SILICON CARBIDE MEMBRANES FOR MICROELECTROMECHANICAL SYSTEMS BASED CMUT WITH INFLUENCE FACTORS

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I. INTRODUCTION

Microelectromechanical Systems (MEMS) based capacitive micromachined ultrasonic transducer (CMUT) has many applications in medical imaging [1]. Ultrasonic transducer technology has been long dominated by piezoelectric transducers, particularly in the medical ultrasound imaging. The best popular materials used for fabricating CMUT membranes are silicon nitride (Si_3N_4), polysilicon, chromium and aluminum are characteristically used to shape electrodes on top of these membranes. But current technology of CMUT demands the silicon carbide (SiC) for membrane material where the electrode instead of being on top of the membrane is placed beneath the membrane. It offers greatest contiguity of the upper and subordinate electrodes. For this it decreases the transduction gap enlightening the electro-mechanical coupling and sensitivity of the device. Aside from this, it is reported that the CMUT has a resonance frequency of 1.7 MHz and a 3 dB-bandwidth of 0.15 MHz. Also, the higher Young's modulus (260 GPa) of SiC with its little residual stress (± 30 MPa). Consequences in great strength and resilient CMUT membranes, which led to the studies presented in this paper. All the results are validated by FEM simulation.

II. PROPOSED MODEL

The SiC membranes based CMUT with a membrane radius of 55 μm consists of six layers. A single cell CMUT consists of a silicon carbide layer as the vibrating membrane and an electrode made of aluminum which acts as the top electrode, followed by a cavity which acts as an electrostatic transduction gap. A second electrode is formed using aluminum with more thickness to form the lowermost electrode. A layer of dielectric Si_3N_4 film as an insulator is introduced among the cavity and the lowermost electrode to prevent the two electrodes from shorting in case of contact. The bottom layer is silicon dioxide acting as a substrate on which all the above layers are formed. The materials used and their thicknesses taken for the structural modeling of the device is given in Table 1.

Table 1. Materials used with thickness

Material Used	Thickness	Layer
Silicon Carbide (SiC)	2 μm	Top membrane
Aluminum (Al)	60 nm	Top electrode
Cavity (Air)	450 nm	Electrostatic transduction gap
Aluminum (Al)	300 nm	Bottom electrode
Silicon Nitride (Si_3N_4)	500 nm	Dielectric film as an insulator
Silicon Dioxide (SiO_2)	2 μm	Substrate

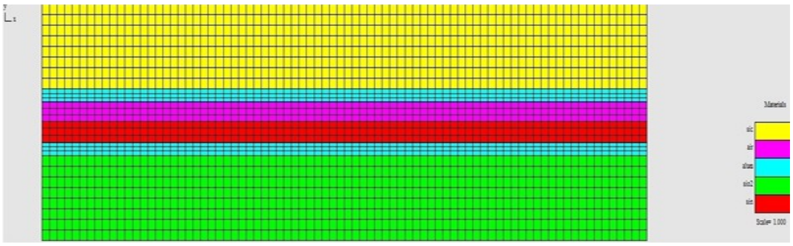

Figure 1. FEM simulated 2D model of SiC CMUT element

The modeling of the device is first carried out by calculating the equivalent capacitance of the device. Although in previous studies like in literature there are two capacitances one of which is contributed by the vibrating membrane and the other by the insulating material, while in this studies the two capacitances are contributed by the transduction gap and the insulating material since the top electrode is beneath the membrane as discussed in the first section. Also, a 2D view of the device simulated using PZFlex based on the finite element method is also provided in Fig. 1. The coupling factor, also known as the *k* factor of an electromechanical transducer is its capability to transform electrical into mechanical energy, and vice versa. As soon as the CMUT functions as a transmitter with an electrical input, the coupling factor *k* is the ratio of amount of mechanical energy transported to the load to whole energy put in storage in the device.

III. RESULTS & DISCUSSION

Characterization of the device to maximize its performance in terms of sensitivity, energy conversion efficiency and operating point, the capacitance behavior, coupling factor, and collapse voltage of the CMUT are analyzed based on mathematical model. Smaller gap thickness and insulator thickness represent smaller spacing between the two electrodes producing greater field force (voltage across the plates) and a superior flux (charge composed on the plates) for any voltage applied across the two electrodes which result in larger capacitance. Materials with high dielectric constant have greater permittivity which allows them to proposal less disagreement to field flux for a specified amount of field force than materials with less permittivity. All these results can be understood from simple observation of conventional capacitor plates, an estimation of capacitance for any pair of disconnected conductors can be computed with the analytical model. All the results are validated by FEM simulation. The device capacitance calculated for the CMUT at a 55 μm membrane radius is 0.1627 pF producing a force of 1.264 μN.

As the coupling distance (effective gap distance) increases, the coupling capacitance will decrease reducing the intensity of the output energy. In CMUT the membrane transports in the direction of the applied electric field and the membrane vibration in the transverse direction is negligible [2]. Also in a CMUT, the coupling distance is a function of both the gap distance and insulator thickness. It is found that the coupling factor of the proposed device at a 40 V DC bias voltage is 0.383 i.e., the coupling efficiency of the CMUT is 38.3%. When the surface tension increases, it shrinks the membrane surface area causing the coupling capacitance to decrease which leads to a reduction in the coupling factor.

Many studies shown that CMUTs can operate both in the conventional mode and collapse mode [3]. The collapse voltage calculated is 78.06 V with a coupling factor of 0.7, this means the operating DC bias strongly dictates the performance of the transducer by improving the coupling factor. From the characteristics of collapse voltage, we can understand that the collapse voltage is lower for a larger membrane radius and increases when the membrane thickness is increased respectively. This is because the spring constant of the membrane decreases making the membrane less stiff and increases make the membrane stiffer that means higher elasticity. Here also, all the results are validated by FEM simulation.

IV. CONCLUSIONS

The general behaviour of silicon carbide membranes capacitive micromachined ultrasonic transducers with its influence factors is demonstrated in this paper. The device capacitance depends on the transduction gap thickness, insulator thickness, membrane radius, and the material used as an insulator. A larger device capacitance means greater force generated by the membrane, which means higher sensitivity. So, to get a high sensitive CMUT the transduction gap and the insulator layer thickness must be very small with a large the membrane radius and the material used as an insulating layer must have high relative permittivity. This paper also presents the coupling factor (k_w^2) and how it is affected by the collapse voltage. This observation tells us that, increasing the membrane thickness as we increase the membrane radius and balancing the two can give high capacitance and high coupling factor resulting in better sensitivity and efficient energy conversion of the device, provided the effective gap distance is as small as possible. A finite element analysis can be performed using FEM simulators. These simulated results can be associated with the outcomes presented in this paper for future generation and design of CMUTs.

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