A Critical Review of the Market Status and Industry Challenges of Producing Consumer Grade MEMS Gyroscopes

By Steven Nasiri, Martin Lim, and Mike Housholder

Introduction

This past decade (2000-2009) will go down in history as one in which devices based on microelectromechanical systems (MEMS) technology broke barriers and emerged into the consumer market. Entry of MEMS sensors into consumer products has been under consideration since the 1980s but was never fully realized in part due to their bulky size, cost and some inherent reliability issues when compared to their semiconductor counterparts. Initially starting with hard disk drive protection, MEMS accelerometers were the first to break barriers by providing robust and reliable products that met consumer market price points. Nintendo's Wii game console was the first to fully embrace accelerometer technology and make it a household name. Shortly thereafter, the Apple iPhone made accelerometer production volumes climb through the roof as portrait/landscape orientation and motion gaming quickly became standard features in most smartphones. MEMS-based microphones also are credited with getting MEMS technology into various consumer markets.

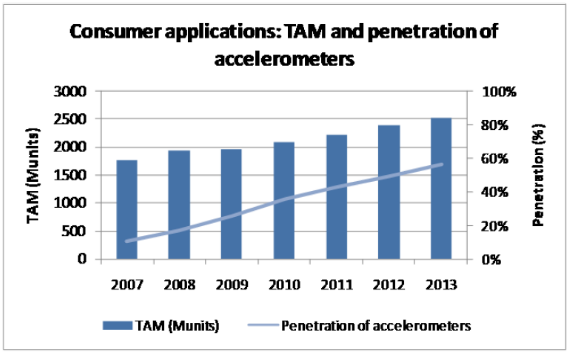
This past decade also saw the emergence of MEMS gyroscopes into various consumer products. Initial applications for consumer-grade MEMS gyros started with providing the hand jitter information in digital still cameras to enable optical image stabilization. But once again Nintendo blazed the trail in 2009 by adding the Wii MotionPlus to its already popular Wii game console to bring MEMS gyroscopes into the limelight.

In December 2009, *EETimes* named MEMS gyroscopes as one of the hot applications for 2010, and we predict that in this next decade more sophisticated integrated MEMS inertial sensors and *MotionProcessing™* technology will find their way into every kind of consumer electronics product from cell phones to game controllers and remotes, and even sports clothing and exercise equipment.

This paper examines the different gyroscope technologies currently available on the market, provides some details of the challenges and limitations, and provides a vision for future trends in the next generation of products addressing the market needs for processing motion.

MEMS Gyroscope Market Update

The mass-market adoption of MEMS accelerometers into consumer electronics devices started in 2006 with the launch of the Nintendo Wii game console and received another positive bump in 2007 with the launch of the Apple iPhone. Since then, the MEMS accelerometer has become pervasive and is a must-have feature for basic motion game control, display orientation, and user interface control. Application developers have jumped on the bandwagon and have created compelling applications for the accelerometer in phones that could not have been imagined two or three years ago. Yole Développement estimates that MEMS accelerometers have penetrated between 30 to 40 percent of consumer electronics devices in 2010 and expects this to reach close to 60 percent by 2013. Today, prices for basic motion sensing 3-axis accelerometers are priced at $0.50 and are predicted to drop even lower.

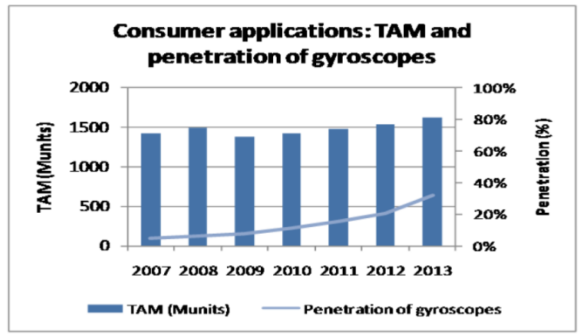


Source: Yole Développement 2009

Many parallels can be drawn between the market growth characteristics of MEMS accelerometers and the potential for growth for MEMS gyroscopes in consumer electronics. In 2006 and 2007 the demand for accelerometers was stoked by their use in the Nintendo Wii and Apple iPhone. The 2009 introduction of the Wii Motion Plus, with an integrated 3-axis MEMS gyroscope, was the first mass-market product that demonstrated the benefits of and potential for 6-axis MotionProcessing with integrated gyros and accelerometers to developers and consumers.

Beyond game consoles, the gyroscope is expected to be the next killer application in mobile phones. Increasing demand for location awareness on the mobile phone for pedestrian navigation, mobile search and social networking will require the accuracy of a gyro in combination with other inertial sensors to track heading in the absence of a wireless signal. Other market drivers for the gyro include image stabilization, augmented reality, 3-D user interface control and gesture shortcuts for phones or TV remotes and motion control for immersive gaming. As was the case with the accelerometer, it is expected that the developer community will introduce breakthrough applications and use-cases for the gyro that are unimaginable today.

