DOI 10.5162/EUROSENSORS2025/MP62

Piezoresistive Pressure Sensors Based on ZrO_2 Substrate Fabricated by Photolithography and Inkjet Printing

Vojtěch Povolný[1], Alexandr Laposa[1], Jiří Kroutil[1]
[1] Czech Technical University in Prague, Department of Microelectronics, Technická 2, 16627 Praha 6, Czech Republic,
povolvoj@fel.cvut.cz

Summary:

This work compares piezoresistive pressure sensors fabricated on ZrO_2 substrates using two different manufacturing technologies: photolithography and inkjet printing. Both fabrication methods produced sensors with precise and reproducible dimensions, with initial tests showing clear differences in sensitivity and performance, highlighting the potential of each technology for specific applications.

Keywords: Piezoresistive sensor, Inkjet printing, Photolithography, Ceramic substrate, Pressure measurement

Background, Motivation and Objective

Piezoresistive pressure sensors using ceramic substrates are particularly suitable for harsh environments due to their excellent mechanical properties, chemical inertness, and thermal stability. Alumina (Al_2O_3) and zirconia (ZrO_2) are widely used ceramic materials. Al_2O_3 is primarily beneficial due to its high hardness and superior wear resistance, whereas ZrO_2 offers enhanced strength, improved fracture toughness, and a comparatively lower Young's modulus [1, 2].

Inkjet printing has recently emerged as an attractive alternative due to its precise deposition capabilities, design flexibility, and cost-effectiveness. In contrast, photolithography remains a benchmark technology known for high precision and reliability in sensor manufacturing. Understanding the comparative performance of these two distinct fabrication methods is critical for optimizing sensor development strategies [3].

The objective of this research is to fabricate and evaluate piezoresistive pressure sensors on ZrO_2 substrates separately using photolithography and inkjet printing to assess their respective strengths and limitations, ultimately providing guidance for selecting optimal fabrication approaches for specific sensor applications.

Description of the New Method or System

Two separate sets of piezoresistive pressure sensors were fabricated using 32 mm diameter ZrO_2 ceramic substrates. Each set featured membranes with a thickness of 600 µm, structured with meander-shaped metal strain gauges.

The first set of sensors was fabricated using traditional photolithography, utilizing precise metal patterning to form aluminum strain gauges. The second set of sensors employed DragonFly IV inkjet printing technology from NanoDimension, applying conductive silver nanoparticle inks. Structures fabricated by photolithography achieved linewidths around 40 µm, gaps of 80 µm, and a uniform thickness of approximately 50 nm. Inkjet-printed structures achieved linewidths around 72 µm, gaps of 110 µm, and a uniform thickness of approximately 1.6 µm (*Fig. 1.*).

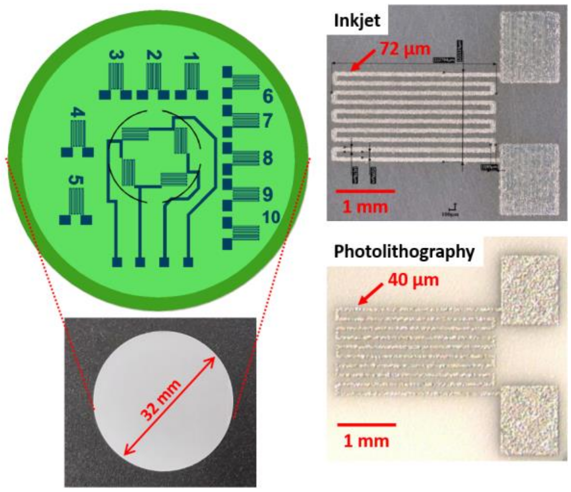

Fig. 1. Layout and details of test structures fabricated by inkjet printing and photolithography.

Results

Both manufacturing methods demonstrated excellent dimensional precision and repeatability. Pressure tests conducted at 27 kPa exhibited differences in sensitivity between the two technologies. The test rig (*Fig. 2.*) includes a custom 3D-printed fixture for mounting ceramic sensor samples, connected to a pneumatic pressure system. The sensors are secured using wing screws and contacted via probe wires for electrical measurements. The setup allows precise pressure application and real-time monitoring of resistance changes using a PC-connected interface. Electrical characterization revealed that sensors fabricated via photolithography exhibited resistance values around ~7 kΩ, which are suitable for conventional sensor applications. In contrast, inkjet-printed sensors showed significantly lower resistance values (~20 Ω), creating challenges for accurate resistance measurement and limiting their practical use in standard pressure sensing applications. The observed difference in resistance is primarily attributed to the disparity in the thickness of the deposited metallization layers between the two fabrication processes.

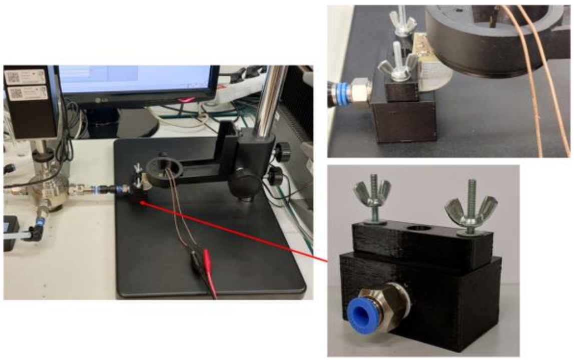

Fig. 2. Measurement setup for pressure sensors

Comparing both technologies, inkjet printing provides benefits including flexible design capabilities and reduced production complexity, while photolithography ensures highly precise patterns and reliable performance suitable for applications requiring stringent specifications.

Future work involves membrane thickness optimization for both methods, employing thinner membranes to enhance sensor sensitivity significantly. Additionally, exploring the integration of carbon-based inks for inkjet-printed sensors is planned, which could enhance performance through increased strain sensitivity and increased resistance.

References

[1] Shakir, R. A., & Géber, R. (2023). Structure and properties of ZrO_2–Al_2O_3–MgO porous ceramic for biomedical applications. Results in Engineering, 18, 101104; doi: 10.1016/j.rineng.2023.101104

[2] L. Zhao, J. Zuo, B. He, and Y. Jiang, “Properties of ceramic substrate materials for high-temperature pressure sensors for operation above 1000 °C,” Journal of Sensors, vol. 2018; doi.org/10.1155/2018/2317295

[3] J. Anglada, J. Molera, N. García, J.M. Colom, M. Pinyol, A. Duran, “Integration of conductive silver sensors on zirconia ceramics by screen-printing for monitoring strain under applied load,” Ceramics International, vol. 49, no. 5, pp. 7583–7590, 2023; doi.org/10.1016/j.ceramint.2022.12.005

Acknowledgements

This research has been supported by the Technology Agency of the Czech Republic under the project FEIM (No. TN02000067 “Future Electronics for Industry 4.0 and Medical 4.0” under the National Centre of Competence Programme. Special thanks go to ELCERAM a.s.,Czech Republic and Profactor GmbH, Austria for specimen manufacturing in the production facilities.