M3P.069

A DOUBLY DECOUPLED MICROMACHINED VIBRATING WHEEL GYROSCOPE

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ABSTRACT

In this paper, a doubly decoupled vibrating wheel gyroscope with novel torsional sensing comb capacitors is presented. The doubly decoupled design and symmetrical structure can efficiently suppress the mechanical coupling of the gyroscope. Moreover, the symmetrically distributed proof masses make it immune from the linear accelerations. Both driving and sensing modes of the gyroscope are dominated by slide film air damping, so it can work even at atmospheric environment. The process for this gyroscope is also compatible with z-axis gyroscope, which makes it potential to realize low cost monolithic MIMU (miniature inertial measurement unit) without vacuum packaging. The gyroscope was fabricated and tested at atmosphere. The sensitivity is 3.1mV/°/s while the nonlinearity is 7.68‰ with the full scale of 900°/s. The noise floor is 0.45°/s/Hz$^{1/2}$.

KEYWORDS

Lateral axis, gyroscope, doubly decoupled

INTRODUCTION

Owing to the advantages on size, weight, cost, power consumption, micromachined gyroscopes are becoming more and more attractive for applications on inertial navigation, automobile safety systems, robotics, consumer electronics, and so on. In the last two decades, various micromachined gyroscopes have been developed.

In order to improve the overall performance of a gyroscope, mechanical coupling between the driving and sensing modes must be suppressed. A decoupled structure is an efficient and low cost approach to suppress the undesired coupling [1-4], which can suppress not only the CFDTS (coupling from driving mode to sensing mode) but also the CFSTD (coupling from sensing mode to driving mode). Many doubly decoupled z-axis gyroscopes have been successfully implemented [1-3]. However, because the lateral-axis gyroscopes have to deal with out-of-plane motions, the doubly decoupled design becomes complicated.

In our previous work, benefiting from the torsional sensing comb capacitors, a doubly decoupled lateral axis gyroscope has been successfully demonstrated [4]. However, like most of the reported MEMS gyroscopes, it is sensitive to linear accelerations along its sensing axis. Therefore, in practical use, it needs either two gyroscopes driving in anti-phase or complicated signal conditioning circuits to cancel out the effect of linear accelerations. Vibrating wheel or tuning fork gyroscopes can minimize the influence of linear accelerations [2, 5, 6], but most of them can only work well in vacuum packaging. In this paper, a doubly decoupled micromachined vibrating wheel gyroscope is presented, which can not only be immune from the linear accelerations along its sensing axis, but also work at atmospheric environment.

STRUCTURE DESIGN

The schematic diagram of the proposed gyroscope is shown in Fig.1. The gyroscope comprises a circular inner frame (driving mass), a rectangular outer frame (sensing mass), a circular frame between them (proof mass), two groups of driving springs, two groups of sensing springs, one anchor in the centre and two anchors outside. The driving and sensing springs connect the inner anchor, driving mass, proof mass, sensing mass and outer anchors, respectively. All of the structures are symmetrical along y-axis. It should be noted that the proof mass is wider in the x axis than in the y axis so as to obtain larger inertia moment about y-axis.

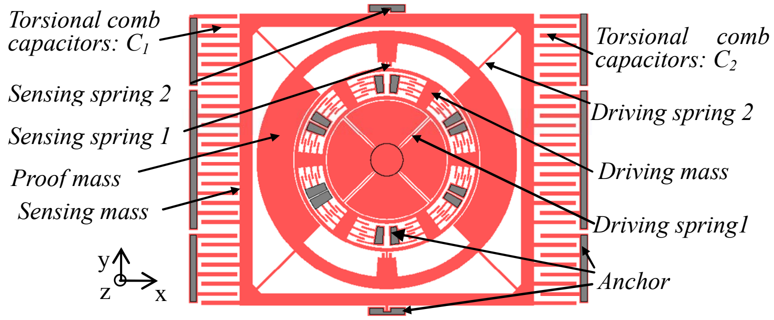

Figure 1: Schematic of the vibrating wheel gyroscope.

