第 12 卷　第 5 期
2004 年 10 月

光学 精密工程
Optics and Precision Engineering

Vol. 12　No. 5
Oct. 2004

Article ID　1004-924X(2004)05-0491-13

Highly sensitive micromachined tunneling sensors

XUE Wei, WANG Jing, CUI Tian-hong

Department of Mechanical Engineering, University of Minnesota, Twin Cities 111, *Church Street S E, Minneapolis, MN* 55455, *USA*

Abstract: Highly sensitive silicon micromachined tunneling sensors with small size and light mass have been widely explored in the last 15 years. Many types of tunneling sensors have been developed. This paper presents a review of silicon micromachined tunneling sensors. Four types of tunneling sensors including accelerometers, gyroscopes, infrared sensors, and magnetic sensors are reviewed. Various designs, fabrication procedures, performance, control systems, and noise constraints of silicon tunneling sensors are described and discussed. Novel polymer-based tunneling accelerometers fabricated by PMMA and hot embossing technique are introduced. The structure, fabrication process and characterization of the polymer-based sensor are presented. We can expect that the polymer tunneling sensor has the potential to become the basis for the next generation of highly sensitive MEMS-based sensors in many areas.

Key words: tunneling sensor; sensitivity; resolution; polymer; hot embossing; low frequency noise

基于 MEMS 微加工技术的高灵敏度隧道传感器的研究

薛　伟,王　晶,崔天宏
(美国明尼苏达大学 机械工程系和纳米加工研究中心)

摘要:基于硅加工的高灵敏微型隧道传感器在过去 15 年里得到了充分的发展。多种隧道传感器被开始出来,例如加速度计,角速度计,红外传感器,磁性传感器等。首先对基于硅加工的隧道传感进行了简单的总结。对四种传感器进行了总结和讨论,包括几种器件的结构设计,加工过程,器件性能,控制电路和系统噪音。特别介绍了一种新型的基于高分子聚合物的隧道加速度计,并讨论了其结构,加工与测试,隧道效应得到了进一步验证。同时给出了这种新型高灵敏传感器在很多领域的应用展望。

关　键　词:隧道传感器;灵敏度;分辨率;聚合物;热模压加工;低频噪音
中图分类号:TP212.1　　**文献标识码**:A

Received date:2004-03-16; **Revised date:**2004-06-27.

1 Introduction

The theoretical transmission probability of electrons through one-dimensional barrier has been studied in quantum mechanics for more than 60 years. However, since the condition to establish the tunneling current is hard to obtain, it takes many years to develop the real applications of the tunneling mechanism. Quantum electron tunneling effect through vacuum or air barrier was originally developed for microscope applications. Binning and Rohrer developed the first Scanning Tunneling Microscope (STM) by utilizing the tunneling mechanism, and they were awarded the Nobel Prize in 1986[1]. Quantum electron tunneling effect has then been widely studied and developed in many applications after the invention of STM. By utilizing the tunneling current, a variety of highly sensitive microsensors can be fabricated, such as accelerometers[2-4], gyroscopes[5], uncooled infrared sensors[6], magnetic sensors[7-8], etc.

Due to the exponential relationship between the tunneling gap and the tunneling current, the sub-changes of the tunneling gap induce measurable changes in the tunneling current. This high sensitivity is independent of the lateral size of the device due to the extremely small size of the sensing (tip) area. This high sensitivity and miniature size make it possible to fabricate micromachined tunneling sensors with high performance, small size, light mass, and low cost. The highly sensitive tunneling sensors are in great demand in many applications such as seismology, navigation, remote temperature sensing, intrusion detection, and magnetic sensing.

This paper has two parts. First, it presents a brief review of the silicon micromachined tunneling sensors, including accelerometer, gyroscope, uncooled infrared sensor, and magnetic sensor. Various designs, operations, fabrication procedures, performance of the silicon tunneling sensors are reviewed. The feedback control circuits and the noise constraints of the sensors are also briefly described and discussed. After the review, a novel polymer-based tunneling accelerometer is introduced and reviewed. Instead of silicon, an inexpensive polymer material, polymethylmethacrylate (PMMA), was chosen as the structural material. The silicon mold inserts were fabricated by conventional silicon-based micromachining techniques such as UV lithography, wet etching, and dry etching. Hot embossing technique was used to produce the polymer structure. Mass production is readily achieved by hot embossing and polymer materials. With simple feedback control circuit, wide-bandwidth, high-sensitivity and high-resolution sensors were successfully developed and characterized. Polymer-based tunneling sensors therefore exhibit great promise as an inexpensive, highly sensitive sensing platform for biosensing applications.

2 Silicon-based tunneling sensors

2.1 Tunneling accelerometer

Among all the MEMS devices, accelerometers have the second largest volume after pressure sensors[9]. The detection of acceleration relies on the classical Newton's mechanics. In other words, when the device is accelerated, the proof mass is displaced due to the inertial force. The tunneling current through the electrodes varies exponentially with the change of the tunneling gap. The acceleration can be recorded by reading out the deflection voltage in the feedback control circuit. Compared with other common and well developed accelerometers such as capacitive, piezoresistive, and piezoelectric accelerometers, the tunneling accelerometer can achieve higher sensitivity and higher resolution with smaller size and lighter mass. The main disadvantage of the tunneling accelerometer is the relatively complicated fabrication process.

The tunneling accelerometer was first introduced by S.B. Waltman and W.J. Kaiser at Jet