A MEMS Microphone Using Levitation Force

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Primary CNF Tools Used: LPCVD N+/P+ Polysilicon-Wet Oxide-CMOS Nitride, MOS clean anneal, Heidelberg mask writer DWL2000, AS200 i-line stepper, Plasma-Therm deep Si etcher, Oxford 80+-100 etchers, Oxford PECVD, Zeiss Ultra SEM, dicing saw, Leica critical point dryer

Abstract:

We report fabrication and preliminary experimental results of a microelectromechanical systems (MEMS) microphone using a levitation force-based electrode configuration. This electrode scheme causes the sensing electrode (attached to a diaphragm) to move away from the biasing electrode as DC source is applied. The devices employing this scheme benefit from pull-in free behavior. Main objective of this work is to fabricate a MEMS microphone whose sensitivity could be improved simply by increasing the bias voltage, without suffering from pull-in instability. The microphone was fabricated at CNF and tested in Binghamton University anechoic chamber. The output of the chip at various bias voltages are measured using a read-out circuit. Experimental results show that the sensitivity of the device increases with increasing bias voltages from 40 volts to 100 volts. The ability to design electrostatic sensors without concerns about pull-in failure can enable a wide range of promising sensor designs.

Summary of Research:

A microphone is an acoustic sensor that converts mechanical motions generated by sound pressure waves into electrical signals. Every year, billions of MEMS microphones have been produced and integrated into consumer products such as smartphones, laptops, hearing aids, smart wireless speakers etc. The sensitivity of the microphone is one of the most important parameters that defines the quality of a microphone. In general, the sensitivity is proportional to the applied bias voltage. However, usual electrode configurations (one fixed and one moving electrode) mostly suffer from pull-in instability, which causes the device stop functioning after some certain DC bias values. The levitation (repulsive) electrode configuration has been widely investigated and shown to be pull-in safe [1-3], which enables MEMS devices to have large travel ranges and proper functioning at high DC loads. This method utilizes fringe electrostatic field to generate a net force that pushes the diaphragm away from the substrate which eliminates the pull-in possibility. The microphone design consists of fixed and moving electrodes which are attached to a rotating diaphragm, see Figure 1. The design includes three sets of electrodes: grounded sensing electrodes, grounded fixed electrodes and biasing electrodes. The moving and fixed electrodes are vertically separated.

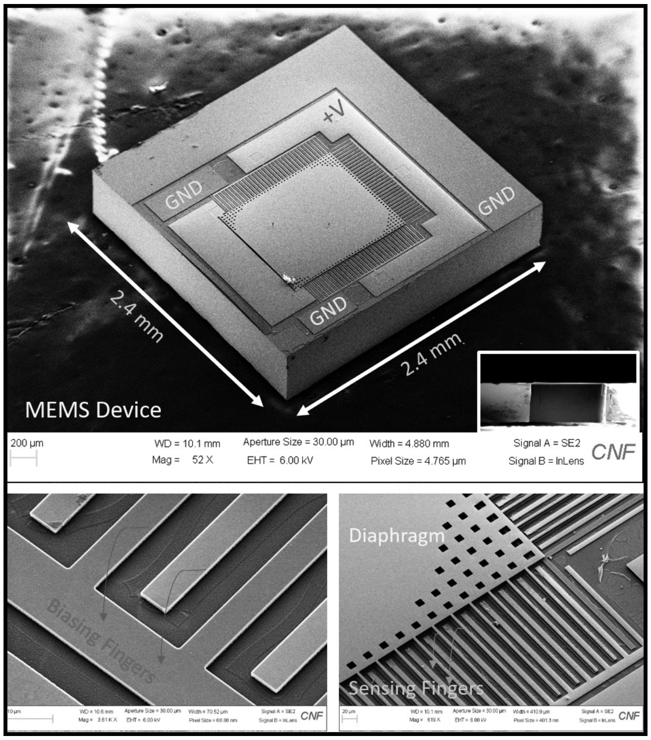

Figure 1: Images of the fabricated device. (Top) SEM image of the microphone and the cross section of the released chip. (Bottom Left) Biasing fixed fingers. (Bottom Right) Moving Finger and the diaphragm.

