

microGauge – a Micro Resonator Gauge (MRG) Featuring a High-Stability Zero for Vacuum Process Control

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Summary:

VAT has developed a micro resonator-based pressure sensor enabling high zero-stability. This is achieved by designing a resonator featuring a high-aspect-ratio gap and driving it in a closed loop configuration in order to use the resulting squeeze-film damping as a measure for the pressure. Additionally, a thermo-mechanical decoupling of the MEMS transducer is minimizing environmental disturbances. A zero stability below 10^{-2} mTorr is being demonstrated over a period of nine months, offering the means to ensure repeatable control in vacuum processing applications for semiconductor manufacturing.

Keywords: micro resonator, pressure sensing, vacuum gauge, semiconductor, process control

Introduction

The semiconductor manufacturing industry is heading towards new challenges in process control, as highlighted in the respective technology roadmaps (e.g. [1]). Atomic sized features, new materials and shrinking process parameter windows are asking for more repeatable and robust pressure control across the entire vacuum tool chain in the production line. Therefore, pressure control requires improvements in many aspects, but in particular the feedback signal from the pressure sensor must be stable and reliable.

Today's prevailing pressure sensor technology for process control is based on capacitance diaphragm gauges (CDG). This type of sensors is known as a direct measurement method, based on the physical concept of measuring pressure by means of the deflection of a membrane. This approach has been optimized for many decades

and is known for its repeatable sensitivity and fast response [2]. However, the sensors lack in performance regarding the stability of the zero level, typically caused by mechanical degradation and the cross-sensitivity to temperature and vibrations. This is mainly related to physical limitations, e.g. minimal membrane thickness and size, and the long-term stability of the gauge reference pressure for absolute sensors.

Resonator-based concepts offer the opportunity to overcome these limitations. We are presenting an approach using rarefied gas damping of a resonator as well as decoupling the MEMS transducer from the environment for achieving high-stability zero and excellent sensitivity down to the high vacuum range.

Micro Resonator Gauge (MRG) Principle

Rarefied gas damping of MEMS structures is a well-known phenomenon [3]. In contrast to using the free-damping of a resonator structure [4], we take advantage of the squeeze-film effect [5]. As shown in Figure 1, the resonator and the surrounding substrate and electrodes form a high-aspect-ratio gap and a corresponding squeeze-film. The damping effect can be correlated to pressure by driving the resonator at a constant amplitude in closed-loop feedback control. As this approach does not rely on a reference pressure, this is a clear advantage over the conventional pressure sensing techniques to achieve ultimate stability of the zero level. To extend the device sensitivity to the high vacuum range, a high-aspect-ratio gap of close to 1000 is fabricated. Therewith, the sensitivity of the transducer can be extended to 0.1 mTorr and below.

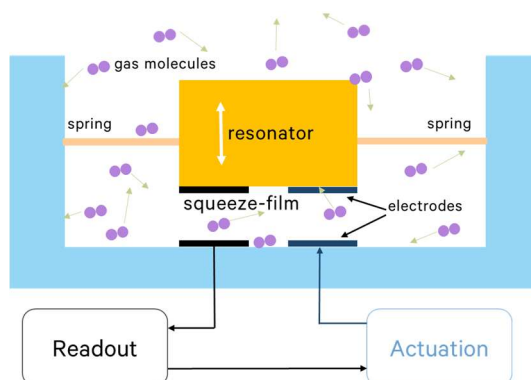


Fig. 1. Schematic cross-section of the MEMS transducer showing the closed-loop operation of a squeeze-film damped resonator.

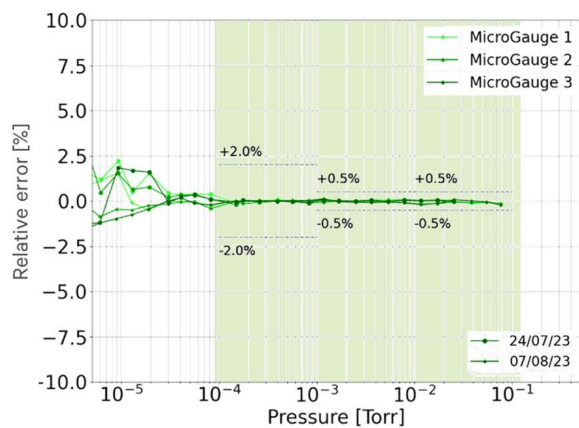


Fig. 2. Accuracy/repeatability of three MRG acquired in two different datasets over an interval of 2 weeks.

MRG Environmental Decoupling

The measurement principle would be significantly impacted by environmental disturbances without an effective decoupling approach. This is mostly related to thermal influence and mechanical noise/vibrations generated by mechanical components and propagated through the whole vacuum equipment.

The MEMS transducer allows for an effective decoupling – no clamping of a membrane, small dimension and local heating for thermal stabilization. The isolation from vibrations proves to be more challenging [6]. The required performance level is obtained by using a tailored mass spring system as a mechanical low pass filter.

Results: Demonstrated MRG Performance

Figure 2 shows the relative error of three MRG sensors with respect to the reference pressure. Two datasets are compared in the time span of two weeks. The dashed lines indicate relative error levels that correspond to the typically achieved ranges for commercial high-end process pressure gauges (CDG type). Our MRG sensors not only stay in these specified tolerance bands, but they show the capability to extend the measurement range by at least one decade without lowering the accuracy and repeatability specification.

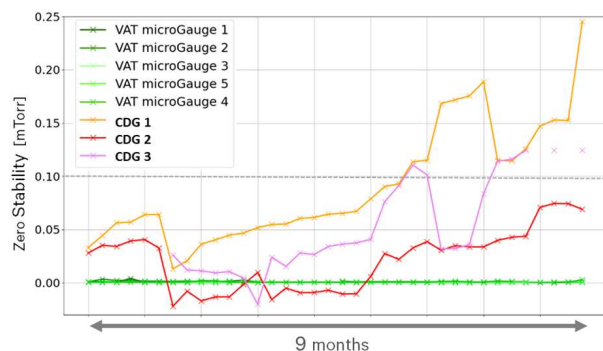


Fig. 3. Comparison of the zero stability of MRG and CDG sensors monitored over a period of 9 months.

The zero-stability of five MRG sensors is depicted in Figure 3. The zero output of the sensors was measured at 10^{-7} Torr or lower, over a period of nine months. These results demonstrate a zero stability below 10^{-2} mTorr across the entire duration of the measurement campaign. This illustrates the technological advantages implemented in the MRG sensor design: the micro resonator based on the squeeze-film damping and an effective thermo-mechanical decoupling from the environment.

Conclusions

A micro resonator gauge (MRG) pressure sensor relying on the squeeze-film damping effect was optimized to extend the range of accurate pressure measurement. Combining the improved sensor performance with an effective decoupling and thermal stabilization of the transducer demonstrated exceptional zero long-term stability. These benefits offer an attractive sensor system that is suitable to meet the challenging requirements for pressure control in semiconductor manufacturing applications.

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