PROJECT DESCRIPTION

Title: *Sub-One-Degree Per Hour High-Performance Gyroscope*

Graduate Student: Jae Yoong Cho (EECS) *Faculty Advisor: Khalil Najafi (EECS)*
Post Doc: Sang Woo Lee (EECS) *Work Began: 01/01/2005*
Funding Source: DARPA

Project Goals:

Micro-gyroscopes are used in a variety of fields including military, automotive, guidance, and consumer products. By taking advantage of small-size, high-precision, highly reliable, and low-cost MEMS fabrication technologies, the resolution of the micro-gyroscope has steadily improved over the past two decades. However, the resolution of the conventional micro-gyroscopes is limited to above one-degree/hr, and its bandwidth reduces drastically as its resolution improves. This project aims to overcome these limits by developing a highly sensitive and environmentally resistant vacuum packaged micro-gyroscope with large bandwidth.

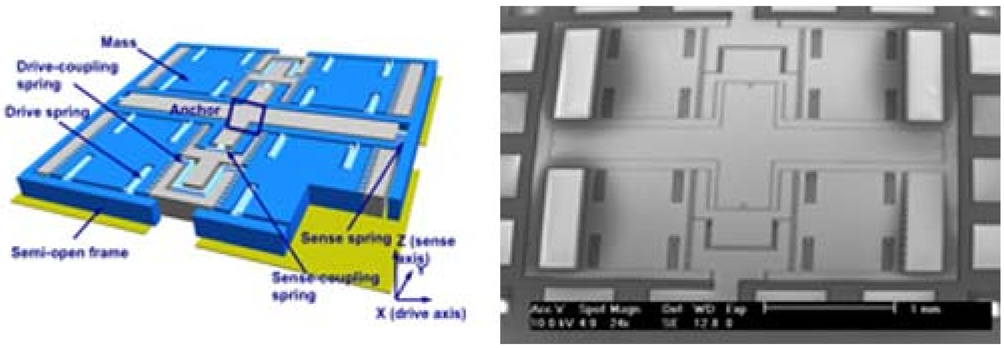

Figure 1: (Left) Structure of the prototype Balanced Oscillating Gyroscope (BOG). (Right) SEM photograph of a fabricated BOG.

Approach and Methodology:

In order to achieve sub-one-degree/hr resolution, it is necessary to discuss the sensor's limiting factors of resolution and bandwidth. Its resolution consists of short-term resolution (angle random walk) and long-term resolution (bias stability). First, angle random walk is limited by quality factor (Q), sensor mass, interface circuitry, and the matching of drive and sense frequencies. Q is influenced by the sensor material, fabrication process, dimension, and vacuum level. Also, large-mass and low-noise interface circuitry have to be used to reduce mechanical and electronic noise, and drive and sense modes have to be matched. Second, bias stability is set by the quadrature error, environmental vibration and temperature change. Among these factors, quadrature error is largely dependent on the precision of microfabrication technology, and vibration and temperature sensitivity is dependent on whether the sensor can differentially cancel the dithering from external vibration and have its mode frequencies to be minimally affected by thermoresidual stress. On the other hand, bandwidth degrades as angle random walk increases under current gyroscope operating methods. Therefore, in order to achieve both good resolution and bandwidth, it is necessary to adopt a different operating method, called the whole angle mode.

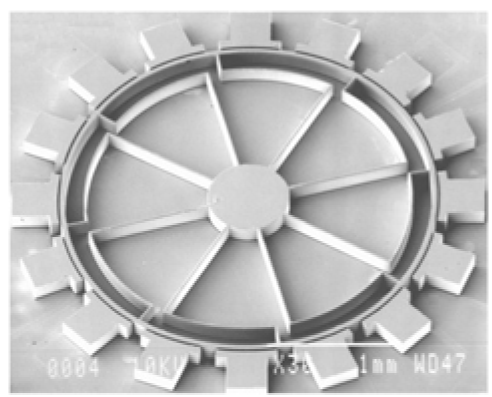

Figure 3: Single-crystal silicon microvibratory ring gyro (2002).

