PROJECT DESCRIPTION

Title: *Low-Power Thermal Isolation for Environment-Resistant Microinstruments*

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Funding Source: DARPA *Work Began: 01/01/2004*

Project Goals:

The environment has a profound impact on the performance of precision micromachined instruments increasingly needed in many applications. To realize the potential of MEMS, it is critical that the environment, especially temperature, around the instrument be controlled. External temperature can easily corrupt the output of an instrument, and can induce long-term undesirable effects that are not easily correctable using electronics. An effective approach to overcome this temperature sensitivity is to control/maintain temperature using a micro-oven. In order to achieve low-power consumption for micro-oven control, a very-high-thermal isolation is needed. This project seeks to develop a new thermal isolation package, and a generic assembly approach for instrument-platform integration.

Approach and Methodology:

Figure 1 illustrates a schematic view of a generic thermal isolation package [1]. A MEMS chip is flip-chip attached onto an isolation platform suspended by long suspensions. Thermal stabilization is provided by maintaining the device at a temperature higher than the maximum environment temperature utilizing a heater and a temperature sensor located on the platform. The heated structure is thermally isolated from the environment by 100μm-thick, crab-leg shape, glass suspensions, anti-radiation shield, and vacuum encapsulation to minimize power dissipation. The suspensions are designed with sufficient stiffness for mechanical support, and flexibility for rejecting environmental vibrations. A wafer-level package cap provides vacuum and vertical feedthroughs. Shock absorption layers [2], and a getter layer [3] for achieving and maintaining high vacuum are formed inside the package.

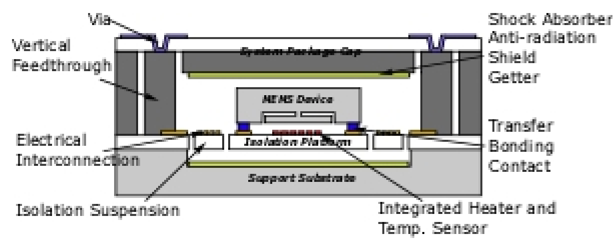

Figure 1: Schematic view of the isolation package.

Role in Supporting the Strategic Plan and Testbeds:

This project will develop a generic package with a controlled environment for MEMS devices, including any sensors/actuators requiring a vacuum and/or hermetic package with controlled temperature levels. This generic technology supports both WIMS testbeds.

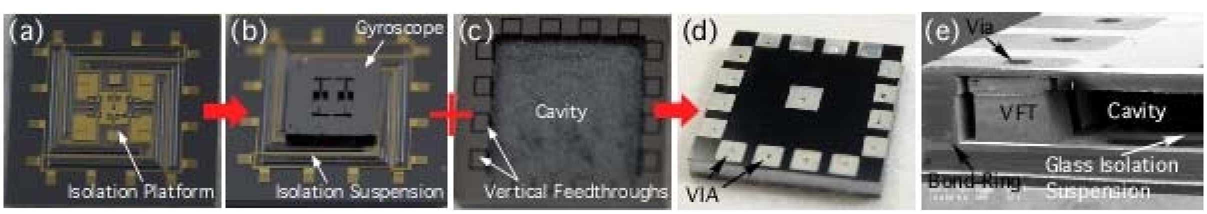

Figure 2: Picture of the process sequence (a-d), and SEM view of the package (e).

Results and Accomplishments:

Figure 2 shows the process sequence and fabricated package. It is noted that any kind of MEMS devices can be assembled since the chips are packaged after they are fabricated using any given process. The entire process is done at the wafer-level.

Performance has been evaluated by packaging Pirani gauges and mode-matched tuning fork gyroscopes (M^2-TFGs) [4]. The package has maintained vacuum-levels of ~6mTorr for >6 months (Figure 3 (a)). The packaged gyroscope shows a high-Q mode-matched operation (Q_{EFF}~55,000) at a constant temperature of 25°C.

The packaged gyroscope is tested in a temperature chamber for its thermal performance evaluation. Without oven control, the drive frequency varies at 17.3ppm/°C over a temperature range of 100°C, but stays constant at the same temperature without any hysteresis during the thermal cycling (Figure 3 (b)).

