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Vacuum and residual gas composition MEMS sensor

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Abstract

The paper presents a MEMS-type vacuum and residual gas composition sensor, which in contrast to the other miniature sensors, works in medium and high vacuum (10^{-5}–10 Pa). It operates on the principle of ionization of gases inside a silicon-glass microchamber. Pressure is estimated on the basis of the discharge current value, and gas composition − on the basis of spectra of the glowing gases, recorded by a miniature fiber spectrometer.

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Keywords: vacuum gauge, pressure sensor, MEMS, residual gas composition sensor, spectrometry

1.1. Introduction

Different types of the miniature vacuum sensors (e.g. membrane, thermo-conductive, resonant) have been presented in the literature for years and they exhibit very good performance [1, 2]. However, most of them loses sensitivity below 10^{-1} Pa. Gas composition analyzers like chromatographs [3] and mass spectrometers are quite complex systems, and their miniature versions are still at the development stage [4]. The presented device (vacuum and residual gas composition MEMS sensor) is suitable for both – determining a pressure level and specifying a composition of the residual gases. It can be used especially in space applications or for evaluating quality of vacuum MEMS packaging.

2. Design and working principle

The MEMS sensor is formed of three silicon wafers (100 oriented, 3-inch, 0.1 Ω·cm resistivity; ITME Poland) and two glass wafers (1.1 mm thick, Borofloat 3.3; Shott Germany). The bottom and the top silicon wafers play a role of cathodes, and the middle silicon wafer with a centrally located square hole is used as an anode. All three

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electrodes are separated by the borosilicate glass spacers. Additionally, two permanent magnets (NdFeB) are located on both sides of the structure. They generate an uniform magnetic field equal to about 0.4 T. The overall dimensions of the sensor are 20×12×10 mm^3 (fig. 1).

The electric potential distribution inside the sensor microchamber is characteristic for the Penning trap architecture (fig. 2). These conditions are favorable for igniting a gas discharge. Magnetic field makes the electrons move in circles, greatly increasing their paths (required especially in a high vacuum). The pressure can be evaluated on the basis of the ion current flowing between the anode and the cathodes, and the residual gases composition can be determined by observing the spectra of glowing gases – characteristic for individual components. To record this effect a miniature fiber spectrometer (Ocean Optics, 90×60×30 mm^3) is connected to the discharge cell.

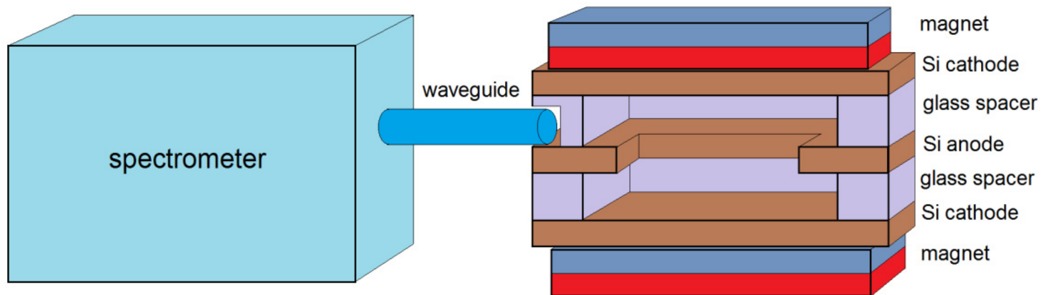


Figure 1: Schematic drawing of vacuum and residual gas composition MEMS sensor (dimensions are not proportional)

