



# MEMS Gyroscope Research based on UB Seed Grant

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## Abstract

In this poster, the research on a novel MEMS gyroscope device based on UB faculty seed grant support is introduced. MEMS (Micro-electro-mechanical Systems) vibratory gyroscopes have attracted tremendous interest among researchers due to their small size, low energy consumption, low cost and long life-time. In my research, I conceived a novel bulk-micromachined electrostatic comb-driven, differential capacitance sensing MEMS vibratory gyroscope based on glass-silicon-glass sandwich-structure. The novel structure eliminates the parasitic capacitances of the gyroscope, which greatly eases the signal sensing. Furthermore, due to the device structure design, the sensing vibration is not coupled to the driving vibration, which improves the device stability. The MEMS gyroscope research is funded by UB seed grant. Based on the research, we published 1 journal paper and 1 conference paper. The research also resulted in the submission of 4 grant proposals, leading to a total funding of \$60,016.77.

## Introduction

MEMS gyroscopes are inertial sensors used to sense the angular velocity or angular acceleration. Due to their small size, low cost and low weight, MEMS gyroscopes are used for inertial navigation of automobiles, aerospace vehicles, satellites, sailing, military missiles and consumer electronic products. For example, iPhone 4th generation (Apple Inc.) is the first smart phone equipped with a built-in 3-axis MEMS gyroscope. MEMS gyroscope can also be used for camera stabilization and signing a check midair.

The signal sensing of capacitive MEMS gyroscopes has been very challenging because their differential capacitance change are generally extremely small (<1fF). In this research, a bulk-micromachined MEMS vibratory gyroscope with glass-silicon-glass sandwich structure is proposed. The proposed gyroscope uses DRIE (Deep Reactive Ion Etching) technique so that the device thickness can be increased from several microns (in surface-micromachining) to hundreds of microns. As a result, the device capacitance can be significantly increased to ease the signal sensing. The gyroscope is based on glass-silicon-glass sandwich structure so that parasitic capacitance can be significantly reduced. Due to the increase of device thickness in bulk-micromachining, the stiction problem in surface-micromachining is avoided. The fabrication uses pre-etched channel in the backside of silicon for the releasing of movable microstructure. The proposed MEMS comb vibratory gyroscope is expected to have excellent performance with easy signal sensing.

## MEMS Vibratory Gyroscope Design

The top view of the proposed MEMS vibratory gyroscope is shown in Figure 1. The microgyroscope is based on glass-silicon-glass compound structure through silicon-glass anodic bonding technique. The dark areas are anchored to the glass substrate, and the areas in light color are floating 10 $\mu$ m above the glass substrates. The left and right driving fingers and the truss are connected to the anchors through folded driving beams. The sensing portion consists of four folded sensing beams and a central mass.

