DESIGN, SIMULATION AND FABRICATION PROCESS OF A SOI BASED 2-DOF VIBRATORY GYROSCOPE

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This paper reports the design, simulation and fabrication process for a 2-DOF decoupled vibratory gyroscope. The structure is deliberately designed to have decoupled drive and sense mode oscillation to prevent unstable operation due to mechanical coupling, resulting in low zero rate out-put drift. At the same time, the closer the drive and sense resonances are, the higher is the angular rate resolution of the gyroscope. This can be achieved by using symmetric suspensions, but it results in reduced bandwidth. The proposed design has been configured to achieve about 150 Hz bandwidth, while ensuring decoupled operation of the drive and sense modes. Fem analysis has been carried out in CoventorWare® MEMS DESIGN software and simulation results show that the drive resonance occurs at 21.48 kHz and sense resonance at 21.63 kHz. The structure is designed for 15 µm this device layer. Fabrication of the design is proposed using DRIE and sacrificial release etching on SOI wafer. DRIE etching with high aspect ratio has been successfully carried out as desired and the results have been presented.

Keywords: MEMS, SOI, CoventorWare®, FEM.

Introduction

MEMS technology, as one of the most promising technologies in the present technological scenario, has attracted researchers from all parts of the globe and the advancements are taking place at a very fast pace. One of the reasons for the rapid developments in MEMS domain is the adoption of the well-established IC fabrication technology, for the realization of MEMS devices. Among the various MEMS devices, gyroscope is one such device which has vast application areas, few of them being consumer products, automotive, defence, aerospace etc.

MEMS vibratory gyroscope consists of two orthogonal components of accelerometers with a single common proof mass or multiple masses. These gyroscopes are based on the principle of transfer of energy form the drive mode to the sense mode due to Coriolis acceleration, in the event of an angular rate input [1]. With the advancement of MEMS technology, various gyroscope structures were proposed and realized. Based on the application, micro-machined gyroscopes have been broadly divided into three categories: 1) Rate grade gyroscope, 2) Inertial grade gyroscope and 3) Tactical grade gyroscope [1, 2]. Plenty of work has been reported regarding rate grade gyros due to their wide commercial application. The technologies employed in the fabrication of such devices are surface micromachining, bulk micromachining and up to some extent electroforming based on LIGA process [3]. However, inertial grade and tactical grade gyroscope devices are relatively complex to fabricate, as they are high performance devices required to meet stringent specifications. Other alternate fabrication processes are being employed besides conventional processes in order to meet the stringent technical requirements. The designing of the gyro devices is of paramount importance in order to render the devices immune to fabrication variations and to avoid extra fabrication trials.

Inertial sensors can be fabricated by using various micromachining technologies such as surface micromachining [4], wet bulk micromachining [5] and machining by DRIE process [6, 7]. One of the main advantages of DRIE process is that high aspect ratio devices can be realized with nearly vertical sidewalls. The advantages of DRIE process are exploited by the use of Silicon-on-Insulator substrates. SOI substrates have a layer of silicon with a very fine tolerance, separated from the bulk substrate using an oxide layer. The oxide layer is formed by thermal oxidation of the bulk substrate and acts as a di-electric. The structure is formed in the top silicon layer and hence the thickness of the structural layer is accurately maintained. Moreover as the device is realized in single crystal silicon, the internal stresses are much less than deposited silicon layers. Further, due to the high selectivity between silicon and silicon-di-oxide in most DRIE machines, the etch stop is well defined and controlled. Several wet and dry release techniques have been reported to release the final structure. Hence the SOI process combines the advantages of DRIE and SOI substrate to precisely fabricate complex structures. In this paper we present the fabrication of 2-DOF gyroscope using SOI process.

Design

Figure1 shows the 3D model of the 2-DOF decoupled gyroscope structure. The anchors of the structure are located at the outer boundary of the device and connected to the movable drive and sense electrodes with the help of suspension beams. There are totally 16 beams in the design, 8 beams in the drive direction (x- direction) and 8 beam in the sense direction (y-direction). The suspension beams are designed and configured such that the drive and sense mode resonances are decoupled with their resonance frequencies separated to achieve a bandwidth of 150 Hz. This structural configuration exhibits minimum cross coupling effect. The design has two sets of stationary comb fingers, one set for the driving and the other set for sensing, that are anchored to the substrate as shown. The device is designed with perforations for sacrificial release of the structure.

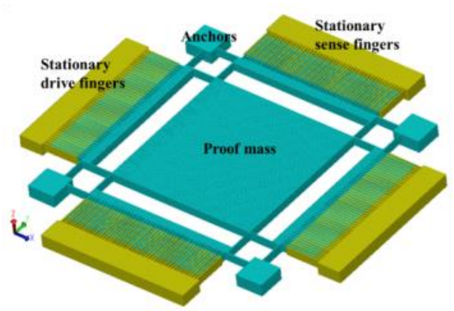

Fig. 1. Solid model of a 2-DOF vibratory gyroscope

FEM Simulation Result

The device is modeled and simulated in CoventorWare$^{®}$ MEMS design environment [8, 9]. Modal analysis is carried out to obtain the resonance frequencies and mode shapes of the device as shown in Fig. 2. The drive and sense resonance frequencies of the device are located at about 21.48 kHz (Fig. 2(a)) and 21.63 kHz (Fig. 2(b)).