Role in Supporting the Strategic Plan and Testbeds:

This project will develop micro-gyroscopes that can serve in various high-precision environmental monitoring systems. Also, this project will support the development of various sensors in WIMS ERC that have common challenges in sensor design, fabrication, interfacing and packaging. Our past effort towards developing a micro vibratory ring gyroscope has played a great role in supporting related projects (Figure 3) [1,2,3]. This process development knowledge can be applied not only to other interrelated projects but also to solve various challenges in the MEMS fabrication.

Results and Accomplishments:

A new gyroscope design, named the Balanced Oscillating Gyroscope (BOG), is developed to cancel the effect of vibration and to be stable over temperature change. It is designed to have drive and sense modes that are complementary to cancel the overall momentum. Also, this design has a single anchor with minimized area at the center. The sensor is fabricated using the silicon-on-glass (SOG) process, and in vacuum this sensor has a sense *Q* of 7400 when its drive and sense modes are tuned within 4Hz. The device demonstrated an angle random walk of 19.8 deg/hr/√Hz and a sensitivity of 5.65mV/deg/sec (Figure 4). Currently, the device structure is modified for quadrature error reduction and precise mode matching. Also, wafer-level vacuum packaging processes are being developed. In addition, a low-noise readout-and-control circuitry board is developed for lower signal coupling, better force rebalance feedback, and closed-loop quadrature cancellation. Also, designs and fabrication technologies of the whole angle mode gyro are currently being developed.

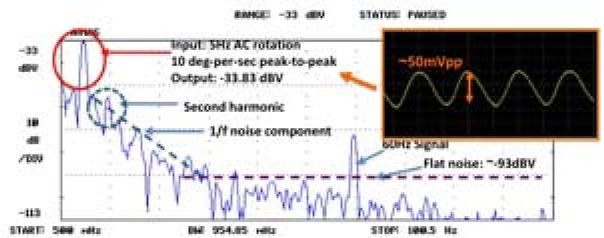

Figure 4: Transient and spectral responses the BOG under rotation with an amplitude of 10 deg/sec peak-to-peak and a frequency of 5Hz, indicating an angle random walk of 19.8 deg/hr/ãHz.

Relevance to Other Work:

Technologies for realizing high-aspect-ratio, low-cost vacuum package, and low stress and temperature dependence are the most commonly addressed issues in the MEMS. The developed technologies will potentially benefit many related industries.

Plans for the Coming Year:

Further development and packaging of the Balance Oscillating Gyroscope (BOG), development of low-noise readout-and-control circuitry, design and fabrication of whole angle mode gyroscopes, testing of the gyroscopes

Expected Milestones and Dates:

- Low-noise interface circuitry development for the BOG and whole angle gyroscopes (10/01/2009)
- Development of prototype whole angle mode gyroscopes (01/01/2010)
- Testing and improvement of the whole angle gyroscopes (04/01/2010)

Expected Contributions, Deliverables, and Company Benefits:

- Develop sub-one-degree/hour microgyroscopes and apply to inertial navigation
- Develop high-aspect-ratio fabrication processes applicable to many other MEMS devices

References and Recent Publications:

1. M. W. Putty et al., “A Micromachined Vibrating Ring Gyroscope,” *Digest, Solid-State Sensors and Actuators Workshop,* Hilton Head, SC, pp. 213–220, June 1994.
2. F. Ayazi et al., “Design and Fabrication of a High-Performance Polysilicon Vibrating Ring Gyroscope,” *Proceedings of Micro Electro Mechanical Systems Workshop,* Heidelberg, Germany, pp. 621–626, February 1998.
3. G. He et al., “A Single-Crystal Silicon Vibrating Ring Gyroscope,” Technical Digest, *IEEE 2002 Int. Conference on Micro Electro Mechanical Systems (MEMS 2002),* Las Vegas, NV, pp. 718–721, January 2002.