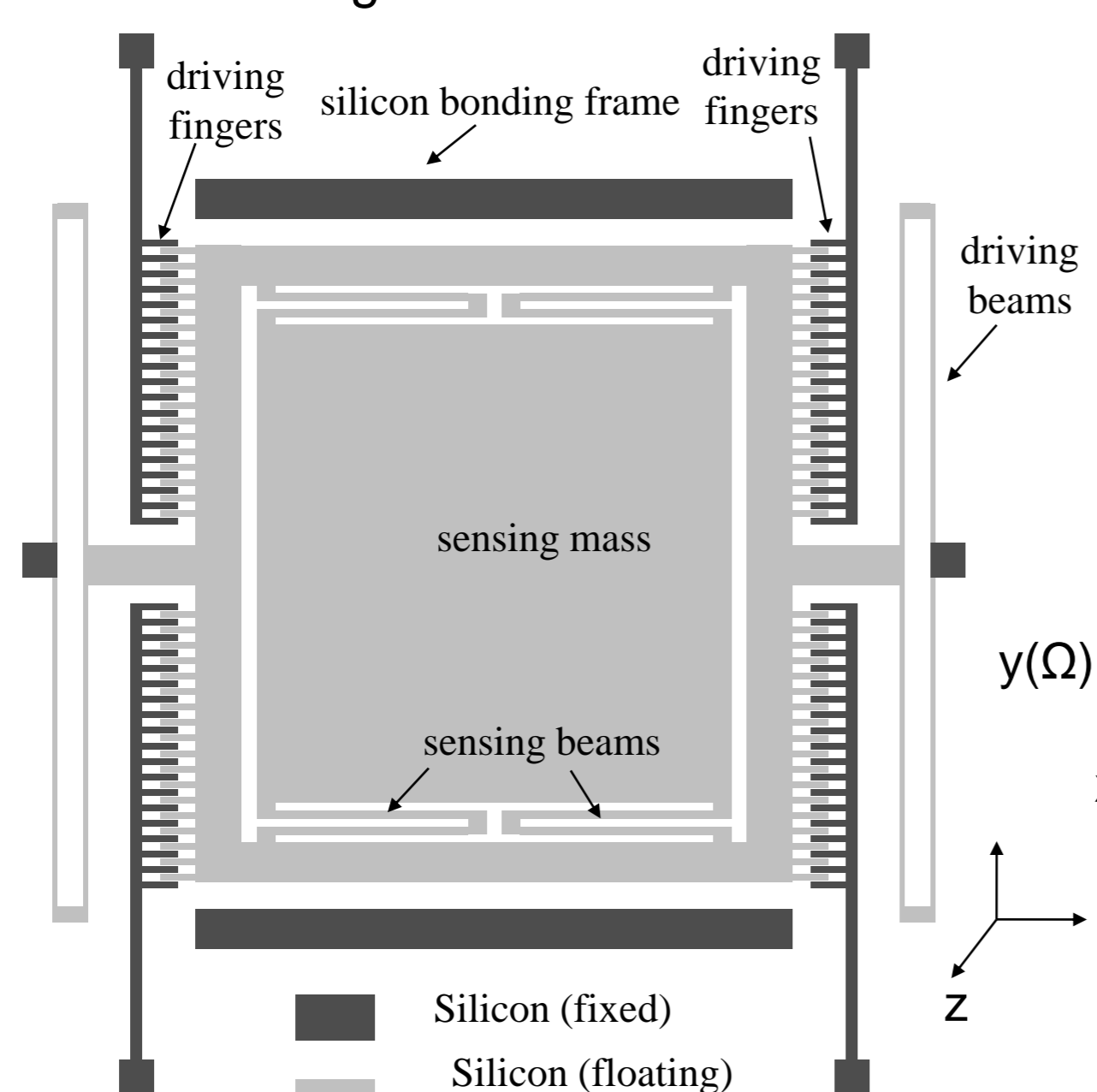


Figure 1: Schematic diagram of the proposed MEMS gyroscope

During operation, AC driving voltages are applied to the left and right fixed driving fingers. This induces alternating electrostatic forces on the movable driving fingers along x-direction in a "push-pull" mode. The truss along with central mass will vibrate along x-direction, which is the driving mode of the gyroscope. If there is an angular velocity along y-direction, the central mass experiences an alternating Coriolis force along z-direction. This in turn will activate the central movable mass to vibrate along z-direction, which is the sensing mode of the gyroscope. The sensing mass constitutes differential sensing capacitance with the aluminum electrodes on the top and bottom glass covers. Due to the sensing vibration, the sensing capacitance gaps change and the sensing differential capacitance also change. By measuring this differential capacitance change, the value of the angular velocity can be determined. This is the working principle of the proposed MEMS gyroscope.

## Design and Analysis of the Microgyroscope

A MEMS vibratory gyroscope generally involves two perpendicular vibration modes: driving mode and sensing mode. The gyroscope can be simplified as a mass suspended by springs along two orthogonal directions, as shown in Fig. 2.