By 2013, four years after the introduction of the Wii MotionPlus, Yole expects that gyroscope technology will penetrate close to 40 percent of the consumer electronics market by 2013 which is in line with the accelerometer growth and attach rate figures between 2007 and 2010. Similar to the accelerometer, the crossing of a critical price barrier is also a key to driving mass-market adoption. In October 2009, InvenSense announced the industry's first 3-axis MEMS gyroscope to cross this barrier.



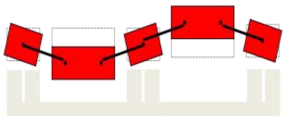
Source: Yole Développement 2009

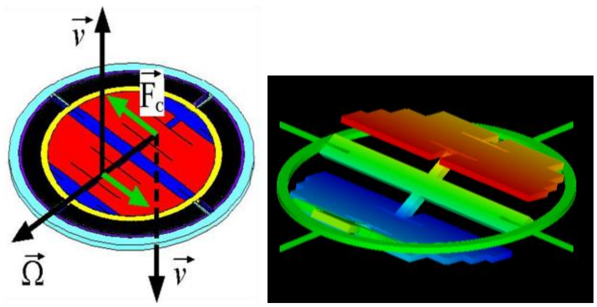
MEMS Gyroscope Basics

The key component of motion processing is the addition of a 3-axis gyroscope to the 3-axis accelerometer. This section reviews some of the key design principles required to meet the demands for consumer grade MEMS gyroscopes.

Coriolis Acceleration

Gyroscopes measure angular velocity (Ω) by sensing Coriolis acceleration. Vibratory tuning fork mass gyroscope implementations typically contain a pair of vibrating masses that are driven to oscillation at a fixed velocity with equal magnitude and in opposite directions (Figure 1). When the gyro device is rotated, the Coriolis acceleration (In micro-Gs) creates an orthogonal force to the vibrating masses that is proportional to the rate of rotation, which is typically measured using capacitive sensing techniques using comb "fingers" along the perimeter of the oscillating proof mass frame structure..





$a_{cor} = 2V_{pm}$ x Ω

Where:

a_{cor} = Coriolis Acceleration

V_{pm} = Velocity of the proof mass

Ω = rate of rotation

Figure 1: Coriolis Acceleration

High quality gyroscope designs have high Coriolis acceleration and low mechanical noise. Achieving high Coriolis acceleration requires a thicker proof mass at a high velocity, that can provide high sensitivity without dependence on a high level of signal amplifications that can lead to higher noise. Brownian noise is the primary mechanical noise source for gyroscopes. Brownian noise decreases with the size and velocity of the proof mass.

External Noise and Vibration

Gyroscopes can have sensitivity to external noise and vibration. Typically, the gyroscopes must operate at a high frequency (20kHz or above) to avoid interference from sound and other environmental noise. High frequency operation requires the gyro proof-mass to be as thick as possible for any out of plane drive or sense mode of operations.

High frequencies bring superior resistance to shock and significantly lower sensitivity to external vibrations, including sound. However, higher freqencies magnify the effect of typical error sources. This can be addressed by advanced design techniques to supress those errors. The fabrication platform plays an important role in determining the highest achieveable operating frequency of the device.

Cross-axis Sensitivity

A good gyro design must also limit cross-axis sensitivity. Cross-axis sensitivity occurs when a gyro axis not only detects rotation in the intended axis, but also responds to rotation in one of the other axes. This introduces a percentage of error into the rotation results reported by the gyro. A robust MEMS gyro design will limit exposure to this effect through advanced design techniques.

Controlled and Reliable Vacuum Environment

Vibratory mass gyroscopes must operate in a hermetically-sealed chamber with a controlled vacuum/pressure over its entire operating life. The reliability of the vacuum seal of this chamber is critical to the long-term accuracy and operation of a gyroscope. Any change in pressure, regardless of whether it is lower or higher, will affect gyro performance. It is essential to have a hermetically-sealed cavity which can preserve the original pressure that was present during the factory calibration. Any leak in to or out of the cavity that increases or decreases pressure will significantly affect gyro performance. The method of sealing the vacuum cavity has a significant effect on the long-term reliability of the vacuum.