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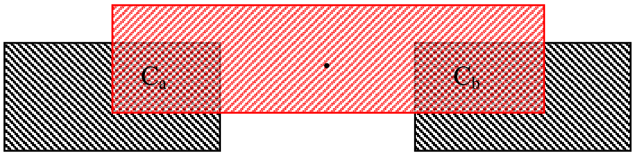
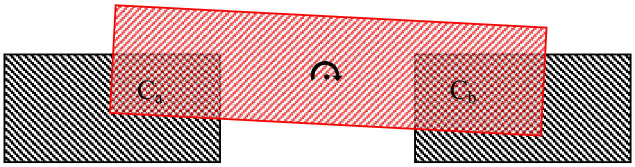
The working principle of the gyroscope is explained as follows. In the driving mode, the inner driving mass and the proof mass are driven to vibrate about z-axis. When there is an angular rate input along x-axis, the proof mass will torsionally vibrate around y-axis due to the induced Coriolis acceleration, which will force the sensing mass vibrating accordingly. Only the motions of the proof mass are coupled by both driving mode and sensing mode. The motions of driving mass and sensing mass are isolated. That is, the gyroscope is doubly decoupled from the undesired mechanical crosstalk. Moreover, because the structure is fully symmetrical about y-axis, any acceleration along z-axis cannot cause rotation around y-axis. Consequently, the structure can immune from the linear accelerations along its sensing axis.



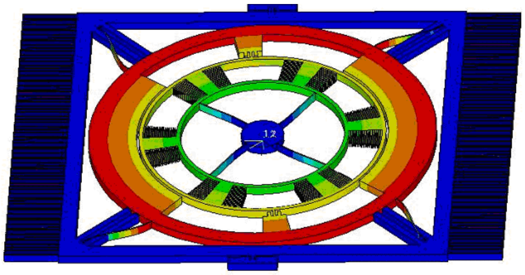
(a). Initial state



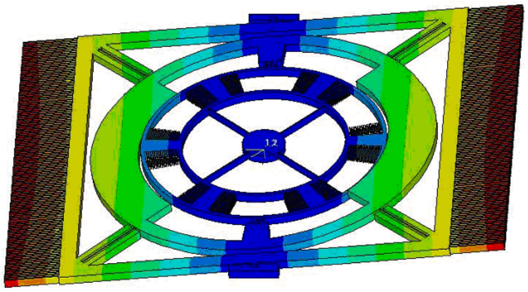
(b). Torsional state

Figure 2: Schematic of the torsional comb capacitors.

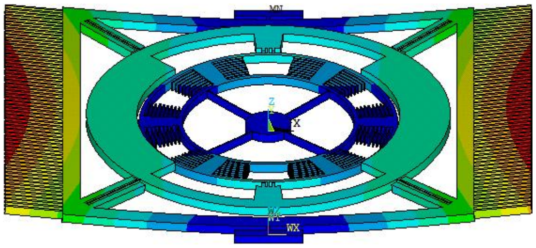
In order to detect out-of-plane motions of the sensing mass, torsional sensing capacitors with uneven height comb fingers are adopted, which have been successfully used in our previous work [4]. Figure 2 shows the schematic of the torsional comb capacitor, which can differentially detect the torsional out-of-plane motions with changing of the overlap area. Therefore, the air damping in such capacitors is dominated by the slide film damping, which make the gyroscope can operate without high cost vacuum packaging.



(a) Driving mode



(b) Sensing mode



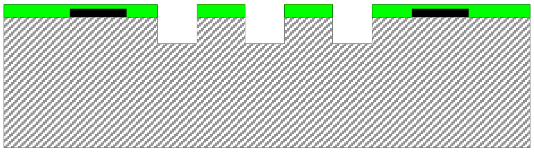
(c) Third mode

Figure 3: Simulated working modes of the gyroscope performed by ANSYS^{TM}.

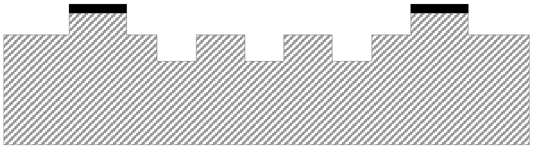
The working modes of the gyroscope are simulated using ANSYS^{TM}, as shown in Fig.3. The simulated frequencies of the driving and sensing modes are 3.673 kHz and 3.800 kHz, respectively. The third mode is 9.651 kHz, much larger than driving and sensing modes. Therefore, it hardly affects working modes.

