A MEMS Repulsive Force Accelerometer

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Primary CNF Tools Used: Heidelberg mask writer - DWL2000, LPCVD N+/P+ polysilicon -wet oxide-CMOS nitride, MOS clean anneal, AS200 i-line stepper, Unaxis 770 deep Si etcher, Oxford 81-100 etchers, Logitech Orbis CMP, Zeiss Ultra SEM, SC4500 evaporator, RTA - AG610, DISCO dicing saw, Leica critical point dryer

Abstract:

This study reports fabrication and experimental characterization of a microelectromechanical systems (MEMS) capacitive accelerometer that utilizes repulsive force electrode configuration consisting of three fixed and one moving electrode. This configuration generates a net upward force on the moving electrode that is attached to a movable proof mass. The net force pushes the moving structure away from the substrate and produces an out-of-plane motion. Having this design comes with various benefits such as elimination of pull-in instability that severely limits functioning of electrostatic devices and causes permanent structural damages. This repulsive configuration concept has been investigated for actuator applications; however, it has not been employed for sensing purposes in the literature. Our goal is to create an accelerometer that works based on the repulsive sensing concept. The accelerometer is designed and fabricated with four-mask process. Following the fabrication, it is fixed on a shaker and tested under various DC bias and excitation levels to characterize its dynamic behavior. Laser Doppler Vibrometer (LDV) is used to measure its dynamic response under base excitation provided by the shaker. At 2.5 kHz excitation frequency, we measured the mechanical sensitivity of the sensor as 0.17, 0.13, and 0.09 μm/g at 40-50-60 V bias, respectively. Experimental results indicate that sensitivity of the accelerometer is the function of operating DC bias, excitation level and the excitation frequency. One can tune the sensitivity of the device by playing with these variables without experiencing pull-in instability, which is a great contribution.

Summary of Research:

The repulsive electrode configuration has been shown to be pull-in safe [1], which enables MEMS devices to have large travel ranges and proper functioning at high DC loads [2]. This method utilizes fringe electrostatic field to generate a net force that pushes away the proof mass from the substrate which eliminates the pull-in possibility. Main goal of this project is to exploit the benefits of utilizing repulsive electrode design in a capacitive sensor. The sensor design consists of fixed and moving electrodes which are attached to a rotating proof mass, see Figure 1. The design includes three sets of electrodes: grounded moving fingers, grounded aligned fixed fingers and voltage loaded unaligned fixed fingers. The moving and aligned fixed fingers are vertically separated with 2 μm initial gap.

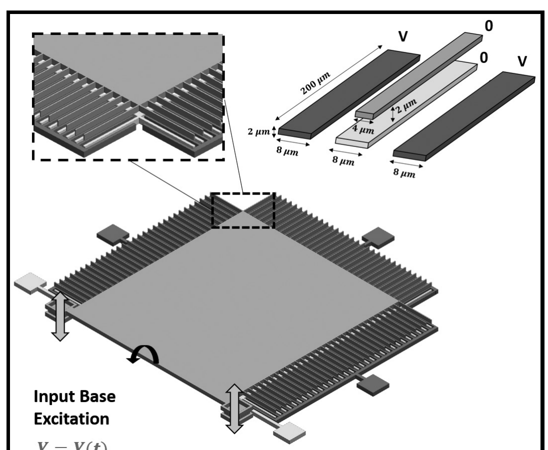
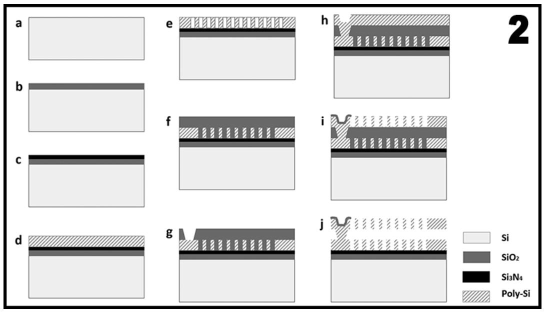
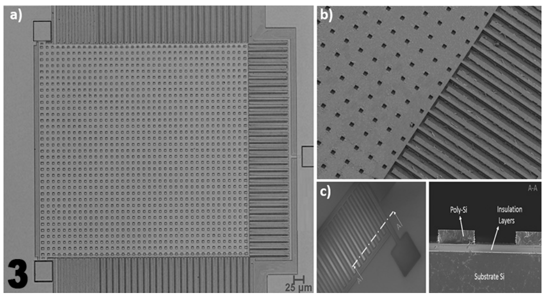


Figure 1: 3D model of the designed sensor showing the details of the proof mass and the electrodes.