Coupled Masses for Rejection of Linear Acceleration

The gyroscope measures rate of rotation and should reject both linear and, if possible, rotational acceleration. Linear and rotational acceleration may significantly interefere with rate of rotation measurement and significantly degrade gyroscope performance. External acceleration may be induced by any external mechanical vibration, including sound. In order to reject linear acceleration it is important to design the gyroscope such that the proof masses do not respond to linear acceleration. In general, two or more masses should be used for detecting rotation for each axis. These masses should be coupled so that the external acceleration forces will be automatically cancelled. Hence, the external acceleration signal is rejected. Uncoupled masses may have different sensitivity to linear acceleration and thus will not be able to reject it completely which will get factored into the gyro output.

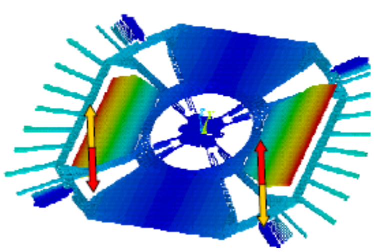


Figure 2a: Un-coupled mass design

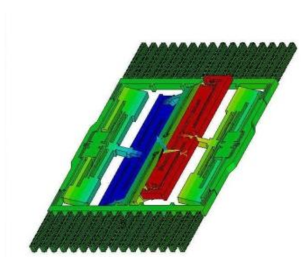


Figure 2b: Coupled mass design

MEMS Fabrication Technology Choices: Surface vs. Bulk (Nasiri-Fabrication)

The fabrication platform plays a crucial role in achieving the key design principles for MEMS gyros. This section will examine two fabrication technologies: surface micromachining and Nasiri-Fabrication (which uses bulk silicon) to examine how each technology adheres to the MEMS gyro design principles outlined in the previous section.

First, it is important to understand that gyroscopes and accelerometers differ significantly in both design and fabrication complexity. An accelerometer is a relatively simple MEMS design requiring only suspended masses and springs that are designed to be responsive to changes in acceleration or gravity. Contrast this to a gyro which is truly a complex micro electro mechanical system that requires the design and fabrication of a high-precision resonator and Coriolis accelerometer measuring a micro-G level signal at high fidelity.

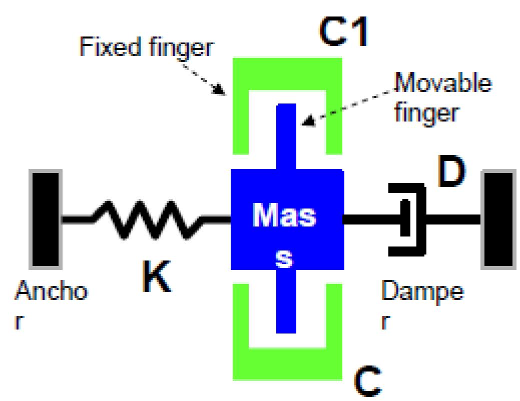


Figure 3: Typical MEMS Accelerometer Structure

By contrast, MEMS gyroscopes drive proof masses into oscillation at fixed velocity in order to measure rate of rotation. The frequency of oscillations is called drive (operating) frequency and is one of the main parameters which distinguishes different MEMS gyroscopes. A Coriolis signal is picked up at the drive frequency and is demodulated with a signal at the drive frequency which converts the sensed rate of rotation signal back to the baseband where it gets processed in a similar way as an accelerometer's linear acceleration signal. Therefore, the transducer signal follows two paths, the first one carrying a Coriolis signal and the second one carrying a drive oscillation signal that is used for demodulation. Any imperfection in oscillation frequency or its phase or amplitude has potential to propagate through both paths and cause inaccuracies that get demodulated down into baseband. In addition, the need for high performance synchronization between two signal paths adds additional complexity.

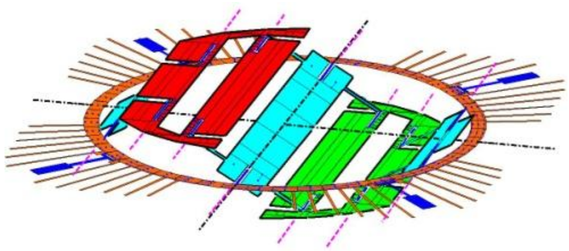


Figure 4: Single-axis, Coupled Mass MEMS Gyro

In short, the complex system-level architecture of the gyroscope mixed with fabrication imperfections tends to have much more severe impact on gyro performance than the corresponding simple signal processing scheme has on the accelerometer performance. Unlike the accelerometer, the gyroscope should contain a very good mechanical oscillator and the synchronization between different signal paths should be literally perfect.

From a fabrication perspective, the accelerometer does not require a high-degree of precision since the principle of transduction is the displacement of mass due to the acceleration. A simple suspension suffices and all fabrication imperfections can be corrected electronically. Further, an accelerometer does not require a controlled vacuum environment for reliable operation. A gyroscope is substantially different in that a repeatable, reliable and high-precision fabrication process is required to achieve the desired performance metrics. Finally, the gyro requires a controlled vacuum over the life of the product for reliable and accurate operation.

