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The Comprehensive Analysis on Various Strategies and Development of Ultrasonic Transducers

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Abstract – We have composed, created, and described two-dimensional 16x16-component capacitive micro machined ultrasonic transducer (CMUT) exhibits. The CMUT cluster elements have a 250-µm pitch, and when tried in drenching, have a 5-Mhz focus recurrence and 99% fragmentary bandwidth. The creation procedure is dependent upon standard silicon micromachining systems and consequently has the focal points of high yield, ease, and simplicity of reconciliation. The transducers have a Si3n4 film and are created on a 400-µm thick silicon substrate. A low parasitic capacitance through-wafer by means of interfaces every CMUT component to a flip-chip bond cushion on the rear of the wafer. Each through-wafer by means of is 20 µm in measurement and 400 µm profound. The interconnects structure metal-encasing semiconductor (MIS) intersections with the encompassing high-resistivity silicon substrate to secure disengagement and to lessen parasitic capacitance.

Each through-wafer by means of has under 0.06 pf of parasitic capacitance. We have researched an Au-In flip-chip holding methodology to unite the 2d CMUT exhibit to a specially coordinated circuit (IC) with transmit and accept electronics. To create this methodology, we created fan out structures on silicon, and flip-chip fortified these test kicks the bucket to a level surface covered with gold. The normal arrangement safety for every knock is about 3 Ohms, and 100% yield is gotten for what added up to 30 knocks.

Capacitive micro machined ultrasonic transducers (Cmuts), presented around a decade back, have been indicated to be a great elective to customary piezoelectric transducers in different angles, for example, affectability, transduction proficiency, and bandwidth. In this paper, we talk about the standards of capacitive transducer operation that underlie these angles. A hefty portion of the key characteristics of capacitive ultrasonic transducers are empowered with micromachining innovation. Micromachining permits us to scale down unit extents and produce capacitive transducers that perform similarly to their piezoelectric partners. The creation procedure is depicted quickly, furthermore the execution of the CMUT transducers is assessed by exhibiting characterization results. It is indicated that the transduction proficiency as characterized by the electromechanical coupling coefficient could be near solidarity with fitting apparatus plan and working voltage.

It is likewise demonstrated that Cmuts give substantial bandwidth (123% partial bandwidth)! in drenching requisitions which make as high transient and pivotal determination. At last, the possibility of utilizing Cmuts is exhibited by indicating imaging cases in air and in drench.

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INTRODUCTION

Electrostatic transducers have long been being used for sound wave excitation and discovery (Kuhl 1954; Hunt 1982). The central mechanism of the transduction is the vibration of a meager plate under electrostatic powers. Numerous macro scale apparatuses utilize this mechanism for producing and sensing sonic waves. A condenser microphone is the most well-known illustration. In the most straightforward manifestation of this unit, a flimsy metal film is extended above a back electrode shaping a little hole. This structure constitutes a capacitor, which is charged by a dc voltage connected through a substantial resistor. The point when the unit is laid open to sound waves, the crevice tallness is tweaked at the same recurrence of the approaching weight field. This incites a change in the unit capacitance, producing a yield voltage corresponding to the plentifulness of the field. The capacitor structure can likewise be utilized to create sound waves. In the event that the predisposition film is determined by an air conditioner voltage, a symphonious field is created in the sound-bearing medium. The striking point of interest of the electrostatic units thought about to alternate sorts of transducers, for example, piezoelectric and magneto strict is the characteristic impedance match between the transducer what's more the encompassing medium. The low-mechanical impedance of the film is generally insignificant. This outcomes in exceptionally effective coupling of the sound waves into and from the sound-bearing medium.

