high spatial imaging beyond the depth of optical diffraction [1–4]. Although most current transducers for medical applications are ceramicbased, the development of PVDF-based transducers is attracting attention because of the wideband frequency response, low impendence, and considerable flexibility of these devices [5, 6].

Generally, focused PVDF transducer can generally be categorized in two types: lens focused and self-focused. The lens focused transducer usually employs a solid acoustic lens attached in front of the PVDF element [3, 4]. In self-focused transducer, the PVDF piezoelectric element is directly spherically shaped for point focusing [7]. However, attaching an acoustic lens to the PVDF element can significantly reduce the transducer sensitivity. Furthermore, because the focal lengths of these two kinds of transducers are fixed, the lateral resolution will degrade quickly as the image plane fall out of focal zone.

Therefore, more interest has been directed to develop PVDF annular array for extend the field of depth. In this configuration, a series of concentric rings are applied with different delays to dynamically change the focusing depth, and an acoustic focusing spot up to sub-millimeter can be obtained [8–12]. To date, PVDF annular arrays have been employed in ultrasound and back-reflect scanning photoacoustic microscopy, and studies of varies annular array designs have been reported [11, 12].

In this paper, we for the first time to proposethe lithography on commonly useda-luminum coated PVDF films to build the annular array for PAE imaging, instead of a commonly used ceramic based focal fixed transducer for improved field of depth. The materials used in this method are cheap, and the fabrication process is simple. The PVDF array built with this method had a hole at its center for light illumination with a multi-mode fiber to facilitate backward photoacoustic detection. The acoustic field characteristics of the built array were measured, which was compared with the results from a simple linear acoustic calculation model, and finally phantom experiments were conducted to demonstrate its applications in PAE imaging.

2 Materials and methods

2.1 Device fabricatio

The fabrication process and the crosssectional structure of the proposed aluminum coated PVDF annular array is shown in Fig. 1. In this method, the annular array pattern was first inversely printed on a mask film. In the following step, a thin layer of photosensitive ink was uniformly painted on the aluminum coating of the PVDF film. After being dried in open air, the photosensitive ink layer was covered with the mask film and was exposed to UV light. Then, the annular array pattern on the photosensitive ink layer was developed with acetone, and 1% HCl was used in etching the aluminum coating. Thereafter, the remaining photosensitive ink layer was taken off, and wires were bonded to the etched annular electrodes with conductive epoxy (E-Solder 3022, Von. RollIsola, CT). Finally, the wired PVDF film was wired, shielded and sealed in aluminum alloy housing with non-conductive epoxy as the backing material, and the center hole was drilled sequentially.