To conclude, gyroscopes rely more on the qualities and characteristics of the fabrication process to achieve the desired reliability and performance metrics than an accelerometer. Fabrication methods that have proven stable for accelerometers may not translate well to gyroscopes.

Surface Micromachining Challenges

There are several short comings and drawbacks to this technology that has made it slow to become a universal process for gyroscope sensors. In fact it can be argued that although applicable for accelerometers, surface micromachining may have insurmountable challenges preventing the manufacture of gyroscopes. Vapor-deposited materials like the commonly used polysilicon require extensive characterization, process controls and equipment maintenance. Additionally, they are challenged by material limitations involving stress and thickness. After decades of interest to develop thick structural layers, the current state-of-the-art processes are limited to only around 15 um. This restricts the operation frequency of a vibratory gyro to 10kHz. At 10kHz; the gyro will operate in the range of audio sound energy in the normal human hearing range (20 to 20,000Hz) and will be sensitive to acoustic and environmental noise and vibration. Using a mobile phone as an example, the performance of the gyro can be impacted by the ringing or vibrating of the phone, the speakerphone, or simply noise from a large crowd or from music. Figures 5 and 6 below illustrate sensitivity to noise in a gyro with thin structural layers and low resonant frequency. In Figure 5, a gyro design based on surface micromachining registers sensitivity to an external noise source of ~4.2kHz, while the InvenSense gyro, has thicker structures and a higher resonant frequency to operate outside of the audible range. The InvenSense gyro registers no sensitivity to this noise source. In Figure 6, the InvenSense gyro and a surface micromachined gyro are placed on top of a mobile phone. The oscilloscope screen shots show the response of the gyro to the audible ring of the phone.

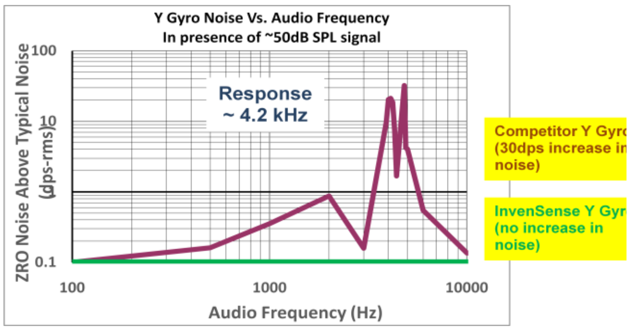


Figure 5: High Frequencies Applied to Thin 14um Gyro Proof Mass

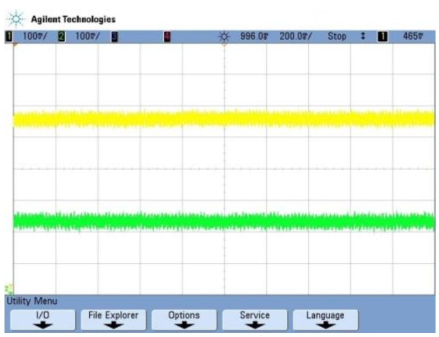


Figure 6a: InvenSense gyro: No sensitivity to audible phone ringing

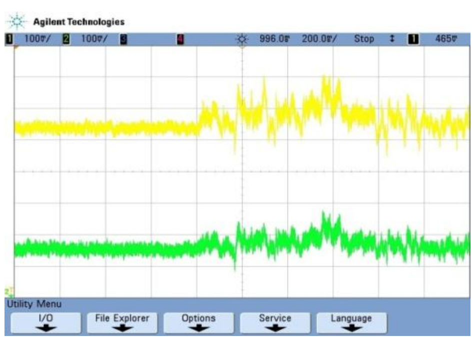


Figure 6b: Surface micromachined gyro: Sensitivity to audible phone ringing

Another challenge with SMM is that standard CMOS poly is not sufficient for most MEMS applications. A customized and much thicker poly process is required which severely limits the transferability of the process from one CMOS line to another. This impacts scalability to lower geometry processes as new investment is required each time to deploy the custom poly process within a new technology CMOS node line.

Finally, SMM requires that signal routing be done at the MEMS level. Limited to two layers of poly, crossovers are required at the device layer which can lead to high cross talk. Routing options are limited and can lead to an increase in MEMS area. A thick isolation layer is also required for out of plane sensing adding to the complexity and non-standard CMOS processing.