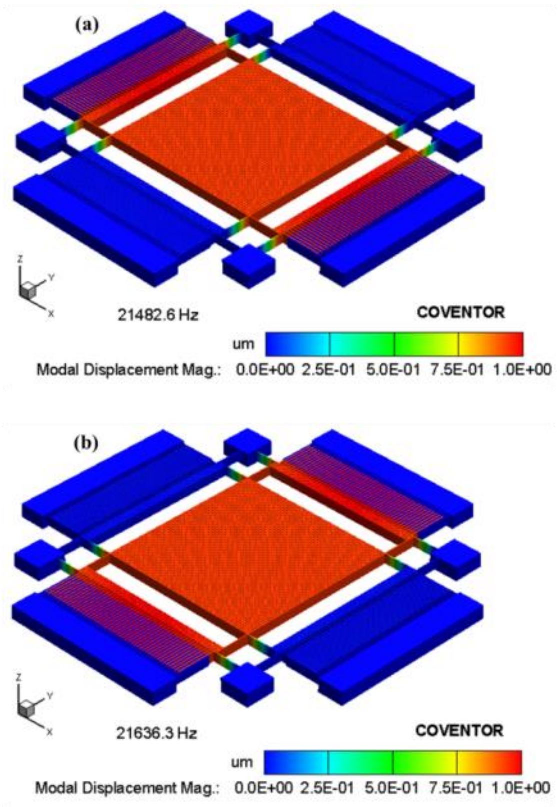

Fig. 2. FEA: Mode shape simulation of a 1-DOF drive mode and 1-DOF sense mode gyroscope

SOI Fabrication Process

- The proposed fabrication process uses Silicon-on-Insulator wafer with 15 μm device layer, 4 μm buried oxide and 675 μm handle layer as the starting material.
- The process uses Deep reactive Ion etching to realize high aspect ratio structure and finally the structure is released by sacrificial etching of the buried oxide using Vapor phase etching.
- Aluminum is deposited to a thickness of 10000 Å on the silicon device layer using sputtering process. Subsequently, lithography and etching is carried out selectively to realize the metal pads for wire bonding. The pads are located on the four proof mass anchors and on all the four stationary comb anchors.
- This is followed by Lithography of the structural layer and subsequently baking is done to harden the resist before it undergoes DRIE process.
- Silicon is etched up to buried oxide using controlled process parameters. At the end of this step, the structural layer is formed with the necessary metal pads.
- The structural layer is then released by sacrificial etching of buried oxide using Vapor phase etching process. The etching is time based and ensures perfect release of the structure while limiting the undercut to a minimum.
- The released devices are mechanically pushed using a probe to confirm release.

Result

As per the process flow described above, the device is fabricated using the two mask SOI process. Lithography process has been carried out to pattern the structure with a minimum feature size of 3 μm that is the gap between comb fingers. Microscope image of the device after lithography patterning is shown in Fig.3. The device layer including the proof mass, movable and stationary comb fingers is etched using DRIE with an aspect ratio of 1:5. The microscope image after DRIE is shown in Fig. 4 a,b, showing the comb fingers and perforations in proof mass. The sidewall angle is measured to be around 91.2 degree.

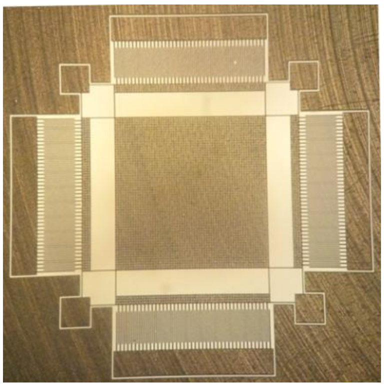

Fig. 3. Photolithography pattern of the device

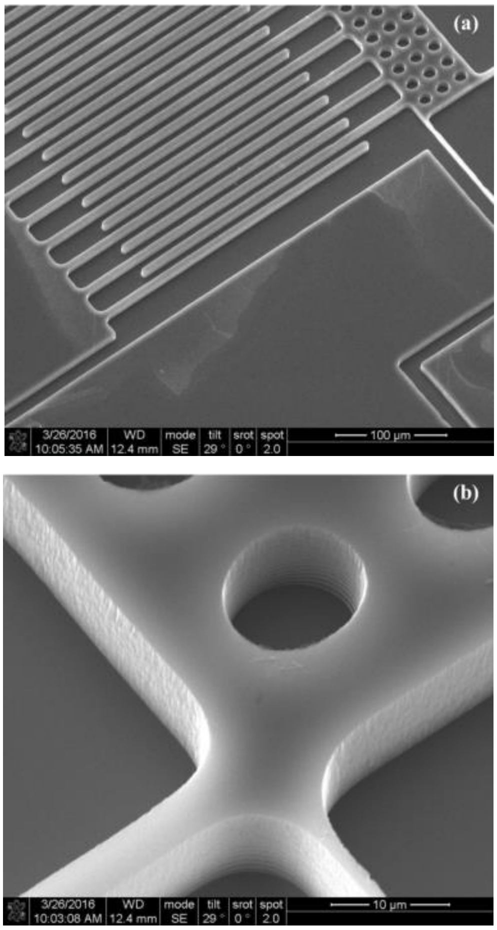

Fig. 4. Etching results

Conclusion

This paper presented the design, simulation and process flow of a MEMS vibratory gyroscope using a method employing the Deep Reactive Ion Etching of a SOI wafer. The device is designed to achieve decoupled drive and sense resonance modes and for SOI process compatibility. Two mask SOI process is proposed for fabrication of the device. The successful completion of lithography and DRIE which are two major steps of SOI process demonstrates the feasibility of realizing the 2-DOF gyroscope devices using the proposed SOI process.

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