Residual Stress in the Silicon Membrane of Circular CMUT

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Abstract

During last twenty years capacitive micromachined ultrasonic transducers (CMUT) have been developed extremely fast [1-2]. CMUT is an attractive alternative to traditional piezoelectric transducer, which converts electrical signal to mechanical vibration and vice versa. The main advantages of CMUT compared to most common solution: wide bandwidth (improved image resolution) and compatibility with standard CMOS processes (potentiality could be integrated with electronic circuits on the same wafer). At this moment CMUT are mainly used in ultrasound imaging technic [2], but it also could be used for exciting and receiving acoustic waves in air [3] and solids, for example Lamb waves in silicon substrate [4].

The present work aims at describing nonlinear behavior of circular CMUT with regard to residual stress state to be determined. Additionally we investigated the influence of residual stress on such technical parameters of the CMUT as eigenfrequency, capacitance, coupling, collapse voltage and input impedance.

There are two main ways to fabricate CMUT: sacrificial release process and wafer bonding technology [2]. In this paper [5] we used anodic bonding of a silicon on insulator wafer on a glass wafer for CMUT fabrication with four different membrane radius: 50 um, 70 um, 100 um and 150 um. The experiment consisted of measuring the membrane deflection and resonance frequency of the membrane after fabrication with zero dc bias voltage. Some discrepancies, strongly tied to the membrane radius, were noted compared to the theoretical values issued from analytic calculations (error up to 57% for 150 um radius). Also it was found that the center of the membrane had non-zero deflection, resulting from relaxation of residual stress. This stress appear due to two stage fabrication process: wafers bonding and Si film release. In the case of relatively small membrane deflections (<0.2 of membrane thickness), the membrane displacement is proportional to the applied force. For larger deflections midplane stretching leads to nonlinear relationship between displacement and force [6], in our case it was observed as eigenfrequency increasing for membrane with radius of 100 um and 150 um.

For analysis we used reduced two dimensional axisymmetric CMUT model (Figure 1) and electromechanics modeling. We defined bending stress distribution in silicon using equation: $Sr=S0/(h/2)*z$, where Sr is radial component of stress, h is thickness of silicon membrane, S0 is stress in upper surface of membrane and z is perpendicular distance to the midplane axis. Other stress components are equal to zero.

The value of bending stress was obtained from analysis of the deflection center of the membrane and CMUT resonance frequency for different values of the bending stress. The results for different radius and for both approaches are quite similar. The average value of amplitude of bending stress is 75 MPa. After the residual stress definition, collapse voltage, capacitance, coupling and input impedance were calculated. The calculated result is in a good agreement with experimental results (Figure 2).

Our future plans include using this data for further modifying of the fabrication process and residual stress reduction.

Reference

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Figures used in the abstract

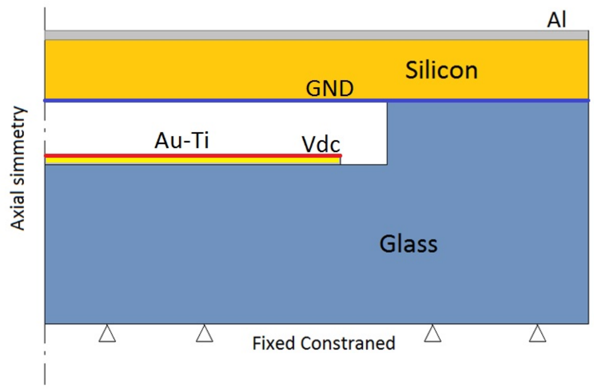

Figure 1: Cross sectional view of CMUT cell with applied mechanical and electrical boundary conditions

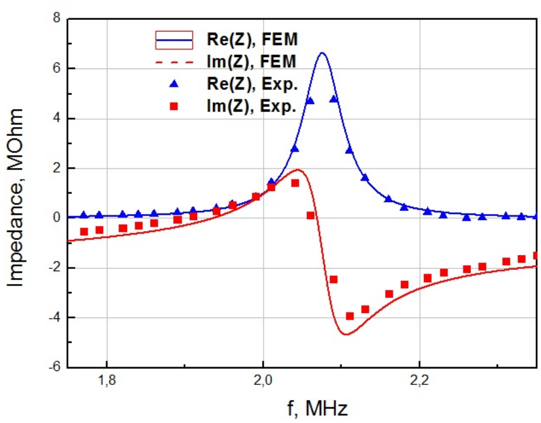

Figure 2: Experimental and simulated input impedance of single circular CMUT with 50 um radius. Bias voltage is 150 V

Figure 3

Figure 4