Nasiri-Fabrication Platform

At the onset, InvenSense founders recognized the magnitude of challenges to not only develop a gyro but to design for manufacturability. This required a robust fabrication platform that is beyond the traditional MEMS fabrication techniques such as surface micromachining and back side bulk etching that is suitable for accelerometers and pressure sensors respectively. A paradigm shift in the approach was required to address fundamental issues of producing a MEMS gyro at a market acceptable price point. Thorough understanding of the gyro operation and performance tradeoffs was considered to formulate a breakthrough fabrication platform that was both scalable and portable to multiple foundries. As a fabless company, InvenSense was not encumbered by any legacy processing and was free to develop a platform that was unique to support the many challenges associated with producing a low-cost, high volume consumer grade gyro. The approach addresses all the components that influence cost, size, and performance with a stable quality structure material for design, a cost-effective packaging technique, and an electronics integration solution.

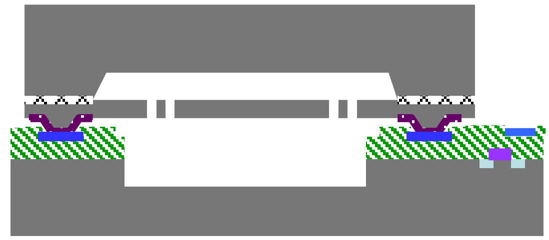
Nasiri-Fabrication uses single-crystal bulk silicon and represents the latest evolution in MEMS fabrication.

The premise was to develop the lowest cost MEMS fabrication platform by addressing wafer-level packaging and integration while providing scalability to lower geometries. This is the first MEMS fabrication process that allows for the integration of MEMS and CMOS with no interdependency on CMOS technology. The process outlined below uses six simple mask levels with only one critical mask level to define the complex suspension, masses and capacitive sensing features. Manufacturing uses standard off-the-shelf processes and commercially available equipment.

(a) The engineered silicon on insulator (ESOI) wafer is formed using a standard silicon handle wafer with simple etched targets for backside alignment (mask 1); followed by oxidation and cavity etch (mask 2). A second wafer is fusion bonded to the handle wafer and subsequently thinned to define the device layer thickness.

(b) The MEMS wafer is completed by etching the device layer to form standoffs (mask 3) that define the seal ring and electrical contacts to CMOS; depositing and patterning a germanium layer (mask 4) over standoffs; and patterning (mask 5) and deep reactive ion etching the device layer to form the mechanical structure.

(c) A standard CMOS wafer fabricated by an independent foundry and a cavity (mask 6) is etched into CMOS wafer to provide clearance for moving MEMS structures.



(d) The MEMS wafer is bonded to the CMOS wafer using AlGe eutectic bonding between the Al on the CMOS and the Ge on the MEMS wafer. After bonding, a portion of the MEMS wafer is removed by conventional tab saws to expose the CMOS wire bond pads.

The use of bulk silicon allows for thicker MEMS structures (20-100µm) which provides inherently better noise and sensitivity performance due to higher proof-mass velocities and allows for operation outside of the audio range. Figure 9 below shows a bulk micromachined 35µm gyro proof mass capable of reliable operation above 30kHz, well outside of the audio range.

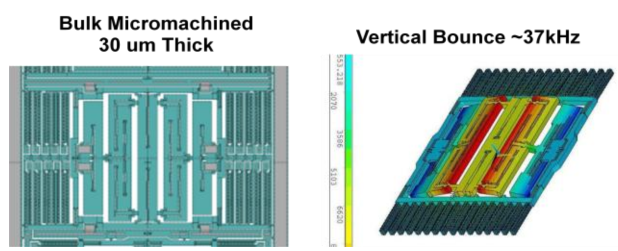


Figure 9: High Frequencies Applied to a Bulk Micromachined Gyro Proof Mass

The electronics integration is essential to the realization of a low cost gyro. Low-noise small signal processing is required to accurately detect small changes in displacement due to the Coriolis force. Not only are differential capacitance detection techniques supported by the CMOS to MEMS contacts during bonding, but localized differential capacitance schemes are also enabled due to the compact size of the contacts and its demonstrated reliability. Unlike multi-chip solutions where the first stage capacitance signal routing must occur on the MEMS substrate, all signal routing in Nasiri-Fabrication is done on the CMOS substrate and fully leverages the high conductance, highly compact metal routing capability of the multi-metal CMOS process. Electronic shielding is enabled, routing congestion reduced, and signal fidelity is preserved.

Table 1 illustrates the contrast of MEMS fabrication technologies between Nasiri-Fabrication and Surface Micromachining. The SMM process is based on a published process supporting accelerometers and not necessarily gyros.

