学校编码：10384　　　　分类号____密级____
学号：19920061151879　　　　UDC____

厦门大学

硕　士　学　位　论　文

基于 MEMS 的压电超声技术的研究

Investigation of Piezoelectric Ultrasonic Technology Based on MEMS

孙宏明

指导教师姓名：郭航 教授

专　业　名　称：测试计量技术及仪器

论文提交日期：2009 年 5 月

论文答辩时间：

学位授予日期：

答辩委员会主席：___

评阅人：___

2009 年 5 月

厦门大学学位论文原创性声明

本人呈交的学位论文是本人在导师指导下,独立完成的研究成果。本人在论文写作中参考其他个人或集体已经发表的研究成果，均在文中以适当方式明确标明，并符合法律规范和《厦门大学研究生学术活动规范（试行）》。

另外,该学位论文为（　　　　　　　　　　　　　　）课题（组）的研究成果，获得（　　　　　　　　　　）课题（组）经费或实验室的资助，在（　　　　　　　　　）实验室完成。（请在以上括号内填写课题或课题组负责人或实验室名称，未有此项声明内容的，可以不作特别声明。）

声明人（签名）:

年　　月　　日

厦门大学学位论文著作权使用声明

本人同意厦门大学根据《中华人民共和国学位条例暂行实施办法》等规定保留和使用此学位论文，并向主管部门或其指定机构送交学位论文（包括纸质版和电子版），允许学位论文进入厦门大学图书馆及其数据库被查阅、借阅。本人同意厦门大学将学位论文加入全国博士、硕士学位论文共建单位数据库进行检索，将学位论文的标题和摘要汇编出版，采用影印、缩印或者其它方式合理复制学位论文。

本学位论文属于：

（　　）1.经厦门大学保密委员会审查核定的保密学位论文，于　　年　　月　　日解密，解密后适用上述授权。

（　　）2.不保密，适用上述授权。

（请在以上相应括号内打“√”或填上相应内容。保密学位论文应是已经厦门大学保密委员会审定过的学位论文，未经厦门大学保密委员会审定的学位论文均为公开学位论文。此声明栏不填写的，默认为公开学位论文，均适用上述授权。）

声明人（签名）：

年　　月　　日

摘 要

本文主要研究基于 MEMS 的压电超声技术，包括超声检测、超声微流体驱动技术和 ZnO 压电薄膜材料及器件的研究，研究课题属于当前微机电系统中较为前沿和创新的学科领域，如下所述：

1、超声共振谱技术(Resonant Ultrasound Spectrum, 简称 RUS)是上个世纪九十年代发展起来的一种表征材料特性的方法，该方法成为现代超声检测的较为常用的技术手段，其测量的范围广泛，在 MEMS 领域内，可用于微型器件的检测。在 RUS 测量过程中，试件样品通常被夹在两片压电换能器之间， 压电换能器可以采用 PZT 或其他的压电陶瓷或晶体。但是，因为压电片表面是光滑的，试件难以准确地夹在两片压电片中间并且保证每次测量装夹的位置都一致，从而降低测量准确性，尤其当试件很小时，这种影响更为显著。针对此问题，本文提出并设计了一种新型的超声检测换能器结构，并对它进行分析。

通过与单独 PZT-4 换能器结构进行分析比较，PZT/Si 复合结构的静力位移偏差很小，约为 2%，其各阶共振频率与单独 PZT-4 相差不大，这些分析表明本文所设计的 PZT/Si 复合压电换能器的工作灵敏度受影响微小，可以用于超声共振谱的测量当中。最后利用 MEMS 技术制造出了该复合换能器件的初步结构。

2、微流体技术是 MEMS 领域内发展迅速的一门学科，其应用广泛，如 DNA 及一些生物分子的测试应用、环境监测、喷墨打印以及 LED、“芯片实验台”和一些 IC 芯片等的散热系统。在微流体学科领域内，利用超声技术驱动与操控微流体近几年成为研究热点，相比其他微流体技术具有很大的研究价值和潜力。声流是超声应用中较为常见的现象，是声波在流体介质中传播由于流体黏性而衰减产生的非定向流动，超声流作为高频声波在流体中的传播，可以驱动流体运动。超声技术应用领域的不断拓展使得超声流的应用研究也越来越广泛，随着 MEMS 技术的不断发展，所制造的微装置尺寸越来越小，声流在微管道内的运动不同于传统的管道，当前有大量的关于声流应用的实验研究，却缺乏对于微尺寸管道内声流的系统理论分析，因此很有必要进行微管道内声流的研究。

本文对设计的 MEMS 微流体装置中微管道内声流进行系统的研究，即利用

PZT 压电片激励 MEMS 微流体装置，使得声波在管道内传播，产生的驱动力引起微管道内部声流的运动。应用流体动力学的基本理论，对声波在管道内部传播时产生的声场驱动力和声流运动进行分析。通过分析可以得到振幅为 10nm，声波频率为 200KHz~1MHz 时，流速可达到 1~9mm/s。根据这些分析，我们可以利用超声方法对 MEMS 微流体装置进行驱动控制以便应用在粒子输送和微管道冷却等方面。

3、ZnO 作为压电薄膜具有较低介电常数和较高的机电耦合系数，可用于 MEMS 麦克风、微加速度传感器以及体声波共振器件等微传感和执行器件中，在 MEMS 领域有着广泛的应用。因此，为了满足压电超声技术中超声波的激励需求，本文研究在不同材料衬底上利用磁控溅射法生长高质量 ZnO 作为压电薄膜，同时，为了实现 ZnO 薄膜器件微制造与 IC 工艺的兼容，本文还在实验的基础上考虑利用 Al 材料作下电极的压电器件的加工工艺。

