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Abstract

Additive Manufacturing Electronics for Packaging High-Frequency Aluminum Nitride Piezoelectric Micromachined Ultrasonic Transducer Probes †

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Abstract: Additive Manufacturing Electronics (AME) is a promising method that has the potential to directly embed piezoelectric micromachined ultrasonic transducer (PMUT) probes into conventional electronic circuits and boards. It enables fast customized prototyping, three-dimensional circuit boards, and small-series production. In this study, annular probes composed of circular suspended Aluminum Nitride (AlN)-based PMUT membranes, addressed in 2-dimensional arrays, were designed, fabricated, and encapsulated using AME technology.

Keywords: additive manufacturing electronics; PMUT; aluminum nitride; ultrasonic probes

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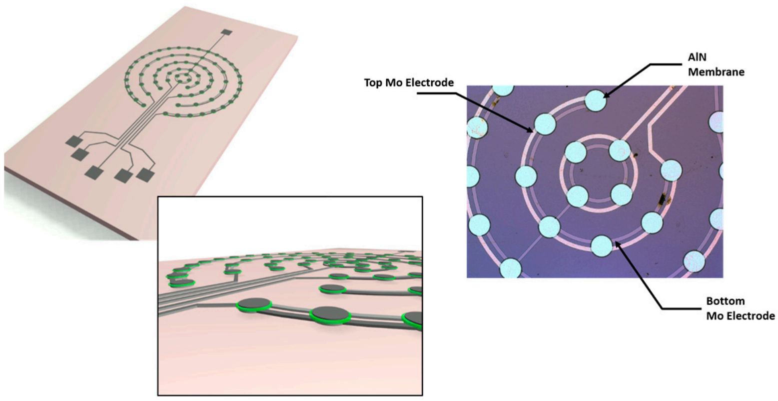
1. Introduction

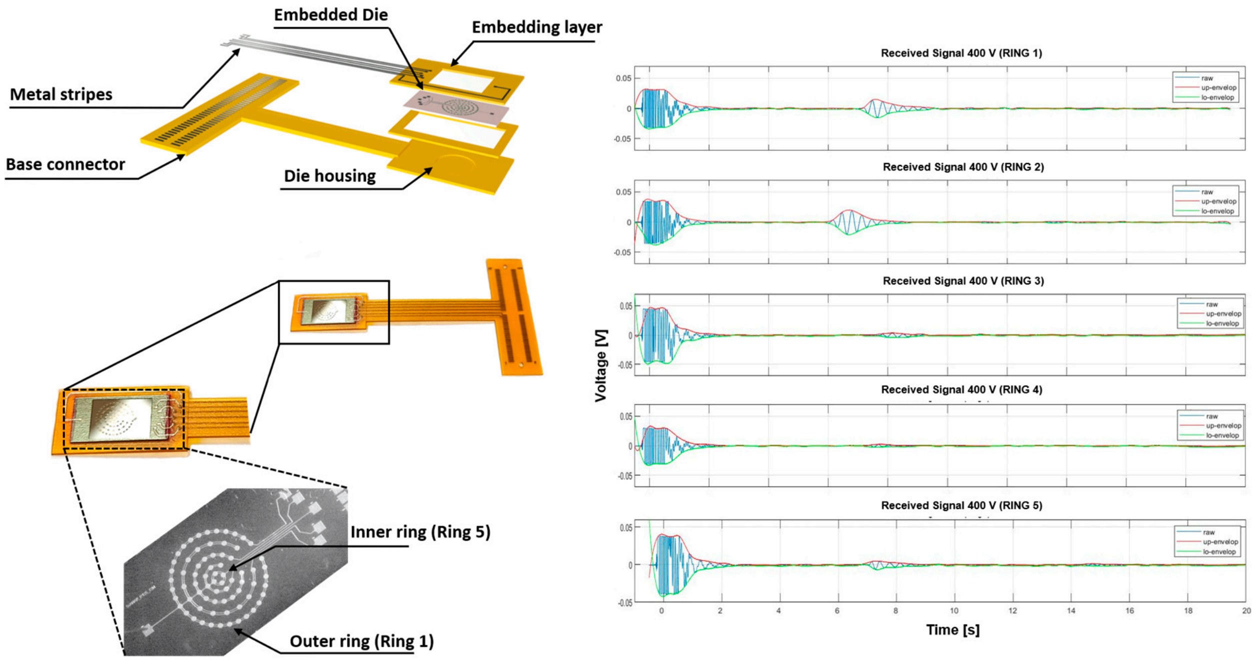
Medical imaging applications frequently involve scanning human body tissues using high-frequency ultrasonic transducers (2–15 MHz). Micromachined ultrasonic transducers (MUTs) have replaced traditional piezo-ceramic devices [1] in high-resolution imaging because of their small size, the low cost during production, and integration with conventional circuitry and CMOS technology. They enable a higher level of sensing capability and allow an overall decrease in device dimensions, thus becoming extremely attractive for mass manufacturing. Flexural membranes with circular, annular, or dome shapes can be used to develop MUTs, which can be activated using various transduction methods. Among them, capacitive (CMUT) [2,3] and piezoelectric (PMUT) [4–7] arrays have been extensively studied. In particular, PMUT probes have evolved significantly in recent years due to the substantial improvements in piezoelectric thin-film technology and miniaturization. The main advantages of PMUTs include higher sensitivity, faster response times, and greater design flexibility. Nevertheless, encapsulating small-size PMUTs is still subject to several constraints. In this regard, Additive Manufacturing Electronics (AME) is a promising method that has the potential to directly combine PMUTs into conventional electronic circuits [8–13]. It would enable fast customized prototyping, three-dimensional circuit boards, and small-series production.