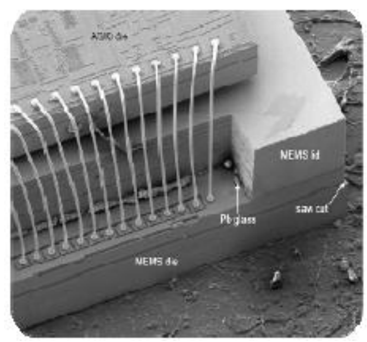
Parameter	Nasiri-Fabrication	Surface MicroMachining
Substrate isolation layer thickness	1 um	4 um
Structural thickness	>30um	< 15 um
Sacrificial Material and thickness	None needed	SIO2 2-3 um thick
Critical photo CD prep	None needed	CMP for planarizing thick isolation and sacrificial layers
Structure release	None needed	Sacrificial layer etch
Stiction mitigation	None needed	HF vapor etch
Capping wafer	CMOS wafer	Additional dummy cap wafer
Routing material	4 layer metal from CMOS	2 layer POLY from MEMS
Vacuum sustainment	None needed	Getter required – apply to dummy cap wafer

Table 1: Wafer Level Packaging solution summary

Consumer applications demand low cost without compromising performance. The Nasiri-Fabrication platform met this double edged challenge by solving many of the key design and packaging challenges facing gyros. The cornerstone of the process is the Wafer Level Packaging (WLP) technique integrating the CMOS and MEMS wafers.

MEMS Packaging, Testing and Reliability

Surface micromachining uses either a stacked die or side-by-side die approach. In the example below (Figure 10), the two die are stacked vertically and are wire-bonded together. The MEMS die and CMOS die are each singulated from their respective wafer substrates. This approach does not allow for wafer-level testing of the gyro. All testing must be done at the package-level (final test) which leads to increased test and packaging costs. In the long-term, the reliance on wire-bonding CMOS and MEMS instead of wafer-level bonding will prevent the path to chip-scale package (CSP) for the smallest solution size.



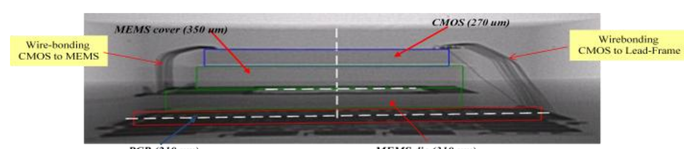


Figure 10: Surface micromachined MEMS wire-bonded to CMOS

The MEMS die itself is capped using a dummy wafer that increases the cost and thickness of the overall solution. These two layers are vacuum-sealed, typically using a glass frit seal ring. The glass frit seal is not hermetic and its brittleness is susceptible to micro-fractures. Potential micro-leaks coupled with outgassing of the glass frit material require the costly process of depositing a getter. A getter is a desiccant that absorbs gas molecules that either leak into or outgass from the MEMS cavity to maintain a high vacuum. The resultant vacuum level is uncontrollable and time-varying and by design overcompensates at the beginning and degrades over the life of the product.

This last point is actually of greater importance than first realized. One of the key functional parameters for building a vibrating mass gyroscope is to achieve a mass with constant velocity. To achieve such an objective requires a stable and constant damping factor which is directly a function of the vacuum. Adding getters to maintain the vacuum is perhaps good for achieving hermeticity over the product lifetime, but by definition does not guarantee a constant vacuum and hence leads to reliability problems, particularly in humid environments.

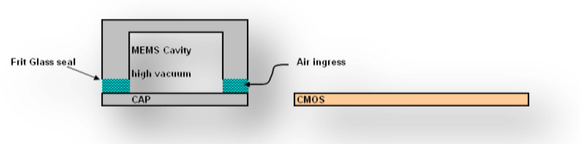


Figure 11: Two Chip Surface Micromachined MEMS Cavity Frit Glass Seal with Getter on Cap Wafer

Two industry standard tests are commonly used to determine the reliability of semiconductor devices: Highly Accelerated Stress Test (HAST) and Temperature and Humidity Unbiased test (THUB). HAST exposes the gyroscope to an environment of 130°C at 80 percent humidity for 96 hours unbiased. This accelerated test indicates potential gross failure areas in a relatively short time span. THUB subjects the gyro to an environment of 85°C and 85 percent humidity for 1,000 hours while not powered. This test describes the performance of the part over its expected lifetime.

These two tests can expose the limitation of getters in a gyroscope application. Long-term exposure to humidity can compromise the vacuum integrity of the frit glass and getter system. In a gyroscope, this can lead to Zero Rate Output (ZRO) shifts that degrade performance. The charts below show the results of HAST and THUB testing of both surface micromachined and Nasiri-Fabrication-based gyroscopes. As you can see the hermetic seal of Nasiri-Fabrication sustains consistent performance over time while the ZRO shifts observed on the surface micromachined part are an indication of a compromised package.