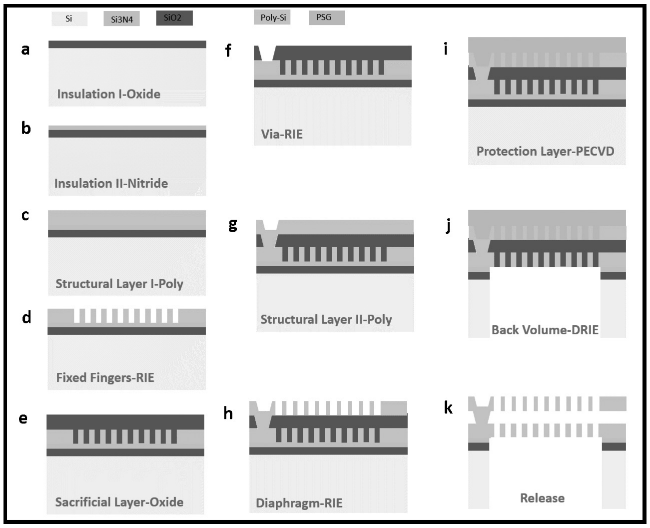

Figure 2: Fabrication process flow of the sensor.

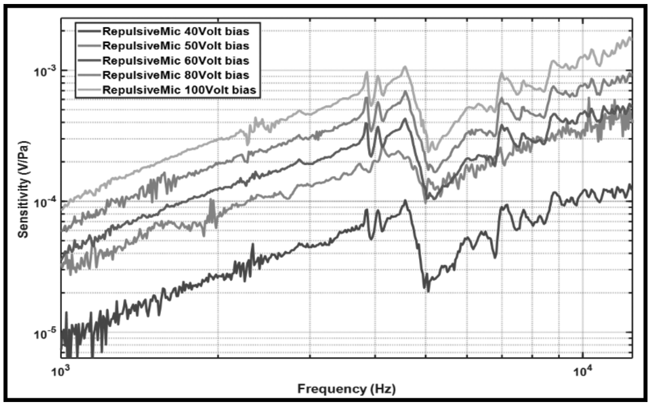

Figure 3: Experimental results. Shows the change of sensitivity of the microphone as the DC bias increases.

Process flow for the fabrication of the MEMS microphone is depicted in Figure 2. We started with 100 mm silicon wafers and grew 1 µm thick LPCVD silicon dioxide as an insulation layer. Following this step LPCVD low stress silicon nitride was deposited on top of the oxide layer. On top of the insulation layers 2 µm thick polysilicon layer was deposited and annealed using LPCVD furnace. This layer was etched using Unaxis 770 silicon etcher to form fixed fingers, Figure 3. On top of the fingers, 4 µm thick sacrificial layer of LPCVD high-temperature-oxide (HTO) was deposited. Then, Logitech Orbis chemical mechanical polisher (CMP) was used to remove half of the oxide layer which yielded around 2 µm vertical gap between fixed and moving electrodes. Then, Oxford 100 etcher is used to create vias on this sacrificial layer. Later, second 2 µm thick polysilicon layer was deposited and annealed to reduce the residual film stresses. This layer was etched to form the diaphragm and the sensing electrodes.

Next, we deposit phosphosilicate glass (PSG) using Oxford PECVD tool. This layer mechanically supported the diaphragm while etching the back-volume of the device. The back volume was created by etching the bulk silicon using Plasma-Therm deep silicon etcher. Then, wafers were diced into 2.4 mm by 2.4 mm chips, which are then released in HF:HCl mixture and critical-point-dried.

After the microphone was released the chip was glued on a printed-circuit-board (PCB) and wire-bonded. A charge amplifier-based read-out circuit was used to obtain electrical signals. The acoustic tests for the microphone were performed in the anechoic chamber at Binghamton University. We applied various DC voltages to the biasing electrodes. This DC voltage created an out-of-plane motion to the diaphragm and increased the initial gap between the diaphragm and the fixed electrodes. The sound pressure was created by a loudspeaker by sweeping a broad range of pure tone signals (100 Hz-20 Khz). The incident pressure measured using a Bruel&Kjaer 4138 reference microphone. The electronic output from the chip was detected using a charge amplifier read-out circuit. The circuit consisted of an operational, capacitors and feedback-resistors. The sensitivity plot was obtained by measuring the output voltage relative to the sound pressure. The signals were acquired using a National Instruments Data Acquisition System.

Figure 3 shows the measured electrical response of the microphone for a wide range of bias voltages. It is shown that levitation electrode concept improves the sensitivity of a MEMS microphone simply by increasing the DC bias voltage without any pull-in failure.

This approach can enable designs that employ large bias voltages without adversely impacting the diaphragm's mechanical response.

References:

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