FABRICATION PROCESS

The proposed gyroscope was fabricated by the modified silicon on glass process with five masks, which was developed in our former work [4]. The fabrication process is shown in Fig.4. The height difference for the sensing comb fingers are 10μm on both sides. The photo of the fabricated gyroscope is shown in Fig.5. Figure 6 is the SEM photo of the torsional comb capacitors.



(a)



(b)

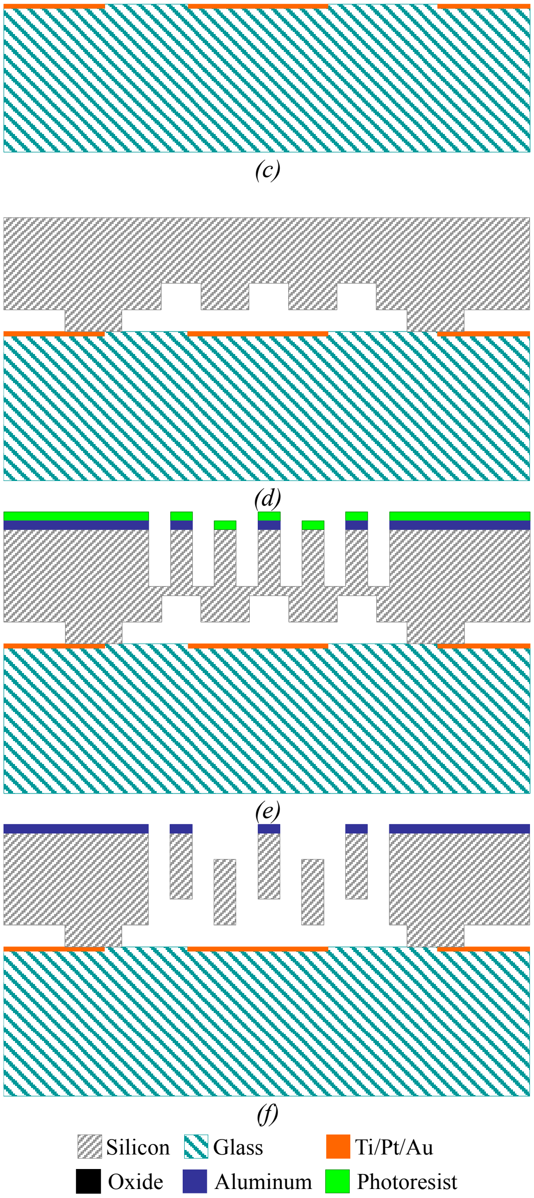


Figure 4: Fabrication process of the gyroscope.

