Abstract

Microcantilevers are sensitive micromechanical platforms used to detect small forces and surface stresses arising due to changes in physical environment. They are popularly used as mechanical probes in scanning probe microscopy to obtain 3D surface topography of samples up to atomic scale resolution. These microcantilevers find applications in biosensing, environment monitoring, air flow measurement, micro bolometry, Atomic Force Microscopy (AFM), etc., Furthermore, microcantilevers form versatile, compliant platforms for producing mechanical actuation. Microcantilever based actuators are used as RF switches, bio manipulators, micro relays and microfluidic valves. Conventionally, microcantilevers are fabricated using silicon, silicon nitride or silicon dioxide. However, in recent times polymers are being used as alternate materials for fabricating microcantilevers. These polymer microcantilevers offer several advantages and versatilities.

The aim of the present thesis work is to the design, fabricate, characterize and evaluate the performance of piezoresistive SU8 microcantilevers for low flow rate measurement and thermal actuation. Finite element (FE) simulation was used to determine the stress distribution across a stressed microcantilever structure. The results of FE simulations enable suitable piezo resistor design for integration with the cantilever. Various surface micromachining techniques were attempted to fabricate freely suspended SU8 microcantilevers with gold thin film piezo resistors. Electrical interconnection was established using ball bump aided epoxy bonding technique. The fabricated SU8 microcantilever sensor was mechanically characterized and its strain sensitivity was evaluated. These sensors were employed for low gas flow rate measurement in the range 0 to 100 mL/min. The sensor response was found to be linear, repeatable and consistent with different flow rates. The fabricated SU8 microcantilever device also exhibited thermomechanical actuation. Hence, the performance of the device due to Joule heating of the piezo resistor was studied in detail. A nonlinear thermomechanical model was proposed to accurately estimate the thermal behavior of the polymer microcantilever. This study underscores the need to consider nonlinear thermo-elastic properties of polymers while modeling their thermomechanical response. Both finite element simulation and experimental result indicate nonlinear thermomechanical response of the SU8 based thermal actuator. The developed microsystem presents simultaneous sensing and actuation mechanisms. Hence, they are suitable for integration with Lab-on-chip-devices. This thesis in divided into 8 chapters and the brief summary is as follows:

Chapter 1

This chapter gives a brief introduction to the state-of-art scenario of MEMS technology and its relevance in the field of sensors and actuators. Later, an overview of micromachining techniques used for the fabrication of MEMS devices is discussed. Microcantilever based devices and their applications are discussed. In particular, their use as non-thermal flow sensors is presented. Also, the need for polymeric microcantilever sensors for low gas flow rate measurement is discussed. At the end, the objective, scope of present work and the organization of the thesis are discussed.

Chapter 2

The aspect of SU8 microcantilever design for flow measurement is presented. Relevant piezo resistivity theory required for the design of thin film piezo resistor is explained. Finite element simulation was used to identify regions of maximum stress in the microcantilever due to fluid flow interactions. The geometry and shape of thin film piezo resistor was chosen based on the simulation results. Finally, the optimal design parameters of piezoresistive SU8 microcantilever sensor are summarized.

Chapter 3

This chapter describes the processes involved in the fabrication of piezoresistive SU8 microcantilevers. Surface micromachining techniques such as wet oxidation, lift-off, thin film deposition, sacrificial layer etching etc. were used during the fabrication. Wet oxidation was used to grow uniform, dense oxide for sacrificial layer. Gold thin films were deposited using RF sputtering technique and patterned using UV

photolithography. SU8 microcantilevers were patterned using photolithography and freely suspended SU8 microcantilevers were obtained by selectively etching the sacrificial layer. The issues of residual stress in suspended SU8 microcantilever are discussed. Finally, an optimal fabrication process was obtained to build SU8 microcantilever with integrated piezo resistor.

Chapter 4

The fabricated flow sensor needs to be connected with the external circuitry via electrical interconnects. This chapter discusses the process of packaging and electrical interconnection with the fabricated SU8 microcantilever sensor. The issues of making wire bonding onto SU8 chip using conventional wire bonding techniques are described. Alternate wire bonding techniques such as epoxy bonding was attempted. Finally, ball bump aided epoxy bonding technique was developed and used for making electrical interconnection with the sensor.

Chapter 5

In this chapter the fabricated and packaged microcantilever sensor was characterized to evaluate its electro-mechanical performance. The sensor response was evaluated experimentally by providing known mechanical displacement via precisely controlled piezo stage. At the end, the sensor characteristics such as gauge factor of the piezo resistor, deflection sensitivity of the microcantilever sensor, its hysteresis, linearity and repeatability were also obtained.

Chapter 6

This chapter describes the performance study of piezoresistive SU8 cantilever sensor for low gas flow rate measurement in the range 10 to 500 mL/min. The measured flow sensitivity was about 1.103×10-5 mL/min. Finite element simulations were used to estimate the cantilever deflection due to gas flow. The simulation results show quadratic dependence of cantilever deflection on gas flow rate. For a flow rate between 0 to100 mL/min, the experimental results agree well with the simulation results showing a linear trend in this range.

Chapter 7

This chapter presents the nonlinear thermomechanical analysis and thermal actuation of fabricated SU8 microcantilevers. The thermomechanical analysis of the actuator incorporates nonlinear temperature-dependent properties of SU8 polymer to accurately model its thermal response during actuation. The issues of residual stress developed within the SU8 microstructure during fabrication are discussed and a novel strategy was proposed to release the residual stress in the fabricated actuators. The thermomechanical response of the actuator was obtained experimentally. The measured average actuation range of about 8.5 µm was produced for an actuation current of 5 mA. It was found that the results of nonlinear thermomechanical analysis agree well with the experimental result.

Chapter 8

The chapter summarizes the results and conclusions drawn from the present work. Also, the scope of future work is discussed.