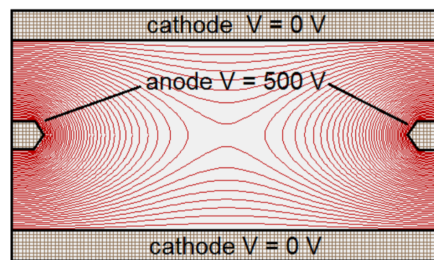
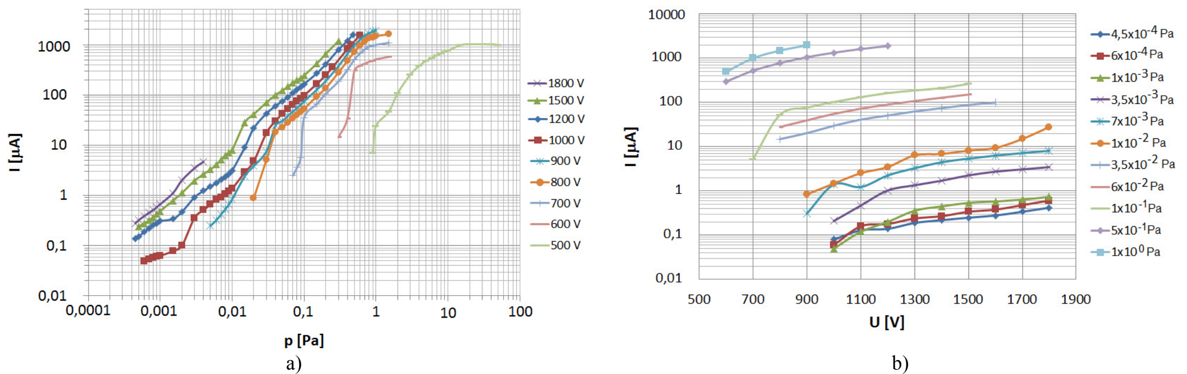


Figure 2: The electric field distribution inside the sensor microchamber

3. Experiment

First, the vacuum sensor has been placed in a reference vacuum chamber and characterized in a wide air pressure range. To obtain a discharge inside the structure, anode-cathode voltage needs to be at least 500 V. In low vacuum (~10 Pa) it corresponds to discharge current equal to about 1 mA (fig. 3a). With decreasing pressure, discharge current decreases, about 1 order of magnitude for 1 order of magnitude of pressure, down to the level when it completely vanishes. To maintain a discharge in high vacuum, voltage has to be increased (even above 1500 V). The increase of voltage causes also the increase of the current, therefore the measurements are more reliable (fig. 3b). On the other hand, in low vacuum one cannot applied too high values, because they would cause breakdowns and dissipation of a very high power. This is a reason, why there is a need of adjusting anode-cathode voltage value to different pressure ranges. The widest pressure range can be covered when voltage is set to 1000–1200 V.

The total pressure limit for the sensor is still unknown. In figure 3 curves start from 4.5×10^{-4} Pa, but it was a limit of our vacuum set-up. In hermetically sealed structures, during on-chip pumping [5], the lowest measured current reached few nanoamperes, which gives pressure between 10^{-6}–10^{-5} Pa.



a) b)

Figure 3: Discharge current as a function of: a) air pressure for anode-cathode voltage from 500 to 1800 V, b) anode-cathode voltage for air pressure from 1 to 4.5×10^{-4} Pa.

Calibration curves have been determined not only for air, but in the second experimental stage also for different kinds of gases introduced into reference vacuum chamber: nitrogen, oxygen, helium, argon, neon, CO_2 and hydrogen. These compounds differ in molecule sizes and effective cross-section, and this correlates with measured discharge currents (fig. 4). The largest current was obtained for carbon dioxide, quite similar values were measured for air, nitrogen, oxygen and argon, the lowest currents correspond to hydrogen and helium.

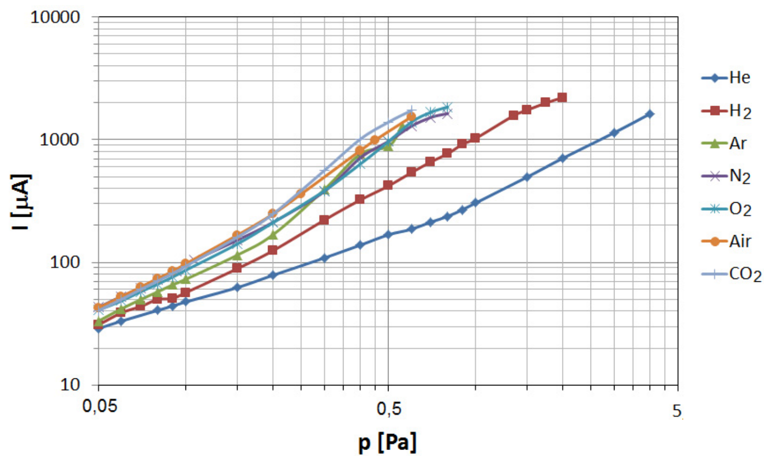


Figure 4: Discharge current as a function of pressure for different gas species, U_{AC} = 1000 V, base pressure 2×10^{-5} Pa.

