高温壓阻式感測器之研究

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摘要

此論文研究可工作於高温的壓阻式感測器，以滿足在高温環境下，日益增加的量測需求。高温壓阻式感測器之製作，需要使用可工作於高温的半導體材料。在這個論文研究中，以絕緣層上覆多晶矽結構(PSOI)及單晶 6H-SiC 等兩種材料分別作為高温壓阻式感測器的材料。由於 PSOI 材料結構上具有絕緣層，在壓阻和基材間無 PN 接合，因此可用在 250℃以上的工作環境。在另一方面，由於 6H-SiC 具有能帶三倍寬於矽的特性，因此被預測可工作在 700℃以上的環境。為了進一步研究高温壓阻式感測器，首先，在論文裏將提出高温壓阻式壓力感測器。由於多晶矽具有等向的壓阻性，且 6H-SiC 亦同樣地在(0001)晶面上具有等向的壓阻性，因此，具中央突起結構之圓形薄板被用來作為感測器的結構。這樣的結構，使得製作出的壓力感測器不但具有高靈敏度，在適當的封裝設計下亦具有過載的保護機制。在求得具中央突起結構圓形薄板壓力感測器之解析解後，可

得感測器的設計指導方針，其包括：圓形薄板上壓阻位置及中央突起結構半徑與圓形薄板半徑比之決定、過載保護的設計，以及中央突起結構觸碰底板後，感測器第二靈敏度的計算。

具中央突起圓形薄板之結構除可作為壓力感測器之應用外，由於接觸力可經由中央突起結構傳遞，文中更進一步應用該結構，提出壓阻式力感測器。在相同的感測器結構下，由於負載改為力，力感測器之解析解不同壓力感測器。在建立該感測器模型後，文中對於擺放壓阻的位置以提高靈敏度、減少線性誤差，以及感測器的過載保護設計上有具體之建議。

在分別分析及設計壓力與力感測器之後，論文將敘述製作 PSOI 及 6H-SiC 壓阻式感測器的微製程。所製作的壓力及力感測器的面積為 4×4 釐米。在量測之後，PSOI 力感測器在室溫下具有-9.9 μV/V/g.w.的靈敏度，1.5%的非線性度及 4.3%的遲滯度。6H-SiC 力感測器在室溫下具有-31 μV/V/g.w.的靈敏度，9.8%的非線性度及 24%的遲滯度。

在高溫測試 PSOI 及 6H-SiC 壓力感測器之前，發展基於粗鋁的打線、氧化鋁陶瓷隔離片及載具、和高溫密封黏膠的封裝技術。經測試的結果，該封裝於 350℃、10 Bar 的大氣壓力下，仍維持密封的特性。PSOI 壓阻式壓力感測器可工作至 300℃。在測試後，其於室溫具有 377 μV/V/Bar 的靈敏度、0.07%的非線性度及 0.47%的遲滯度。偏移量的溫度係數(TCO)及靈敏度的溫度係數(TCS)分別為 6.88 μV/V/°C 和-0.0002 %/°C。6H-SiC 壓力感測器於量測溫度超過 200℃時發生

破裂。雖然如此，它在室溫下具有 1.0 mV/V/Bar 的靈敏度、3%的非線性度及 7%的遲滯度。其偏移量的溫度係數及靈敏度的溫度係數分別為 1.74 μV/V/°C 及 -0.361 %/°C。

綜合上述，此論文研究可工作於高溫的壓阻式感測器。在分別求得基於具中央突起結構之圓形薄板的壓力及力感測器解析解後，可設計具有高靈敏度及過載保護的感測器。所設計的感測器分別使用兩種高溫材料製造：PSOI 及單晶 6H-SiC。在發展針對 PSOI 及單晶 6H-SiC 的微製造後，可分別製作出所設計的壓阻式壓力及力感測器。在量測後，所製作出的高溫壓阻式感測器具有高靈敏度、高線性度及低遲滯度，證明此論文研究所提出之設計及製作高溫壓阻式感測器方法為具體可行。