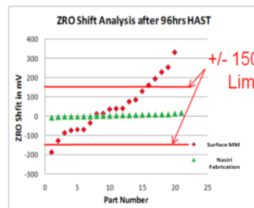


Fig 12a. HAST test, ZRO shown

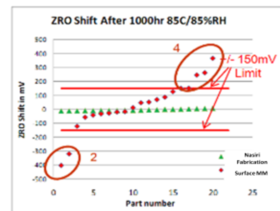


Fig 12b. THUB test, ZRO shown

In addition to the higher cost associated with additional materials, the seal ring width and signal routing add substantial wafer cost in terms of area required. In total, the seal-ring, electrical connections, and spacing for cross-talk reduction can increase the MEMS area by 200 percent which can greatly impact solution size and cost, both of which are critical for the consumer electronics market. The Nasiri-Fabrication seal ring is less than 80um wide and adds only about 15 percent to the total MEMS area.

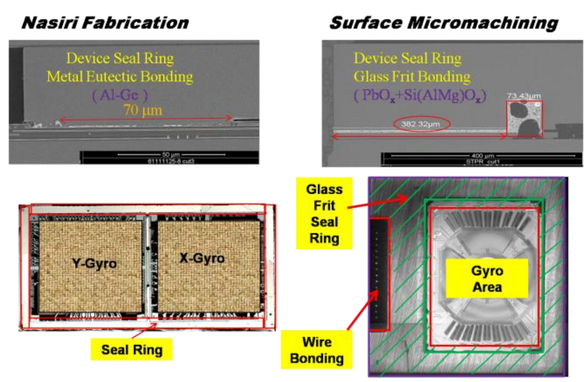


Figure 13: Comparison of seal ring impact on total solution size

Nasiri-Fabrication: Packaging, Testing and Reliability

The Nasiri-Fabrication process, patented by InvenSense, uses a wafer-to-wafer bonding process that allows for direct integration of the fabricated MEMS wafers to any off-the-shelf CMOS wafer at the wafer level. Although the wafer bonding process uses off-the-shelf wafer bonding equipment, the bonding process itself is proprietary and patented by InvenSense and allows for a eutectic bonding of the MEMS wafers directly to the aluminum layer on the CMOS wafer without the addition of other material layers on top of the aluminum. This process leads to smaller package footprints and package heights. In one bonding step, Nasiri-Fabrication provides for wafer-scale integration by making electrical interconnects between the MEMS and CMOS, and wafer scale packaging by simultaneously providing a fully hermetic seal of the MEMS structures. The seal does not require the use of frit glass or getters and provides a reliable and controlled vacuum level over the full life of the product. The inherent materials used are not susceptible to outgassing.

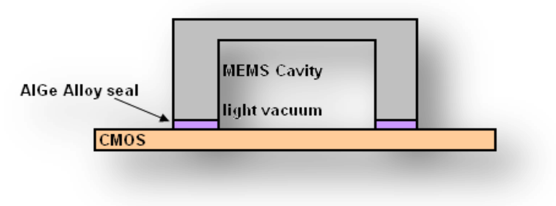


Figure 14: Nasiri-Fabrication MEMS Cavity with Eutectic AlGe Hermetic Seal to CMOS

Wafer level integration of MEMS, electronics and micro packaging addresses the widely recognized high package and test costs associated with MEMS devices. Each die is fully encapsulated and is packaged using standard, low-cost QFN packages, as shown in Figure 15. Furthermore, the bonded wafer has full functionality, allowing each die to be tested at wafer probe. Wafer-level testing provides mapping information for timely feedback to the foundries for improved process control, and provides device-level traceability by programming information at wafer sort test. Using conventional high speed testers at the wafer probing level reduces the test costs associated with custom testers needed for sensitivity calibration of packaged parts.

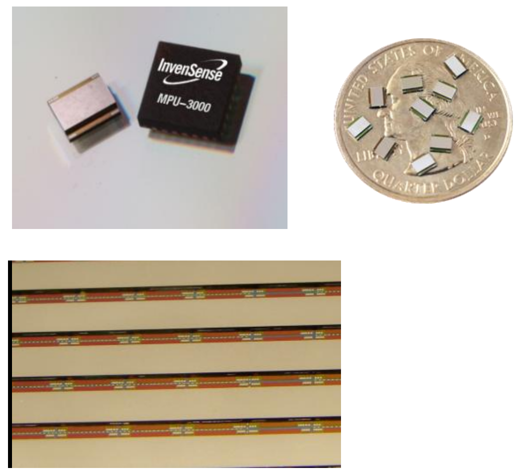


Figure 15: Nasiri-Fabrication (wafer-level bonding)

There is no overhead for the bond pads. The efficiencies of this packaging technology, combined with the reduced wafer-level testing costs, leads to a design optimized for the size and cost constraints of the consumer electronics market. The wafer-level bonding technique provides the only viable solution for MEMS+CMOS chip-scale package (CSP) design for reduced cost and solution size.

