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MEMS Precision Sensors Based on Process Innovation Technology

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Abstract: This article introduces a novel process for achieving micro-scale thermal isolation through solid porous 3D microstructures. It proposes a method to improve existing thermal MEMS devices by utilizing thin-film membrane structures, develops a model for estimating the thermal conductivity of porous microstructures, and constructs porous 3D microstructures made of three different powder materials, studying their applicability for thermal isolation. Breakthroughs have been achieved in process preparation technology, enabling the production of precision MEMS sensors. These sensors are expected to find wide applications in smart cars, intelligent healthcare, electronic resonance sensors, and other fields.

Keywords: Micro-Electromechanical Systems; Sensor; Etching Process; Single Crystal Wafer.

1. Research Background

Through-silicon via (TSV) etching and MEMS applications require a wide range of etching depths. In the 1980s, deep reactive ion etching (DRIE) was extensively studied in the field of MEMS, especially in micromechanical manufacturing. The results entered mass production in the 1990s.

By 2018, DRIE achieved breakthroughs in manufacturing multilayer complex MEMS structures. Researchers used DRIE to create high aspect ratio microstructures and integrated different structural layers through wafer bonding. This provided support for high-precision manufacturing in fields such as inertial sensors and microfluidic devices. With continued research on MEMS, DRIE technology reached maturity in mass production by 2022, particularly in consumer electronics. Optimized DRIE processes enabled large-scale production of MEMS microphones and accelerometers in smartphones while ensuring product consistency and reliability.

In 2023, DRIE technology made further progress in manufacturing MEMS devices for microwave and millimeter-wave applications. High aspect ratio microstructures were used to produce high-performance filters and antennas for millimeter-wave frequencies, showing superior characteristics in communication and radar systems.

2. Research Status at Home and Abroad

(a) International Research Status

MEMS (Micro-Electro-Mechanical Systems) technology is a multidisciplinary field combining microelectronics, optics, and microfluidics. It has found widespread global application. Here is an overview of MEMS process technology research abroad:

1. Silicon-based MEMS Process Technology: This is the primary approach abroad, focusing on improving the precision of silicon micromachining and ensuring reproducibility in MEMS processes. For example, the European CSEM institute developed a new micromachining technology called "plowing technique" that improves the accuracy and surface finish of silicon micro-machining.
2. Piezoelectric MEMS Process Technology: This branch is mainly used for MEMS devices like micro-mechanical oscillators and sensors. Researchers at the University of Arizona are studying new piezoelectric materials that enhance the performance and stability of micro-mechanical oscillators.
3. Bio-MEMS Process Technology: A burgeoning field focused on biomedical devices and biosensors. For example, researchers at MIT are studying a new biomaterial called "polymer microarray," which can be used to create highly sensitive biosensors and microfluidic controllers.
4. Optical MEMS Process Technology: Another branch of MEMS technology that is primarily used in micro-optical devices and optical sensors.

Overall, international MEMS research focuses on improving material properties and manufacturing process reproducibility to meet the needs of various applications.

(b) Domestic Research Status

China's MEMS (Micro-Electro-Mechanical Systems) manufacturing process technology has made significant progress and achievements, summarized as follows:

1. Manufacturing Process Research: China's MEMS manufacturing process has reached a certain level, with capabilities in thin-film deposition, photolithography, wet etching, ion beam etching, and laser micromachining.
2. Design and Simulation Research: With advances in computer technology, various design and simulation software have become increasingly sophisticated, providing strong support for MEMS research and development.
3. Application Research: China's MEMS application research is expanding, covering areas like sensors, micro-electromechanical systems, optical devices, and biomedical applications. Many MEMS products have been successfully applied in industrial control, environmental monitoring, medical diagnostics, and have received positive market feedback.
4. National Policy Support: The Chinese government highly prioritizes the development of MEMS technology,

formulating policies and plans such as the "863 Plan," "New Generation Information Technology Initiative," and "Integrated Circuit Industry Development Plan" to ensure policy support and funding, promoting the growth of MEMS technology.

Despite significant progress in MEMS manufacturing process technology, China still lags behind developed countries and needs to further strengthen research and development.

3. Core Technologies

This work presents a new process for achieving microscale thermal isolation through solid porous 3D microstructures, improving existing thermal MEMS devices using thin-film membrane structures. A model for estimating the thermal conductivity of porous microstructures was developed, and porous 3D microstructures made from three different powder materials were constructed to study their suitability for thermal isolation.

This process enables the production of six-inch and eight-inch wafers at the micron level. For six-inch wafers, a batch yield of 95% can be achieved, producing up to 576 sensor chips per wafer, making it an industry leader.

During the development of precise MEMS sensors, the project faced challenges with high-pressure etching processes, including deep silicon etching, uneven top-to-bottom passivation, and rough sidewalls. To address these, three core technologies were proposed:

1. Innovative Introduction of Micron-sized Solid Porous Structures: By designing innovative material structures, the thermal resistance effect is enhanced, preventing high-temperature deformation, reducing product loss, and increasing the production efficiency of low-power devices such as wearables.
2. Pseudo-Bosch Etching MEMS Deep Etching Structural Technology: By improving equipment to increase molecular space utilization, the optimal etching aspect ratio was determined through thousands of experiments, enhancing yield and broadening the application scope.
3. Optimizing Bulk Silicon MEMS Long Mask Microfabrication Standard Processes: The wafer chip etching layout was redesigned, and after applying the first two technologies, the preparation process was refined, improving batch production capacity.

These technologies enabled high-precision deep silicon etching at the micron scale and successfully developed and applied a model for estimating the thermal conductivity of porous microstructures. The depth can reach several hundred microns, with widths of 5-10 microns, using porous 3D microstructures made from three different powders.

4. Conclusion

The MEMS device industry has increasingly high technological requirements, and its process flows have become more complex. Due to the diverse types of MEMS sensors, each with unique functions and application scenarios, there is no standardized fabrication process. They differ in design principles, system structures, and packaging forms. Currently, China faces challenges in the MEMS sensor field, including insufficient system applications and supporting services, as well as uneven distribution of industrial resources. This is particularly evident in the relatively weak technology in upstream sectors such as design, processes, and materials. However, some regions that have developed more maturely have established a comprehensive MEMS industry system and research innovation mechanisms, achieving several key technological breakthroughs and gradually forming an industrial agglomeration effect, laying a foundation for the commercialization of MEMS devices.

Looking ahead, we can leverage the advantages of industrial clusters, fully utilize the benefits of resource aggregation, enhance product brand effects, optimize industrial structures, and improve the MEMS industry chain. At the same time, we should promote deep collaboration between enterprises and research institutions, construct a development model that integrates industry, academia, and research, and form a sensor industry base with strong independent innovation capabilities and a complete industrial chain. Additionally, improving the investment and financing environment and technology transfer mechanisms will facilitate the healthy and rapid development of the MEMS sensor industry.

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