Chapter 1

Introduction

Fabry-Perot cavity-based sensors have been widely studied for their versatility; for example they have been used to sense both pressure and temperature [1, 2] . This kind of sensor, usually combined with optical fibers, detects changes in optical path length induced by either a change in the refractive index or a change in physical length of the cavity. Unlike "intrinsic" optical fiber sensors where a fiber is used as a sensing element, a cavity is used as a sensing element and optical fibers are used as an interconnect in this "extrinsic" system [3] . Advantages of Fabry-Perot cavity sensors include high sensitivity and localized measurement. However, it has been very hard to construct high quality Fabry-Perot cavity sensors due to the immaturity of their fabrication techniques. Thus Fabry-Perot cavity based sensors were not commercially realized until the mid 80’s even though the basic principle has been long recognized.

Meanwhile, micromachining techniques have rapidly been developed over the last two decades for their great impact on microsensors [4, 5] and microelectromechanical systems [6] . The techniques have utilized well established VLSI technology and produced 3-dimensional microstructures on the scale of a few hundred microns in a silicon substrate. Compatibility with VLSI technology allows microstructures to be integrated with driving circuits or signal conditioning circuits on the same chip, improving functionality of the microstructures [7] and reducing noise problems. Especially performance of microsensors has been dramatically improved by using this technology. For example, pressure microsensors and accelerometers integrated with signal conditioning circuits have being widely used in the automobile industry.

Micromachining techniques also make Fabry-Perot cavity based devices more attractive by reducing the size and the cost of the sensing element. One commonly used method of building a micro Fabry-Perot cavity is a hybrid assembly technique using a fusion bonding process. Using this technique Fabry-Perot cavity based devices, such as tunable filters [8] and pressure sensors [9, 10] , have been demonstrated. However, a high quality micro Fabry-Perot cavity frequently requires an elaborate fusion bonding process, leading to low manufacturing yield. As an alternative, surface micromachined Fabry-Perot cavity based devices have recently developed. Among those devices are a tunable interferometer [11] and a pressure sensor [12] . Surface micromachining techniques eliminate the fusion bonding step and instead etch a sacrificial layer to form a high quality cavity with an air gap, achieving higher yield and better performance through precisely controlled thickness of the cavity gap.

The motivation behind this study is the construction of a pressure microsensor which will be used to measure pressure inside a bearing (an ARPA project entitled, "Journal and Thrust Bearings with Actively Deformable Surfaces"). The microsensor will at the final stage be integrated into the bearing surface to measure the pressure distribution over the bearing surface. The microsensor embedded in mechanical systems should allow localized measurements without disturbing the measurand. For instance, local measurements will determine dynamic characteristics of the fluid film in a bearing, allowing bearing performance to be monitored. The microsensor for pressure measurement could be implemented using optical interferometry. Pressure applied to the diaphragm would be measured by detecting the deflection of the diaphragm.

The greatest advantage of optical measurement is that remote data acquisition can be achieved without degradation of signal to noise ratio (S/N ratio) in harsh environments, such as those where high temperature or electromagnetic interference prevail. For piezoresistive and capacitive sensors, on-sensor-chip electronics integration is usually necessary to improve S/N ratio. Even for piezoresistive sensors, additional electronics are commonly required for correcting the offset and sensitivity to temperature coefficients. Optical measurement can also avoid pressure averaging effects that reduce the sensitivity of piezoresistive pressure sensors. Compared with capacitive pressure sensors, the dimensions of an optical sensing element can be much smaller.

In this dissertation newly developed fabrication techniques for Fabry-Perot cavity based sensors will be presented. The sensors will be used to measure differential pressure applied to the cavity. Measurement and simulation results for the sensors will be compared. In addition to the experimental work, a design study for manufacture of Fabry-Perot cavity sensors will be discussed. Through the design study it will be shown that there exists an optimum design of the sensor which gives high yield with a specific level of performance.

Chapter 2 discusses a method which calculates the optical response of a multilayer Fabry-Perot cavity sensor. Studies on a multilayer Fabry-Perot cavity based device have frequently used a simplified model to calculate optical response of a multilayer Fabry-Perot cavity [10, 11] . The simplified model uses equivalent lumped reflectivity of a multilayer mirror and represents a multilayer cavity by a cavity with two very thin mirrors, ignoring phase interactions at each reflection. In chapter 2 a method will be introduced which takes into account the phase interactions at each reflection. The method utilizes the characteristic matrix of each layer in the cavity and calculates the optical response of the multilayer cavity, e.g., reflectance or transmittance. To verify the method, a multilayer Fabry-Perot cavity has been fabricated and the transmittance of the cavity has been measured and compared with the calculation. The method will later be used to calculate the sensitivity of the optical response to thickness variations in the layers of the cavity.

Chapter 3 discusses the design for manufacture of Fabry-Perot cavity based sensors where thickness variation of a layer is concerned. In this chapter variation of optical response due to process-induced thickness variation in a layer will be analytically calculated. From this calculation we will find an operating regime where the optical response is the most insensitive to process-induced thickness variation. We will also show how the variation of optical response due to process-induced error impacts accuracy of manufactured sensors.

Chapter 4 discusses the mechanical properties of a multilayer film stack, such as the Young’s Modulus and residual stress. The mechanical properties of a stack, i.e., a mirror of a cavity, will be calculated and will be used to simulate deflection of the stack when external pressure is applied to the stack. Also, it will be shown how the residual stress of a stack affects the deflection of a multiple film stack.

Chapter 5 first overviews general micromachining techniques, including surface and bulk micromachining. Later, the processing techniques involved in the fabrication of Fabry-Perot cavity based sensors will be presented. The processing techniques allow a Fabry-Perot cavity with an air gap to be constructed without wafer bonding, and front-to-back alignment of a silicon substrate. Also, fabrication problems associated with micromachined structures, such as cracks or sticking, will be discussed.

Chapter 6 discusses measurements using Fabry-Perot cavity sensors. Pressure measurements, for both free space and optical fiber illumination, will be presented. Also, simulation of the pressure measurement will be performed, taking into account of the averaging effect on the cavity respone caused by the shape of deflection of a mirror.

Finally, Chapter 7 identifies the main contributions of this dissertation and discusses future work to be done.