Later propels in the silicon micromachining systems empowered the manufacture of microelectro-mechanical systems (MEMS) based electrostatic transducers (haller and Khuri-Yakub 1996; Soh et al. 1996; Ladabaum et al. 1998). Scaling down capacity of the silicon micromachining procedure made the creation of gadgets working at ultrasonic frequencies conceivable. These gadgets are called capacitive micromachined ultrasonic transducers (Cmuts). Cmuts are made of little and flimsy films that are suspended over a conductive silicon substrate by protecting posts. The breadth of the film ranges from 10 mm to several micrometers. The crevice between the layer also the substrate is vacuum fixed or left unsealed at will and it might be as little as 500 Å. The films are either conductive or covered with a conductive electrode and basically make little capacitors together with the substrate. This structure brings about exceptionally productive transducers that can contend with their piezoelectric partners regarding productivity and bandwidth.

Since its idea in the mid-1990s, the capacitive micro machined ultrasonic transducer (CMUT) has turned into an progressively swearing up and down to alternative to the piezoelectric transducer. A CMUT is made out of a slight layer backed by sidewalls over a dainty cavity. Commonly, numerous layers are joined in parallel to structure a solitary component. These layers are covered with a layer of metal, and structure capacitors with the back plate. The films are predisposition with a DC voltage, and vibrate when an AC voltage is connected, along these lines creating ultrasonic waves. These capacitors are additionally used to sense impinging ultrasonic waves. In the event that the electric field over the pit of the CMUT arrives at the size of something like 108 V/m, the CMUT turns into an effective electromechanical transduction mechanism.

Advanced micromechanical electrical systems (MEMS) engineering empowers the manufacture of vacuum cavities with statures of under 0.1 µm. Electrical field quality on the request of 108 V/m is effectively accomplished by applying a couple of tens of DC predisposition volts over the vacuum depression. Notwithstanding the high transduction productivity, Cmuts have wide bandwidth in inundation provisions, and could be effectively created to blanket a wide run of working frequencies. Additionally, innate to the standard silicon micromachining procedure, Cmuts revel in high yield, high consistency and low unit cost. At last, Cmuts could be coordinated with the front-end electronics utilizing interconnection methods, for example, through-wafer vias and flip-chip holding. These incorporation systems could be minimized, and with the consideration of front end electronics, moderate the misfortunes because of interfacing link

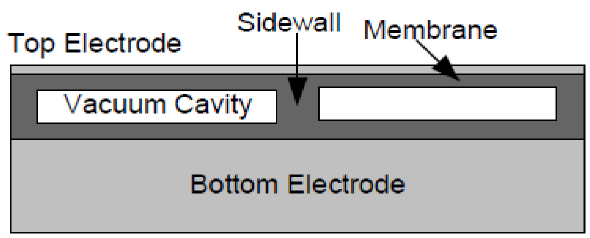

Figure : A simplified schematic of a CMUT.

FUNDAMENTAL OF ULTRASONIC CONCEPTS

Sound generated above the human hearing range (typically 20 kHz) is called ultrasound. However, the frequency range normally employed in ultrasonic nondestructive testing and thickness gaging is 100 kHz to 50 MHz. Although ultrasound behaves in a similar manner to audible sound, it has a much shorter wavelength. This means it can be reflected off very small surfaces such as defects inside materials. It is this property that makes ultrasound useful for nondestructive testing of materials.

The Acoustic Spectrum in Figure breaks down sound into 3 ranges of frequencies. The Ultrasonic Range is then broken down further into 3 sub sections.

Ultran has achieved an authoritative position in the ultrasonic industry by continually introducing innovative solutions to very complex problems. This is the result of combining two critical elements. The first element is Ultran's inter-disciplinary team of scientists and engineers in a comprehensive laboratory facility. Equally important is a very close and confidential working relationship with our customers.

CMUTs are made of thin membranes which are essentially parallel plate capacitors with a gap between the plates. Figure is a schematic drawing of the cross section of a typical membrane. The conductive silicon wafer on which the membrane is fabricated make up one of the plates of the capacitor. The other plate of the capacitor is the metal electrode on top of the membrane.