A STUDY OF HIGH TEMPERATURE PIEZORESISTIVE SENSORS

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ABSTRACT

To fulfill the increasing need for measurement devices in high temperature environment, sensors that can work at high temperature are investigated in this dissertation research. In this research, both polycrystalline Silicon-on-Insulator (PSOI) and single crystal 6H-SiC substrates are used as high temperature piezoresistive sensor materials. Because PSOI has an insulation layer between the piezoresistors and the substrate so it forms no pn-junctions, the PSOI piezoresistive sensor can work at temperatures above 250°C. 6H-SiC has a wide band gap (about 3 times that of silicon), thus 6H-SiC piezoresistive sensors are predicted to work above 700°C. To further contribute to research related to high temperature piezoresistive sensors, a high

temperature piezoresistive pressure sensor is proposed in this dissertation at first. Because polysilicon shows isotropic piezoresistivity and 6H-SiC shows isotropic piezoresistivity on the (0001) surface, a circular membrane with center boss structure is chosen for the design of the sensor. With such a structure, the pressure sensor has not only high sensitivity but also an over-range protection mechanism if the package is designed properly. After deriving the analytic solution for the pressure sensor based on the circular membrane with center boss structure, guidelines which include the arrangement of the piezoresistors on the circular membrane, the determination of the ratio of the center boss radius to the circular membrane radius, the design of over-range protection and the calculation of the second sensitivity when the center boss touches the bottom plate are given.

To further utilize the circular membrane with center boss structure, a piezoresistive tactile sensor is proposed because the contacting force can be conducted from the center boss structure. Since the applied load is a force, the analytic solution of the tactile sensor is different from the one of the pressure sensor. After the derivation of the sensor’s model, the arrangement of the piezoresistors and the design of the over-range protection are suggested in order to maximize the sensitivity while minimizing the loss of linearity.

Then the micro fabrication process of the PSOI and 6H-SiC sensor is developed.

Both the fabricated pressure and tactile sensors have a size of 4×4 mm^2. After testing, the PSOI tactile sensor shows a sensitivity of -9.9 μV/V/g.w., a nonlinearity of 1.5% and a hysteresis of 4.3% at room temperature. The 6H-SiC tactile sensor has a sensitivity of -31 μV/V/g.w., a nonlinearity of 9.8% and a hysteresis of 24% at room temperature.

Before the testing of the PSOI and 6H-SiC pressure sensor at high temperatures, a package based on thick aluminum bonding wire, alumina spacer and carrier and high temperature hermetic sealing adhesives is developed which is capable of maintaining hermetic at a pressure of 10 bar and a temperature of 350°C. The PSOI piezoresistive pressure sensor is tested up to 300°C and has a sensitivity of 378 μV/V/bar, a nonlinearity of 0.07% and a hysteresis of 0.47% at room temperature. TCO and TCS are 6.88 μV/V/°C and -0.0002 %/°C, respectively. The 6H-SiC pressure sensor is measured up to 200°C and was found broken as the temperature goes further higher. However, it has a sensitivity of 1.0 mV/V/bar, a nonlinearity of 3% and a hysteresis of 7% at room temperature. TCO and TCS of the 6H-SiC pressure sensor are 1.74 μV/V/°C and -0.361 %/°C, respectively.

To summarize, piezoresistive sensors that can work at high temperatures are studied in this dissertation research. With the derived analytic solutions, both the pressure and tactile piezoresistive sensor based on a circular membrane with center

boss structure can be designed with high sensitivity and over-range protection. Two kinds of semiconductor materials, namely PSOI and 6H-SiC, are used to fabricate the designed sensors. With the developed micro fabrication process for PSOI and 6H-SiC, the piezoresistive pressure and tactile sensor are fabricated. After the measurement, all the fabricated high temperature piezoresistive sensors demonstrate high sensitivity, good linearity and low hysteresis. Thus, a feasible way of making high temperature piezoresistive sensors is presented.

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