The fabrication process flow of the accelerometer is shown in Figure 2. The process starts with a 100 mm silicon wafer. First, LPCVD silicon dioxide is grown as an insulation layer. Following this step,





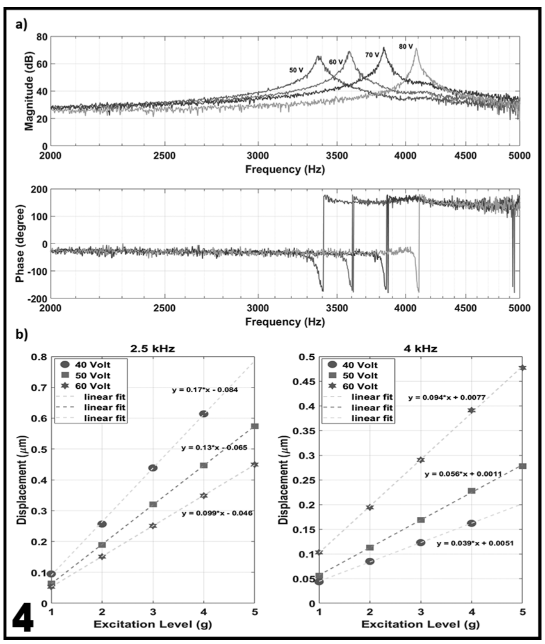


Figure 2, top: *Fabrication process flow of the sensor. (a) 4-inch, 525 µm thick silicon wafer. (b-c) Insulation layers growth and deposition, respectively. (d) First layer of 2 µm thick phosphorus doped polysilicon deposition. (e) RIE etch of polysilicon. (f) Sacrificial layer deposition and CMP processes. (g) Anchor etch on sacrificial layer. (h) Second 2 µm thick polysilicon deposition. (i) Polysilicon etch and gold deposition on the pads. (j) Proof mass release in HF:HCl mixture.* ***Figure 3, middle:*** *Images of the fabricated device. (a) Top view of the proof mass. (b) Moving and fixed fingers for the released device. (c) Fixed fingers and the cross-sectional view.* ***Figure 4, bottom:*** *Experimental results. (a) Shows the transfer function of the device which is performed to measure the resonance frequency of the sensor under various DC bias. (b) Shows the mechanical sensitivity (slope) of the sensor.*

LPCVD low stress silicon nitride is deposited on top of the oxide layer. After deposition of insulation layers first structural polysilicon layer is deposited using LPCVD furnace. Unaxis 770 plasma etcher is used to form fixed fingers out of this layer. On top of these fixed fingers, a sacrificial layer of LPCVD high-temperature-oxide (HTO) is deposited. Then, Logitech Orbis chemical mechanical polisher (CMP) is used to remove the step difference between fixed fingers and the proof mass. After the CMP process, vias are formed by etching the oxide layer using Oxford PlasmaLab 100 etcher. Later, second polysilicon layer is deposited and followed by annealing to reduce the residual film stresses. This layer is etched to form the proof mass attached with fingers and suspending torsional springs. Next, we deposit Cr and Au on the pads using evaporation tool SC4500 evaporator. After the evaporation process the wafers are diced and released in HF:HCl mixture. The fabricated device is presented in Figure 3.

The device is attached and wired to a PCB that is mounted on the head of a shaker. The device is excited in a vacuum environment. The side fingers are applied a DC bias while the shaker is vibrating with an AC harmonic signal which is the source of the base excitation. Laser Doppler vibrometer interfaced with data acquisition box is used to monitor the time-response of the device. The results are presented in Figure 4. Figure 4a shows the change of the resonance frequency of the device as the DC bias changes. Due to the fringe electrostatic forcing, as the DC load increases effective stiffness of the structure increases which results in shift of the resonance frequency. Figure 4b shows the relative motion of the proof mass when it is subjected to different excitation levels varying from 1g to 5g. Experimental results show that mechanical sensitivity (Figure 4b) of the device is the function of the applied DC bias and the frequency of the excitation. We are currently performing experiments to measure the response of the device to various shock impulses such as half-sine.

References:

[1] S. He and R. B. Mrad, "Design, Modeling, and Demonstration of a MEMS Repulsive-Force Out-of-Plane Electrostatic Micro Actuator", Journal of Microelectromechanical Systems, Vol. 17, no. 3, pp. 532-547, June 2008. doi: 10.1109/JMEMS.2008.921710.

[2] Towfighian S, He S, Ben Mrad R. "A Low Voltage Electrostatic Micro Actuator for Large Out-of-Plane Displacement.", ASME. IDETC/CIe, Vol. 4: doi:10.1115/DETC2014-34283.