Fabrication Platform Summary

The following chart summarizes the fabrication characteristics of both MEMS fabrication platforms. A case can be made that the more advanced Nasiri-Fabrication platform is best suited to achieve the core gyro design principals outlined earlier in this paper.

	Nasiri-Fabrication	Surface Micromachining
Hermeticity	Inherent in manufacturing platform	Requires large seal ring to maintain hermeticity (uses frit glass and getter desiccant)
Signal Routing	•Routing done on CMOS layer, since electrical connections between CMOS and MEMS are made at wafer level •6 metal layers •High routability •Low cross talk and shielding	•Routing done at MEMS level. •Limited to 2 layer of poly, which requires crossovers, which is done at device layer •High cross talk •Limited routing; less effective use of area •Thick isolation layer required for out of plane sensing
Testability	Wafer-scale *and* packaged-unit testing	Testing in final package only
Structure Thickness	35μm allows for operation out of the audio range	14μm confines design to audio range. Ambient noise deteriorates noise performance
Wafer Cap	CMOS wafer; no extra layers required	Additional dummy wafer
Chip-scale Packaging (CSP)	Only fabrication platform capable of small chip-scale packaging	Not possible due to dependence on wire-bonding between MEMS and CMOS

Gyro Manufacturing for Consumer Applications: Case in Point

A survey of MEMS gyro producers illustrates the lack of manufacturability for consumer applications. The table below clearly shows that today the secret to achieving a low-cost, high-volume and high performance consumer grade gyroscope is to have a suitable fabrication platform. Having in-house MEMS fabs and even a CMOS fab provides no assurance of achieving lower cost. Despite in-house fabrication capabilities, most vendors' \$5-\$10 per axis solutions severely miss the desired sub-one dollar per axis requirement for consumer applications. Although some companies have been successful manufacturing and delivering accelerometer solutions that meet consumer price points, achieving a low cost gyro has remained a constant challenge for many.

Company	In House MEMS	In House CMOS	MEMS Technology	Start Devel.	# of axis Gyro	Gyro MKT	Gyro $/axis	Consumer 3-axis Accel
Bosch	yes	Yes	Surface MM	1995	Z & X/Y	VSC	>$10	$0.5
ADI	yes	Yes	Surface MM	1995	Z	VSC	>$10	$0.5
Kionix	yes	No	Bulk	2000	Stopped	N/A	N/A	$0.5
Freescale	yes	yes	Surface/SOI	2002	Stopped	N/A	N/A	$0.5
Silicon Sensing	yes	no	Bulk	2002	Z	Nav	>$10	N/A
Melexis	yes	yes	Surface	2003	Z	Nav	>$5	N/A
Sensordynamic	yes	no	Surface	2004	Z	VSC	>$7	N/A
VTI	yes	no	Bulk	2004	Z	Nav	>$7	N/A
Murata	yes	no	Bulk	2002	Z	Nav	>$5	N/A
Sensonor	yes	no	Bulk	2000	Z	Nav	>$5	N/A

Table 3: MEMS Gyro Supplier Landscape

Conclusion

MEMS gyroscopes are staged to become the must-have function in 2010 across a broad array of consumer electronics devices including cell phones, portable and fixed game consoles, digital cameras, 3D remote controls, and toys. This paper has identified the key design principles and challenges of implementation of a consumer grade MEMS gyroscope. The gyroscope, more so than most technologies, depends on the qualities and characteristics of its fabrication platform to meet the size, cost and performance requirements of high-volume consumer electronics products. Surface micromachining is a stable, well-proven fabrication technology that has seen success with high-volume consumer MEMS microphones and accelerometers. However, the unique design challenges of a MEMS gyroscope require further advancements in MEMS fabrication to achieve the same success seen by the accelerometer. The Nasiri-Fabrication platform, with nearly 100MU shipped, is uniquely suited to address the key challenges of the consumer MEMS gyroscope and will be one of the key factors in bringing the next revolution in *MotionProcessing* technology into everyday consumer applications.

References

EETimes: http://www.eetimes.com/showArticle.jhtml;jsessionid=SGQ1RPAQFGI4PQE1GHPCKH4ATMY32JVN?articleID=222001302

S. Nasiri: A Critical Review of MEMS Gyroscopes Technology and Commercialization Status, 2005

J. Seeger, M. Lim, S. Nasiri: Development of High Performance, High Volume Consumer MEMS Gyroscopes, 2010

Yole Développement: MEMS Accelerometer & Gyroscope and IMU Markets 2008-2013