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High reliability of MEMS packaged capacitive pressure sensor employing 3C-SiC for high temperature

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Abstract

This study develops the prototype of a micro-electro-mechanical systems (MEMS) packaged capacitive pressure sensor employing 3C-SiC diaphragm for high temperature devices. The 3C-SiC diaphragm is designed with the thicknesses of 1.0 µm and the width and length of 2.0 mm x 2.0 mm. The fabricated sensor is combined with a reliable stainless steel o-ring packaging concept as a simple assembly approach to reduce the manufacturing cost. There is an o-ring seal at the sensor devices an advantageous for high reliability, small size, lightweight, smart interface features and easy maintenance services. The stability and performance of the prototype devices has been tested for three test group and measured by using LCR meter. The prototypes of MEMS capacitive pressure sensor are characterized under static pressure of 5.0 MPa and temperatures up to 500°C in a stainless steel chamber with direct capacitance measurement. At room temperature (27°C), the sensitivity of the sensor is 0.0096 pF/MPa in the range of pressure (1.0 – 5.0 MPa), with nonlinearity of 0.49%. At 300°C, the sensitivity is 0.0127 pF/MPa, and the nonlinearity of 0.46%. The sensitivity increased by 0.0031 pF/MPa; corresponding temperature coefficient of sensitivity is 0.058%/°C. At 500°C, the maximum temperature coefficient of output change is 0.073%/°C being measured at 5.0 MPa. The main impact of this work is the ability of the sensor to operate up to 500°C, compare to the previous work using similar 3C-SiC diaphragm that can operates only 300°C. The results also show that MEMS packaged capacitive pressure sensor employing 3C-SiC is performed high reliability for high temperature up to 500°C. In addition, a reliable stainless steel o-ring packaging concept of MEMS packaged capacitive pressure sensor.

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1. Introduction

In recent years, there has been enormous growth in the prevalence of Micro Electro Mechanical Systems (MEMS) technology in harsh environments especially at high temperatures, high oxidizing, corrosive environments, strong vibrations and high radiation. The limitation of silicon based microsystems for harsh environment applications are several such as the operating temperature and radiation limit of silicon electronics due to its narrow bandgap, its ease of oxidation, corrosion and erosion. It is susceptibility to being etched by reactive media and its mechanical strength decay at high temperature. Thus, harsh-environment applications require enabling platform materials such as silicon carbide. It is emergence largely built structures on the development of silicon carbide into thin-film technology related micromachining and microfabrication processes [1].The introduction of silicon carbide into the MEMS materials is encouraged by its favourable mechanical strength, corrosion resistance, electrical and thermal performance, and biocompatibility. Silicon carbide is extremely well suited for harsh environments which were motivated to pursue the development of this platform material for microsystem and particularly appropriate in high temperature pressure sensors [2]. New legislation has provided incentive to reduce emission, pollutants, and noise of MEMS industries. This is recognized by improving sensor an electronics made from reliable high-temperature platforms materials are required for optimizing MEMS performance. The instrumentation is able to provide reliably monitor operating parameters in and around application environments.

Silicon carbide has a potentially useful semiconductor for high temperature applications and its properties do not degrade at elevated temperatures. Silicon carbide is considerate the leading alternative materials to silicon for harsh environments applications because silicon carbide is a capable material for the development of high-temperature solid-state electronics and transducers owing to its excellent electrical, thermal, mechanical and chemical properties [3]. Silicon carbide has excellent electrical characteristics such as the wide band-gap is 9.3 eV, high breakdown electric field (10 times higher than Si), high electron saturation drift velocity low intrinsic carrier concentration which allow stable electronic properties under harsh environments that make it a superior candidate for high-temperature electronic application [4]. In term of mechanical properties, silicon carbide has a higher stiffness and fracture strength as well as resists wear, oxidation and corrosion better than silicon. In addition, an outstanding mechanical and chemical property as compared to silicon makes silicon carbide a more prominent material for MEMS fabrication where highly erosive environments are involved [5]. Silicon based sensors are not well suited for harsh environments applications due to silicon material properties degrade at temperature above 500°C and silicon electronics typically cannot survive extended operation beyond 150°C [6]. Silicon carbide is an extremely rugged, stable material, having higher electrical efficiency and rapid response time when used in power electronics devices [7]. Due to the intended high temperature and pressure of the operating ambient, silicon carbide ultimately stands out as the most suitable material to being more environments friendly. Hence, silicon carbide is used to extend the usefulness of diaphragm-based pressure sensor and necessary electronic in harsh environment applications.

A pressure sensor is combines two principles of measurement into integrated unit with optical and electronic parts [8]. The sensing element for both integrates parts is an employed silicon carbide diaphragm that deflects under differential pressure. Pressure sensors utilize an elastic membrane known as diaphragm to detect pressure differentials. The diaphragm is design to deflect consistent to applied pressure on its surface. The embossed silicon carbide membrane deflects under higher range of extreme pressure differential [9]. The sensing mechanism of this pressure sensor device depends on the capacitance between the mechanically deformed diaphragm and the underlying electrode.

Silicon carbide MEMS capacitive pressure possesses for harsh environment operation capability including platform for high sensitivity and configuration results in improved sensing properties for use in a wide range applications such as automotive, nuclear station, aerospace, and oil and gas exploration [10]. MEMS pressure sensor manufactured using silicon carbide are more robust and extremely strong, thus MEMS pressure sensor based on silicon carbide can operate at high temperatures up to 500°C and under harsh environments compared to its silicon counterparts. This study proposed developments of MEMS pressure sensor based on silicon carbide for monitoring gas turbine performance. Monitoring of the internal pressure and performance inside gas turbine is crucial due to proper operation would ensure less degradation and wear of components, which in turn increases parts lifetime and machine reliability [11].