Discharge current is the most important parameter for determining the pressure, but much information can also be derived from the observation of a glow visible during the ionization process. Each ionized and excited gas molecule which recombines, emits characteristic light waves (fig. 5). The exact composition of the residual gases can be determined on the base of the spectra, recorded by a miniature fiber spectrometer (fig. 6). This method is useful in pressure range from 10^{-1} Pa to 1000 Pa. Below 10^{-1} Pa the discharge becomes dark, and spectrometer is not enough sensitive to record it. Above 1000 Pa the distance between the electrodes is too large to maintain the discharge.

Figure 5. Glow discharge for nitrogen, helium and neon.

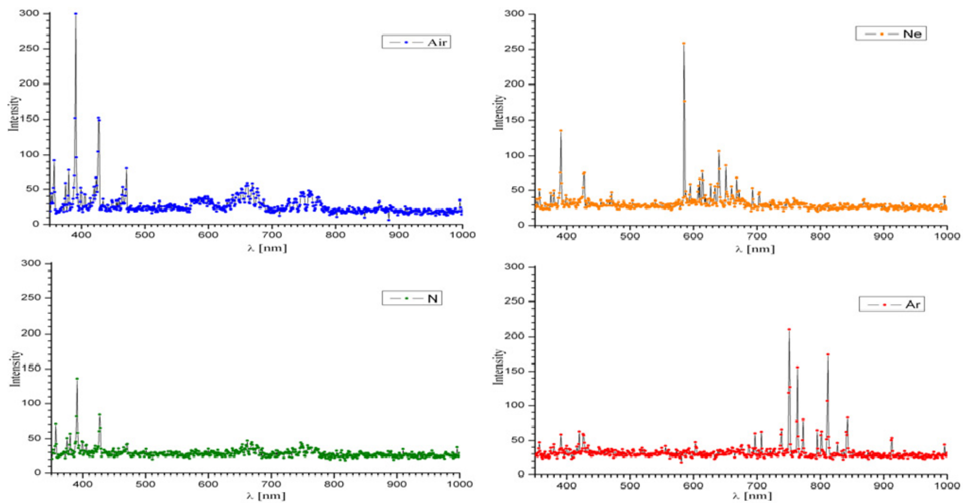


Figure 6. Discharge spectra recorded for: air, nitrogen, neon, argon inside the sensor microchamber; p = 500 Pa

4. Conclusion

A miniature MEMS sensor suitable for determining pressure level and residual gas composition has been presented. Calibration curves obtained for different supply and pressure conditions as well as for different gases have been shown. The pressure gauge works in very wide vacuum range (from 10 to 10^{-5} Pa), and is an only option when one wants to measure high vacuum in a miniature volume.

Acknowledgements

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References

[1] A. Górecka-Drzazga, Miniature and MEMS-type vacuum sensors and pumps, Vacuum 83 (2009) 1419–1426.
[2] F. Volklein, A. Meier, Microstructured vacuum gauges and their future perspectives Vacuum, 82 (2008) 420 – 430
[3] Y. Qin and Y. B. Gianchandani, A facile, standarized fabrication approach and scalable architecture for a micro gas chromatography system with integrated pump, Proc. of Transducers and Eurosensors XXVII Conference 2013, pp. 2755-2758.
[4] Ch.-M. Tassetti, R. Mahieu, J.-S. Danel, O. Peyssonneaux, F. Progent, J-Ph. Polizzi, X. Machuron-Mandard, L. Duraffourg, A MEMS electron impact ion source integrated in a microtime-of-flightmass spectrometer, Sensors & Actuators B: Chemical 189 (2013) 173-176.
[5] T. Grzebyk, A. Górecka-Drzazga, J. A. Dziuban, Glow-discharge ion-sorption micropump for vacuum MEMS, Sensors & Actuators A, 208 (2014) 113-119.