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Advanced Glass Packaging with Integrated Stress Relief Structures for MEMS Pressure Sensors

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Summary:

Advanced glass packaging with integrated stress relief structures for MEMS pressure sensors, enabled by Laser Induced Deep Etching (LIDE) technology, effectively isolates sensing elements from package-induced stresses. Our simulations demonstrate that hermetically sealed corrugated membrane structures reduce thermal induced stress by up to 99,4 % when subjected to CTE mismatch between glass and FR4 substrates. The integrity and mechanical stability of the glass is maintained, as processing with the LIDE technology does not create any imperfections such as microcracks or internal stresses.

Keywords: MEMS sensors, glass packaging, stress relief structures, Laser Induced Deep Etching, glass micro features

Introduction

MEMS pressure sensors are critical components in numerous industrial, automotive, medical, and consumer applications, providing precise pressure measurements in increasingly demanding environments [1, 2, 3]. However, one of the most significant challenges remains the effective isolation of the sensing element from external mechanical and thermal influences [4]. The coupling between the silicon chip and its package, as well as between the package and substrate or circuit board, introduces substantial performance limitations due to thermal mismatch between different materials, creating stresses that directly transfer to the sensor membrane and result in measurement errors [4, 5]. Conventional approaches involve complex and costly stress relief structures that increase production costs and limit miniaturization or the use of soft adhesives that can degrade over time are limited in temperature and pressure stability [4, 6, 7]. This paper explores how Laser Induced Deep Etching (LIDE) technology can be leveraged to create integrated stress relief structures directly within glass packaging for MEMS pressure sensors, potentially enabling higher accuracy, improved reliability, and expanded operating temperature ranges while reducing manufacturing complexity and cost [8, 9].

Glass integrated stress relief structures

This study employed LIDE technology to fabricate integrated stress relief structures in glass packages for MEMS pressure sensors. LIDE is a two-step process: first, a specialized laser process that precisely modifies the glass; second, a selective wet etching process that etches modified regions much faster than unmodified glass. This approach allows for minimum feature sizes down to 5 µm with positional accuracy of ±1 µm with very low surface roughness [9]. We designed and fabricated hermetically sealed glass carrier substrates with corrugated membranes (10 - 30 µm thickness, 400 µm depth, 50 µm channel width) for stress relief as shown in Figure 1. In a previous publication we have demonstrated fracture strength of ~1 GPa of LIDE processed glass springs with cross-sections of 30 µm × 260 µm in mechanical testing confirming the absence of strength-limiting defects [10].

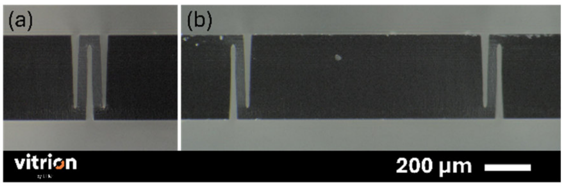

Figure 1: Cross section of double membrane structure and (b) platform with single membrane structures.

The test samples (2.5 × 2.5 mm²) were made of 500 µm thick Borosilicate glass (Schott BF33) that has a very similar coefficient of thermal expansion (CTE) to Si. We have carried out Finite Element Modeling simulations using Ansys Mechanical to optimize designs and predict performance, comparing the substrates with and without stress relief structures. The simulations analyze a thermal induced tensile stress of a Si pressure sensor membrane (20°C to 85°C) caused by the CTE mismatch between borosilicate glass (3.3 ppm/K) and FR4 (16 ppm/K). The Si die (1 × 1 mm²) was placed on the glass sample.

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Simulation Results

FEM simulations of the stack of FR4, BF33 and Si show a significant reduction of the mean Von-Mises stress on the sensor membrane from 15.9 MPa to 0.277 MPa (98.26 % reduction) using a single corrugated membrane (30 µm thickness) for stress relief when subjected to thermal loading representing a 65°C temperature change with a CTE mismatch of 12.7 µm/m/K between borosilicate glass and FR4 substrate. A dual-membrane configuration reduces the induced stress to 0.104 MPa (99.35 % reduction).

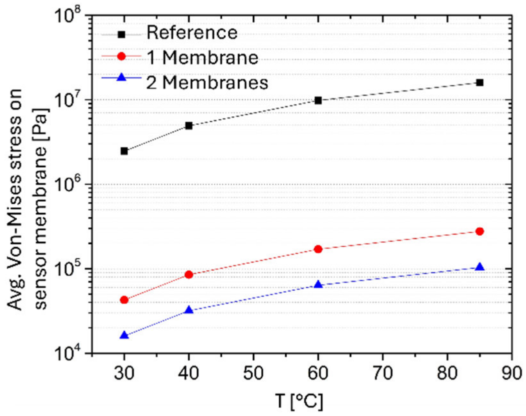

Figure 2: Simulation results of the average Van-Mises stress on the membrane of a 1 × 1 mm² silicon die placed in the middle of the glass substrate without microstructures (Reference), with one membrane and with two membranes (30 µm thickness).

Stress distribution analysis revealed that the microstructures created mechanical "breaks" in stress propagation paths, absorbing and redistributing induced stress while maintaining integrity and out-of-plane stability.

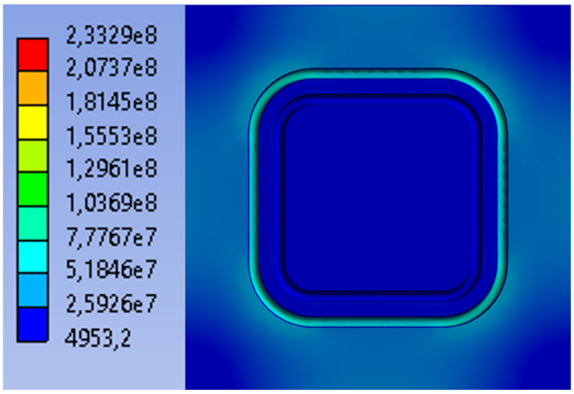

Figure 3: Stress distribution on the glass substrate with two corrugated membranes.

Conclusion

This study demonstrates that micro structured glass has enormous potential for improvements in thermal stability, mechanical stress isolation, and high-temperature operation of MEMS devices facing thermal and mechanical stress challenges. These advancements address critical limitations in current MEMS pressure sensor technology and open new possibilities for applications across automotive, industrial, medical, and aerospace sectors where accurate pressure measurement under varying environmental conditions is essential. Future work will be focused on process integration and optimizing design configuration.

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