The membrane is supported with insulating posts. The membrane is generally made of an insulating material, most commonly silicon nitride (Si_3N_4), and coated with a metal electrode. However, the membrane can be made of a conductive material in which case the metal top electrode is not necessary. Optionally, the top electrode can be coated with an insulating material such as low temperature silicon dioxide (LTO) to provide electrical isolation from the surrounding medium.

Characterization connected with Through-Wafer Interconnects Various test structures are included in the mask layout to independently characterize the CMUT elements and the through-wafer interconnects. To easily test the performance of the CMUTs, array elements without the through-wafer interconnects are fabricated on the same wafer as the regular 2D arrays. Stand-alone through-wafer interconnects are also fabricated on the same wafer to test the interconnect resistance and capacitance.

The metal-insulator-semiconductor structure is extensively studied in semiconductor solid-state physics. The high frequency capacitance of such a structure depends on whether it is operated in the accumulation region or inversion region, and can be expressed as

$$C_{accumulation} = C_O = \frac{K_O \varepsilon_o A}{x_o}, \qquad (1)$$

$$C_{inversion} = \frac{C_O}{1 + \frac{K_O W_T}{K_S x_o}}, \qquad (2)$$

where C_0 is the parallel plate capacitance of the insulator. A_0 is the insulator dielectric constant. $£_0$ is the permittivity of the free space. A is the electrode area. x_a is the insulator thickness. W_T is the maximum depletion width in the bulk silicon, and K_s is the silicon dielectric constant.

A transducer is any device that converts one form of energy to another. An ultrasonic transducer converts electrical energy to mechanical energy, in the form of sound, and vice versa. The main components are the active element, backing, and wear plate.

The required dc bias is applied to the CMUT through a bias tee which essentially adds the dc and the ac voltages as previously shown in Fig. In all the characterizations that will be discussed here, a similar biasing circuitry is used.

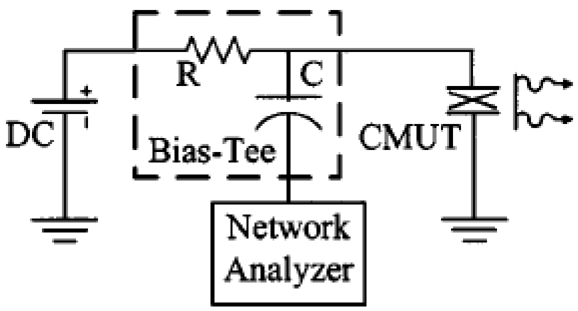

Figure: Schematic of experimental setup used for input impedance measurements

CONCLUSION

CMUTs have emerged in the last decade as a means of generating and detecting acoustical signals by using electrostatic principles. It has been shown that CMUTs can operate comparably to their piezoelectric counterparts both in air and immersion. In this paper, we described the basic principles of operation of CMUTs together with measurement results. We showed that we can indeed predict the behavior of CMUTs beforehand, and design for specific targets. We also described the fabrication process in its simplest form which is based on a wet sacrificial release process.

Finally, we demonstrated the feasibility of using CMUTs in ultrasound applications by showing some imaging results both in air and immersion.

Two-dimensional 16xl6-element CMUT arrays with through-wafer interconnects were designed, fabricated, and tested. The arrays with 150-|im element pitch are suitable for a miniature volumetric medical imaging system used in a 5-mm endoscopic channel. The fabricated devices present uniform resonant frequencies when measured in air. When tested in immersion, the center frequency is close to 5 MHz. and the 3-dB fractional bandwidth is 99%. The peak output pressure at the surface of the transducer is 100 kPa when excited by a 100-ns. 30-V pulse. Pulse-echo measurements were taken for the CMUT with a custom transmit and receive IC. The transducer elements are addressed individually by the through-wafer vias. Tlie through-wafer via has a parasitic capacitance of less than 60 fF. and a series resistance of 20 Q. Preliminary tests show a Au-In flip-chip bonding process provides low bond resistance and 100% yield. A real-time volumetric imaging system based on these 2D CMUT arrays will be demonstrated in the near future.

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