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Abstract

AN ACOUSTICALLY-TRANSPARENT ELECTRICAL CAP FOR PIEZOELECTRIC ULTRASOUND TRANSDUCERS ON SILICON †

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Abstract: Bulk piezoelectric ultrasound transducers on integrated circuits offer unique properties for therapeutic applications of ultrasound neuromodulation. However, current implementations of such transducers are not optimized for the high transmit efficiency required to stimulate neurons. This is mainly due to the challenge of implementing a metal layer on top of the piezoelectric film using microfabrication techniques. Here we propose a micromachined capping structure providing an electrical connection on top of the piezoelectric film with minimal acoustic losses. The structure can potentially be used as a common ground connection in phased-array ultrasound transducers.

Keywords: ultrasound transducer; piezoelectric; microfabrication

1. Introduction

Therapeutic neuromodulation is a promising biomedical application of focused ultrasound, which compared to imaging introduces design emphasis on high transmit efficiency and small form factor [1]. Bulk piezoelectric transducers afford higher transmit efficiency than conventional micromachined ultrasound transducers [2]. However, the integration of bulk piezoelectric film on integrated circuits (ICs) using microfabrication techniques is challenging due to the film thickness. This is especially the case when considering a shared ground terminal connection to the top of the film. Current implementations of such top connection introduce acoustic losses detrimental to the output pressure of the transducer [3]. To overcome these challenges, we propose a microfabricated conductive membrane suspended on a silicon frame as top-level electrical connection. The thickness of the frame can be matched to that of various piezoelectric films.

2. Materials and Methods

The conductive membrane consists of a thin, sputtered Al(1%Si)/Ti layer supported by a polydimethylsiloxane (PDMS) layer. PDMS was chosen by virtue of its mechanical flexibility and suitable acoustic properties, matching those of soft tissues.

Figure 1 depicts the fabrication process of the cap structure, which starts with thinning down a double-side polished 300 μm-thick silicon wafer to match the thickness of the desired piezoelectric film using deep reactive ion etching (DRIE). Next, a 4 μm-thick PECVD silicon dioxide layer was deposited on the front side of the wafer, followed by the sputtering of a 400/40 nm-thick aluminum/titanium layer. Using DRIE, the silicon was etched from the back until landing on the silicon dioxide, creating the membrane and contact openings. Then, PDMS was spin-coated and cured on the aluminum layer. The oxide layer was removed by using buffered HF (1:7), and the wafer was diced (Figure 2(a)). The contact openings were filled with conductive paste to create conductive vias through the silicon frame. Finally, the cap structure was mounted onto the existing ground pad of an IC, with the membrane in contact with the top of the piezoelectric layer as shown in Figure 2(b).

3. Results and Discussion

The integrated system showed good performance. Resistance measured across the Al/Ti/PDMS membrane was 5.7 Ω, which introduced a voltage drop of 0.05 V at operating current with 10 V driving voltage. Preliminary results prove that the proposed cap structure can provide an effective electrical connection to the piezoelectric film, generating a clear ultrasound signal as recorded by a hydrophone (Figure 2(c)). Further testing and optimization will be conducted to tune the output pressure and characterize different thicknesses of PZT for different ultrasound frequencies.

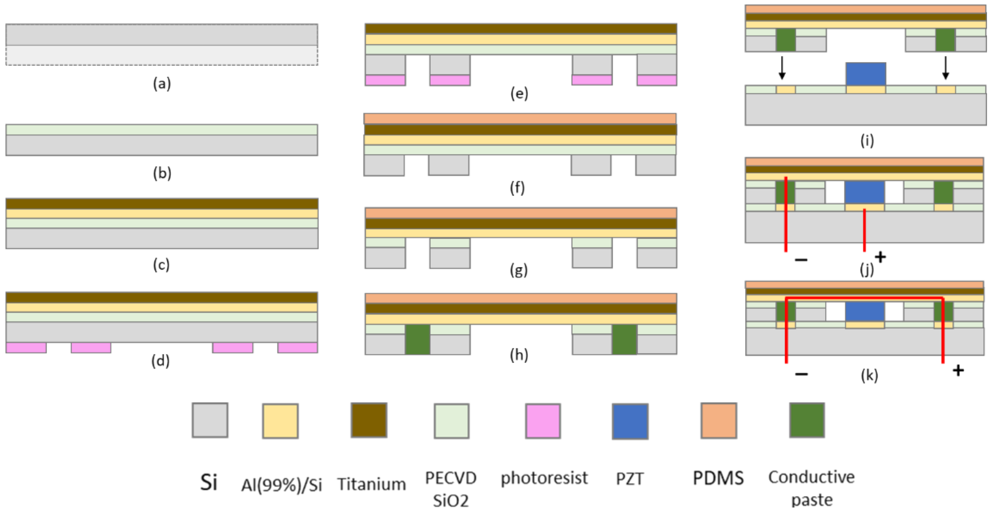

Figure 1. Fabrication and assembly of the capping structure. (a) Thinning down of silicon wafer to match the piezoelectric film thickness. (b) Deposition of PECVD SiO_2. (c) Sputtering of Al(99%)/Si(1%) and Ti. (d) Backside patterning of positive photoresist (AZ 12XT-20PL). (e) Backside DRIE of the Si wafer. (f) Spin-coating of PDMS on the front side of the wafer. (g) Etching of SiO_2 using BHF (1:7). (h) Filling of the contact groove with conductive paste. (i) Assembly of the top-level connection on a test chip. Lead zirconate titanate (PZT) was used as piezoelectric material. (j) Terminal configuration to drive the transducer. (k) Terminal configuration to measure the electric resistance of the membrane.

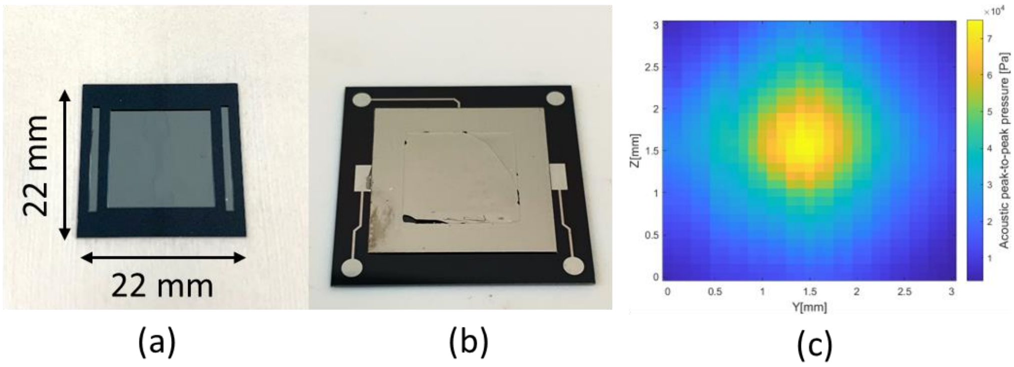

Figure 2. (a) Bottom-view of the proposed cap structure, (b) cap structure assembled on top of a test chip with PZT. (c) Measured pressure profile of the assembled transducer (focal distance: 10 mm).

Conflicts of Interest: The authors declare no conflict of interest.

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