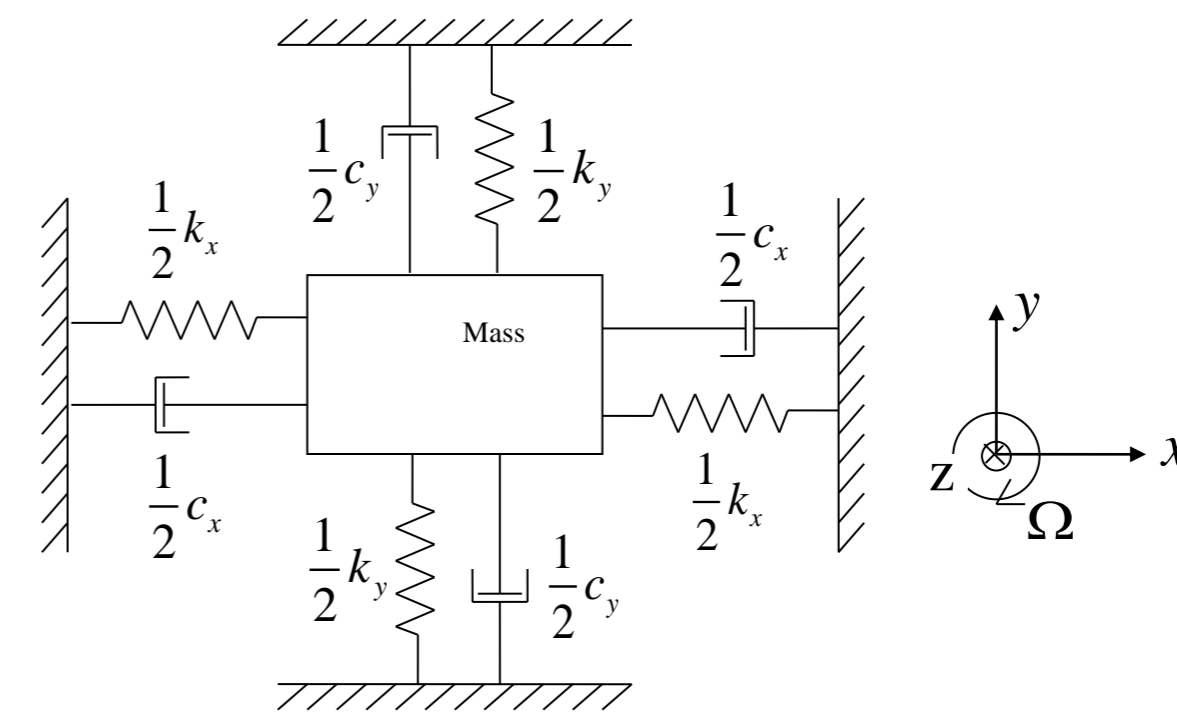


Figure 2: Working principle of a typical MEMS vibratory gyroscope

Theoretical model is used to analyze the performance of the device. The displacement sensitivity of the gyroscope is found to be

$$S_d = \frac{dy_m}{d\Omega} = \frac{2x_m}{\omega_y} \cdot \frac{\omega_x / \omega_y}{\sqrt{[1 - (\omega_x / \omega_y)^2]^2 + \frac{1}{Q_y^2} (\omega_x / \omega_y)^2}}$$

Based on the analysis, a set of optimized design parameters of the gyroscope are achieved, and the corresponding performance parameters of the gyroscope are shown in Table 1.

Table 1. Performance parameters of the designed microgyroscope

Performance Parameters	Values
Static sensing capacitance $C_0$	6.942pF
Driving mode spring constant $k_x$	8.476N/m
Sensing mode spring constant $k_z$	6.044N/m
Driving mode resonant frequency $f_x$	289.017Hz
Sensing mode resonant frequency $f_z$	302.102Hz
Displacement sensitivity $S_d$	105.9nm/(°/sec)
Capacitance sensitivity $S_c$	6.942fF/(°/sec)

ANSYS FEM simulation was used to simulate the gyroscope. The simulated resonant frequencies of the driving and sensing modes of the gyroscope are  $f_x=617.37$ Hz and  $f_z=675.46$ Hz, as shown in Figure3.

