# CHAPTER 1

# INTRODUCTION

Because of the linearity and the easy measurement circuits, piezoresistive sensing is widely-used among the transduction methods. A piezoresistor is a resistor that changes its resistivity with respect to the applied stress. After discovering the piezoresistive effect of silicon[1] and developing the technology of silicon bulk micromachining[2-4], micro piezoresistive silicon pressure sensors were first proposed by Tufte[5] in 1962. Until now, the piezoresistive silicon pressure sensor still plays an important role in Micro Electro-Mechanical Systems (MEMS) industry.

Usually, a micro piezoresistive pressure sensor is based on a silicon substrate. With anisotropic etching, rectangular diaphragms can be formed. Because of the comparable magnitudes of the longitudinal and transverse piezoresistance coefficients, the piezoresistor of the pressure sensor is defined either by ion implantation or by boron diffusion into an n-type silicon substrate. However, the leakage current between p-n junctions will increase with increasing temperature, which limits the working temperature of the sensor to about 120°C. With the increasing demands of electronic devices that can work at high temperatures and in harsh environment[6], the micro piezoresistive sensor based on silicon p-n junction meets its limitations. Therefore, polycrystalline Silicon-on-Insulator (PSOI) structures and SiC substrate materials are introduced to make piezoresistive sensors in this dissertation research.

Like Silicon-on-Insulator (SOI) structures, PSOI structures also have an insulating layer, mostly silicon dioxide, between the polysilicon and the silicon substrate. The polysilicon piezoresistive sensor made by PSOI consists of polysilicon piezoresistors on an oxide layer. There is no leakage current between the piezoresistors and the substrate. Thus, the sensor can work at higher temperatures. Extensive studies of PSOI pressure sensors have been carried out by some authors[7-11]. Low costs and the widely available fabrication process are the advantages of the PSOI material scheme in comparison with SOI or other materials, like SiC. Moreover, the Temperature Coefficient of Resistance (TCR) of polysilicon can be adjusted by the doping type and concentration. It allows the design of temperature-independent piezoresistive sensors[9].

SiC is believed to be a promising material for electronic devices operating at high temperatures, high power and high frequency because it exhibits a larger band gap, a higher breakdown field, a higher thermal conductivity and a higher saturation velocity as compared to Si[12][13]. It is also known for its mechanical hardness, chemical inertness, high thermal conductivity, and electrical stability, making it an excellent material for sensors and actuators for harsh environment applications[14-16]. SiC appears in numerous different polytypes. Among these polytypes, three are of major interest for technical use: 3C-SiC, 4H-SiC, and 6H-SiC. 3C-SiC has been believed to be a superior material to the other polytypes of SiC. However, because of the lack of 3C-SiC single crystal wafers, 3C-SiC can only be heteroepitaxially grown on large-area (100-150 mm) silicon wafers. The silicon substrate can be structured with silicon-based bulk micromachining technologies without attacking the 3C-SiC film and the deposited 3C-SiC film can be patterned by a conventional Reactive Ion Etching (RIE) step. Therefore, it is attractive for MEMS applications. Recently, 3C-SiC deposited on SOI wafer has been used to fabricate piezoresistive pressure sensors. With 3C-SiC piezoresistors and a silicon diaphragm, a working temperature of 450°C was achieved[17][18].

Single crystal 4H-SiC wafers became commercialized and widely available recently. But considering the higher costs and fewer research that is available on 4H-SiC, 6H-SiC is used as the sensor material in this dissertation. The piezoresistive coefficients of n-type $\alpha$-SiC have first been reported by Rapatskaya[19] in 1968. Recently, Shor characterized n-type 6H-SiC piezoresistors from pure single crystalline wafers and obtained a gauge factor of –29.4[20]. Although Rapatskaya made a strain transducer based on $\alpha$-SiC in 1968[21], a systematic study of 6H-SiC high temperature pressure sensors was initiated in 1996 by Okojie, et al[22][23]. They started with an n-type 6H-SiC wafer. The p-type and n-type 6H-SiC single crystalline epi-layers were then deposited on the wafer sequentially. With photoelectrochemical etching, the n-type 6H-SiC piezoresistors were selectively etched and formed. Then, the circular membrane of the sensor is structured by electrochemical etching with dark current. With a special design metallization scheme and package, they demonstrated that a 6H-SiC pressure sensor can operate at temperatures up to 600°C[24]. Some conclusions are made in these researches:

1. Because 6H-SiC belongs to the hexagonal crystals, the piezoresistance coefficient on (0001) surfaces is isotropic.
2. By electrochemical etching, 6H-SiC bulk micromachining can be realized at room temperature. It is an isotropic etching process.
3. As a consequence, a circular membrane is used as structure of the pressure sensor.
4. The highest temperature at which a 6H-SiC pressure sensor can achieve also depends on the reliability of the metallization scheme.
5. The package of the sensor plays an important role in determining the performance of the 6H-SiC pressure sensor in high temperature environment.

To contribute to the research of high temperature piezoresistive sensors, the design and the fabrication of a pressure sensor are considered. Due to the isotropic etching and piezoresistivity of 6H-SiC on (0001) surface, a circular membrane with a center boss is used to maximize the sensitivity of the sensor. Because the center boss in the circular membrane can be used to conduct tactile force, a micro piezoresistive tactile sensor is also introduced in this dissertation to further utilize this structure.

The organization of the dissertation is as follows: in CHAPTER 2, the properties of 6H-SiC concerning the design of piezoresistive sensors will be reviewed and summarized. The analysis and design of the piezoresistive pressure and tactile sensor based on a circular membrane with a center boss structure are discussed in CHAPTER 3. The fabrication and packaging of both PSOI and 6H-SiC piezoresistive sensors will be described in CHAPTER 4. Finally, the measurement results of the fabricated sensors and the conclusion of this work will be given in CHAPTER 5 and CHAPTER 6, respectively.