实验中采用了磁控溅射法在不同衬底上生长厚约 1~2μm 的 ZnO 薄膜，通过实验对样品进行 XRD 和 SEM 测试，来研究磁控溅射过程中工艺参数、衬底及退火工艺对 ZnO 薄膜质量的影响，从而获得制备高质量薄膜的工艺技术以满足压电性能的要求。结果表明，表面沉积 Si_xN_y 薄膜的硅片上生长的 ZnO 薄膜比表面溅射铝膜的硅片上的 C 轴择优取向生长特性好，选择合适的退火处理工艺可使晶体质量有所改善。在此基础上，为了能够与 CMOS 工艺兼容，开发了仍然采用 Al 作为底电极但用一层 Si_xN_y 薄膜与 ZnO 层隔离的 MEMS 压电器件的微制造工艺。

关键词：超声检测，超声流，ZnO

Abstract

In this thesis, we present the investigation of piezoelectric ultrasonic technology that is used into the microfluidic and MEMS ultrasonic testing device. New ultrasonic transducer, microfluidic device and ZnO piezoelectric thin films based on MEMS technology will be studied as follows:

1、Resonant ultrasound spectrum (RUS) has been developed since 1990s, which is a dynamic method to test the mechanical properties of the solid materials and is currently considered by the scientists in the condensed matter physics as the most accurate method to determine the elastic constants of materials. This ultrasonic testing method can be applied into many fields, such as the testing of minimized device in MEMS. In RUS, a solid sample is clamped between two piezoelectric transducers, which are generally PZT or other bulk piezoelectric ceramics or crystals. However, a sample, especially a very small one, is hard to be clamped due to the smooth surface of transducers, and if the sample is clamped at different locations of the piezoelectric transducers, the measured spectra will be fluctuant, lowering the accuracy of RUS measurement. To solve this problem, we propose a new type of PZT/Si composite transducer for RUS.

The new type PZT/Si composite transducer is analyzed by comparing with traditional single PZT transducer. The results show that the error of displacement caused by voltage and static displacement is very small, about 2%. The error will decrease by reducing the size of silicon die. The resonant frequency of PZT/Si transducer is almost equal to that of single PZT plate. It is concluded that the proposed device can be used in ultrasonic testing. In the end, the PZT/Si composite traducer is fabricated by using MEMS technology primarily.

2、With the rapid development of MEMS technology during the past 20 years, many microfluidic devices have been proposed and developed for biomedical applications, especially in biomedical engineering, such as bimolecular detection, human tissue environmental monitoring, drug delivery and cooling of “LAB ON

CHIP” and IC chips so on. Among various types of technologies for manipulating liquids, acoustic/ultrasonic technique is proved to own higher efficiency than the other methods on driving and controlling fluid motion. Ultrasound wave propagating in a viscous fluid will induce acoustic streaming owing to the absorption of the fluid, which can cause unidirectional fluid motion in microchannel. Due to the size of the microdevices that is greatly reduced by using MEMS technology, fluid motion induced by acoustic streaming are quite different from that in the conventional scale device. Many experimental researches on acoustic streaming have been studied. However, very few are studied on acoustic streaming in the microscale. Therefore, it is a challengeable and important task to investigate acoustic streaming flow in microchannel.

In this thesis, acoustic radiation force, acoustic streaming in microchannel actuated by ultrasonic vibration are studied in the proposed device which is composed of a PZT plate, microcavity and microchannel. Basing on the fundamental of fluid dynamics, an analytical study of fluid motion acoustically induced in microchannel is investigated. We have analytically studied the fluid motion driven by acoustic field and forced heat transfer by acoustic streaming in a microchannel in this paper. The maximum velocity of fluid motion in the microchannel can reach up to 1~9mm/s when the frequency of vibration is between 200 KHz and 1 MHz. The results show that acoustic streaming induced by ultrasonic vibration in the microscale is feasible and has potential for developing acoustic MEMS devices for driving fluid motion, drug delivery and micro cooling applications.

3、ZnO piezoelectric thin film has many applications in the MEMS field such as MEMS microphone, micro accelerometer and bulk acoustic wave resonator. For these applications, high-quality ZnO piezoelectric thin film, which has a tendency to grow with strong preferential orientation, is need. In this thesis, we present the growth and characterization of ZnO piezoelectric thin films to obtain the high quality piezoelectric thin films used in piezoelectric ultrasonic application. Meanwhile, aluminum is also used as the bottom electrode to acquire the compatibility of

fabrication of ZnO piezoelectric thin films device and IC technology.

Magnetron RF sputtering technology is used to grow ZnO thin film for piezoelectric applications. We study the influence of annealing process and different substrates, including silicon, aluminum layer and silicon nitride thin film on silicon, on the piezoelectric performance of ZnO thin film by using XRD and SEM to analyze C-axis orientation and crystalline quality of ZnO thin film. The experimental results show that the crystal quality of ZnO thin films deposited on aluminum is worse than that on silicon substrate and silicon nitride layer. It is concluded that the crystal quality of ZnO grains will be influenced by the bottom electrode in the fabrication of ZnO piezoelectric device. To solve this problem, we primarily develop a fabrication process for which the aluminum is still used as the bottom electrode but isolated from the ZnO thin film by a layer of silicon nitride thin film, to meet the requirements of the high quality of the ZnO thin film and compatibility with CMOS technology.

Keywords: Ultrasonic Testing, Acoustic Streaming, ZnO

目 录

Table of Contents