With oven control, the platform and the gyroscope are maintained at 80°C utilizing the integrated heater. The heater is on/off controlled by a comparator and feedback signal from the integrated temperature sensor on the platform. The drive frequency stays within 0.96ppm/°C when the oven control set temperature is fixed at 80°C. Higher frequency stability of 0.22ppm/°C is obtained using a compensated oven control. In the compensated oven control, the set temperature is changed based on the actual external temperature (Figure 3 (c)). Power consumption for heating the device to 80°C is <33mW when the external temperature is −30°C, and it decreases as the environment temperature increases (Figure 3 (d)).

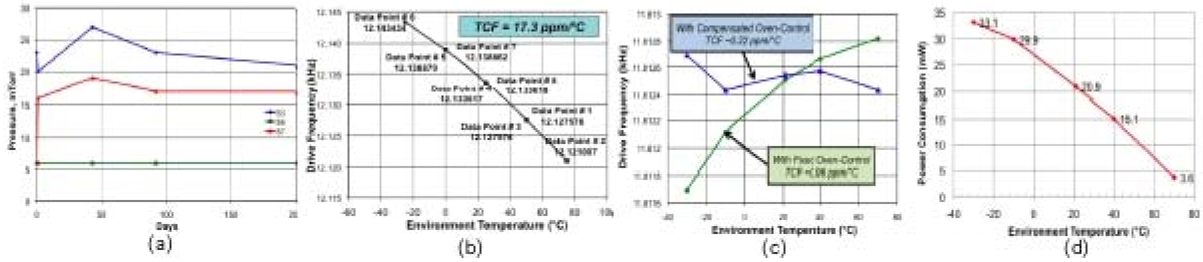

Figure 3: (a) Long-term vacuum-level data measured directly by the packaged Pirani gauge chips; (b) Frequency variation with environment temperature cycling from −30°C to 70°C (w/o oven control); (c) Frequency variation with the oven control; (d) Power-consumption measurement for the oven control at 80°C.

Relevance to Other Work:

While broad research on wafer-level vacuum and hermetic packaging is being carried out, the University of Michigan team is one of the leading groups, with one of the most extensive and advanced efforts in this area.

Plans for the Coming Year:

We will optimize the package design and process for better environmental isolation and lower power consumption. Different types of MEMS devices will be vacuum packaged and tested for the process verification. Design rules for needed vacuum/environment resistant packaging will be prepared.

Expected Milestones and Dates:

- Process verification and develop design rules (11/30/2009)
- Test vacuum-packaged gyroscopes by government sponsors (04/30/2010)

Expected Contributions, Deliverables, and Company Benefits:

- Integrated and power-efficient thermal-isolation technology
- Generic, environmentally protected, batch-micropackaging technology for microinstruments
- Multi-level, wafer-bonding technology

References and Recent Publications:

1. S.-H. Lee, S. W. Lee, and K. Najafi, "A Generic Environment-Resistant Packaging Technology for MEMS," *Transducers 2007,* Lion, France, pp. 335–338, 2007.
2. S. W. Yoon, S. Lee, N. C. Perkins, and K. Najafi, "Shock Protection Using Soft Coating as Shock Stops," *Solid-State Sensors, Actuators, and Microsystems Workshop,* Hilton Head Island, SC, pp. 396–399, 2006.
3. J. Mitchell, G. R. Lahiji, and K. Najafi, "Long-Term Reliability, Burn-In and Analysis of Outgassing in Au-Si Eutectic Wafer-Level Vacuum Packages," *Solid-State Sensors, Actuators, and Microsystems Workshop,* Hilton Head, SC, pp. 376–379, June 2006.
4. A. Sharma, M. F. Zaman, M. Zucher, and F. Ayazi, "A 0.1°/hr Bias Drift Electrically Matched Tuning Fork Microgyroscope," *IEEE 21st International Conference on Micro Electro Mechanical Systems, MEMS 2008,* pp. 6–9, January 2008.