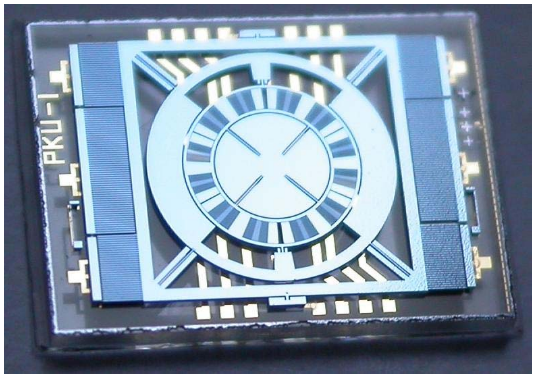


Figure 5: Photo of the whole device, size: 3.7mm×5.6mm

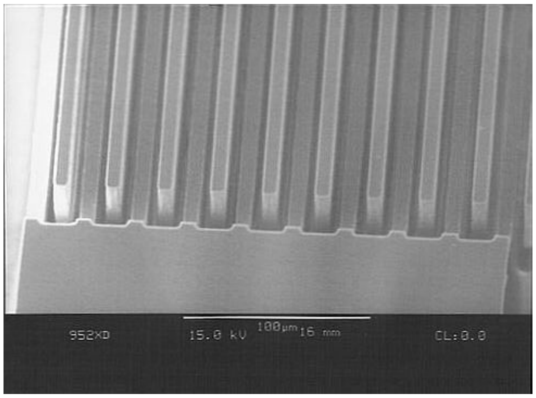


Figure 6: SEM photo of torsional sensing comb capacitors

TEST RESULTS

The gyroscope was packaged in PLCC28 package at atmospheric pressure. The discrete PCB circuit with close loop driving circuit was used to test the gyroscope. Figure 7 shows the frequency-amplitude response of the driving mode, and the measured quality factor is 621. The output of gyroscope under different angular rate input is shown in Fig.8. The measured sensitivity is 3.1mV/°/s and the nonlinearity is 7.68‰ with the full scale of 900°/s. Figure 9 shows the noise spectrum analysis. Noise floor of the gyroscope is 0.45°/s/Hz$^{1/2}$.

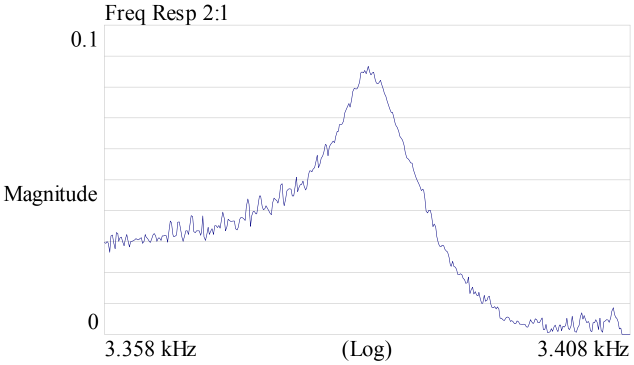


Figure 7: The frequency-amplitude response of the driving mode.

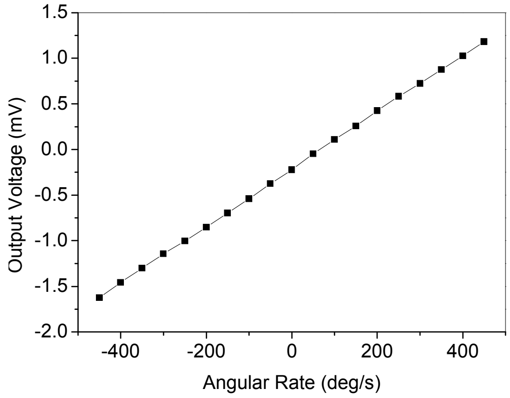


Figure 8: Output of the gyro under different angular rate.

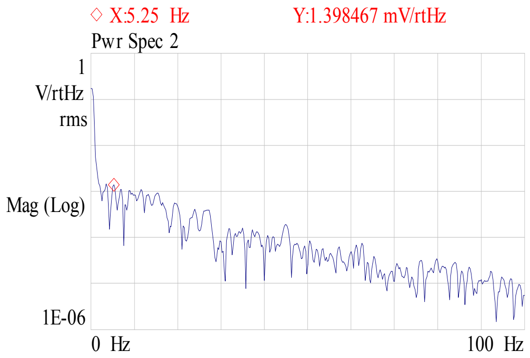


Figure 9: Noise spectrum analysis of the gyroscope.

CONCLUSION

A doubly decoupled vibrating wheel lateral-axis gyroscope is presented. It adopts symmetrically distributed proof masses, which can immune from the linear accelerations. Novel torsional sensing comb finger capacitors make it differentially detect out-of-plane torsional movements and insensitive to movements in other directions. The gyroscope was fabricated and tested at atmosphere. The sensitivity is 3.1mV/°/s while the nonlinearity is 7.68‰ with full scale of 900°/s. The noise floor is 0.45°/s/Hz$^{1/2}$.

ACKNOWLEDGEMENTS

The authors would like to thank the technical staffs of National Key Laboratory of Nano/Micro Fabrication Technology for the support on device fabrication. This work is supported in part by the National Natural Science Foundation of China under Grant No. 50730009.

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