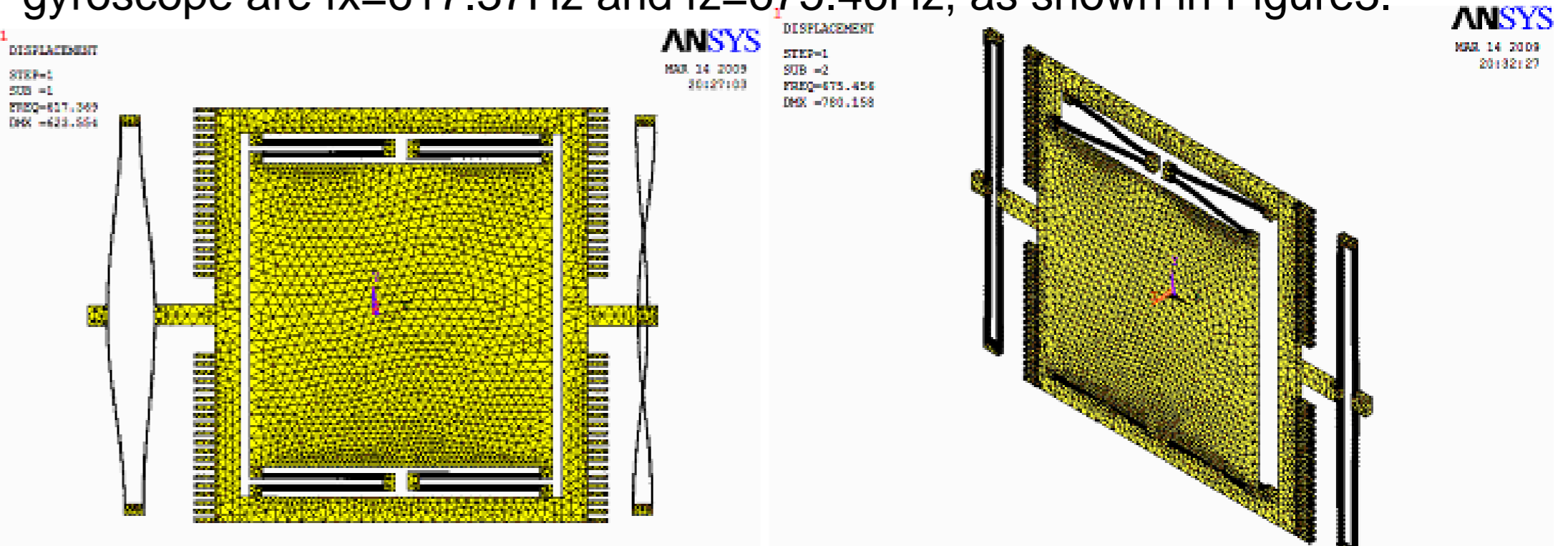


Figure 3: ANSYS simulation of driving and sensing modes of the gyroscope

## Research Outcome of the Project

This research was initially funded by the UB Seed Grant:

Xingguo Xiong (PI), Linfeng Zhang (co-PI), Hassan Bajwa (co-PI), "A Bulk-micromachined MEMS Comb Vibratory Gyroscope", funded by UB seed money grant, funding agency: University of Bridgeport, Period: 05/2009 - 05/2010, funding amount: \$6930.00.

As an outcome of this research, we have published 1 journal paper and 1 conference paper:

- X. Xiong, H. Dong, "Design of a MEMS Gyroscope with Glass-Silicon-Glass Sandwich Structure", *Journal of Micro and Nanosystems*, Vol. 3, No. 1, 2011, accepted, to be published.
- H. Dong, X. Xiong, "Design and Analysis of a MEMS Vibratory Comb Gyroscope", *2009 Northeast ASEE Conference*, Bridgeport, CT, Apr. 3-4, 2009.

Based on the research results from UB seed grant, we submitted 4 additional proposals, leading to a total equivalent funding support of \$60,016.77, as shown in Table 2.

Table 2: Grants resulted from UB seed grant research on MEMS gyroscope

No.	Grant	Funding Agency	Status	Funding amount
1	Xingguo Xiong (PI), Hassan Bajwa (co-PI), Linfeng Zhang (co-PI), "Bulk-micromachined MEMS Gyroscope", 10/01/2010.	Brookhaven National Lab	funded	\$40,000.00 (equivalent)
2	X. Xiong, Gould K450B Logic Analyzer Energy-Related Laboratory Equipment (ERLE) grant, 01/16/2011.	U.S. Department of Energy (DOE)	funded	\$20,016.77 (equivalent)
3	X. Xiong (PI), co-PIs: P. Patra, H. Bajwa, L. Zhang, NSF proposal: "MEMS Gyroscope with Glass-Silicon-Glass Sandwich Structure", 10/07/2010.	National Science Foundation (NSF)	pending	\$242,254.00
4	L. Hmurcik (PI), X. Xiong (co-PI), "A Novel MEMS Comb Vibratory Gyroscope for Aerospace Application", NASA faculty research grant, 05/2010.	Connecticut Space Grant College Consortium	Not funded	\$50,117.00
<b>Total</b>				\$60,016.77 (funded)

## Conclusions and Future Work

In this poster, we introduced our research about a novel bulk-micromachined MEMS gyroscope based on glass-silicon-glass sandwich structure. Initial research was supported by UB seed grant. Based on the research results, we published 1 journal paper, 1 conference paper, submitted 4 additional grant proposals, leading to a total funding support of \$60,016.77. In the future, we will continue to work on the fabrication of the gyroscope, involve more students in the research, publish more papers and submit more grant proposals.