2. Materials and Methods

In this study, annular 2D arrays composed of circular suspended Aluminum Nitride (AlN)-based PMUT membranes were designed and fabricated. Silicon was used as the structural substrate. The thickness of the suspended membranes (t_m = 25 µm, including the AlN film and structural silicon) and their radii (r_m = 100 µm) were accurately engineered to operate at a central frequency of 6 MHz (Figure 1). The AlN-based disks (1µm thick), embedded between two molybdenum electrodes (300 nm thick), were organized in annular arrays (as shown in Figure 1a). The final size of the probe was 6 mm, including up to 72 micro-membranes.



(**a**)



(i) (ii)

(**b**)

Figure 1. (**a**) Annular probe with AlN membranes arranged along five circular rings; (**b**) 3D design of package with final probe encapsulation and transmission measurement in time domain for 1st resonance mode in liquid (Ring 1 is the outer and most populated ring, and Ring 5 is the inner and less populated one).

The PMUT arrays were directly packaged and electrically connected using AME technology. The packaging was printed using Nano Dimension's DragonFly IV® system, whose manufacturing protocol was adequately optimized. AME technology enabled automated probe alignment with a very thin packaging board (500 µm thick) and a direct electrical connection to signal PADs, preventing standard wire bonding (Figure 1b(i)).

3. Results and Discussion

A pulser/receiver and a commercial immersion transducer (1 MHz bandwidth and 5 MHz nominal frequency) were used to analyze the transmitted ultrasound. Negative driving pulses (400 V amplitude, 1 kHz repetition frequency, 30 ns pulse duration) were used to drive each ring separately, while the probe, entirely isolated by a parylene C covering, was immersed in liquid. Figure 1b(ii) shows the emitted signals at a distance of 1 cm from each ring of the annular array (the upper and lower envelopes—red and green traces, respectively—are also reported).

These preliminary results show that the integration of high-frequency PMUT probes and miniaturized architecture using additive manufacturing technology is a promising approach to develop advanced sensors for various ultrasound applications.

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

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