第 17 卷　第 6 期
2009 年 6 月

光学 精密工程
Optics and Precision Engineering

Vol. 17　No. 6
Jun. 2009

文章编号　1004-924X(2009)06-1442-06

高 *g* 值压阻式微加速度计设计

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摘要：利用加速度计的机械变形导致电阻的变化，设计了一种测量高 *g* 值的加速度计。在 CoventorWare 软件下建立了加速度计的加工工艺流程和实体模型。利用压阻分析模块 MemPZR，采用 FEM 分析方法，通过改变压阻块在悬臂梁上的位置，得到压阻块位置与器件输出电流之间的关系，找到了压阻块在悬臂梁上的最优放置位置。改变压阻块的电导率，验证了器件的灵敏度变化与压阻率变化的趋势是一致的。在 20 k*g* 加速度的输入下，得到了压阻块应力的分布，以及电流的大小及分布，和悬臂梁的应力大小及分布，验证了加速度计的抗过载能力。

关　键　词：微机电系统；压阻加速度计
中图分类号：TH824.4　　**文献标识码：**A

Design of high *g* piezoresistive micro-accelerometer

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Abstract：The change in resistivity caused by the mechanical deformation in a micro-accelerometer was used to design an accelerator to measure physical quantities such as high *g* acceleration. The process and a solid model were constructed in CoventorWare. With changing the position of a piezoresistive sensing element on the fix-end cantilever，the optimizing location of the sensing element as well as the relationship between the output current and the location are obtained by using Finite Element Mothod (FEM) in the MemPZR module. Changing the sensitivity by the same percentage，it is proved that electric conductivity changes are coincident with the sensitivity changes of the element. When 20 k*g* acceleration is inputted，the potential distribution of piezoresistor device terminals，the corresponding stresses of the piezoresistive element and the current location are also obtained，which testifies the anti-over loading ability from the stress location in the fix-end cantilever.

Key words：MEMS；piezoresistive accelerometer

1　Introduction

The piezoresistive micro-accelerometer is an electro-mechanical device that measures high G acceleration. Compared to the other accelerometers，this sensor for mechanical signals is based on the piezoresistive effect. Piezoresistive phe-

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Received date：2009-01-20；**Revised date**：2009-04-30.

Foundation item：Supported by the Natural Science Foundation of Liaoning Province(Grant No. ID20082047)

nomenon in semiconductor is linked to a change in the resistivity in the response to an applied stress[1]. The change in resistivity of the micro-accelerometer subject to a mechanical deformation is used to measure physical quantities such as high *g* acceleration[2].

There are several mechanisms for acceleration sensing viz., piezoelectric (Okada 1995), piezoresistive (Roylance and Angell 1979; Allen et al. 1989; Plaza et al. 1998; Pak et al. 1996; Wang et al. 2003; Patridge et al. 2000; Limet al. 1999; Sim et al. 1998; Kwon and Park 1998; Ninget al. 1995; Chen et al. 1997; Eklund and Shkel 2007; Amarasinghe et al. 2006; Kal et al. 2006), capacitive (Butefisch et al. 2000; Yazadi et al. 2003; Wang et al. 2007; Rödjegard et al. 2005; Takao et al. 2001), tunneling (Dong et al. 2005), vibrating beam/resonant beam (Aikele et al. 2001; Tabata and Yamamoto 1999; Burns et al. 1996), etc[3]. Even though each of the above acceleration sensing mechanisms has its own advantages and limitations, piezoresistive accelerometers are widely used due to its structural simplicity, simple fabrication process and read out circuit compared to the other accelerometers. Through optimizing the structure parameters and by virtue of the piezoresistive effect, an accelerometer is desired for the high *g*, which can′t be detected by common sensor or endure the shock in some particle environment such as aeronautical and military industries.

CoventorWare is a typical state-of-the-art design tool for MEMS design and analysis with a lot of advanced features. In this analysis the Designer and Analyzer module are used. The anticipative models can be established in Designer modules. The FEA and BEM analysis are performed in the Analyzer module based on the model.

2 Model constructions

2.1 Process design

The process sequences are shown in Tab. 1. A planar deposit step was added to produce a cristalsilicon piezoresistive layer.

Tab. 1 Process step

Step	Action	Material	Thickness (μm)	Etch depth (μm)
1	Base	Silicon	40.0	-
2	Planar Fill	PSG	3.0	-
3	Planar Fill	cristalsilicon	2.0	-
4	Stright cut	cristalsilicon	-	2.0

The material of piezoresistive sensing element was cristalsilicon. The electrical conductivity is the reciprocal of the resistivity value for p-type silicon. Verify the cristalsilicon electrical conductivity is and piezo-coefficients property values are shown in Tab. 2. The elastic constants are shown in Tab. 3.

Tab. 2 Piezo coefficients

Pi_11	6.6×10^{5}
Pi_12	-1.1×10^{-5}
Pi_44	1.38×10^{-3}

Tab. 3 Elastic Constants

E_1, E_2, E_3	1.30×10^{5}
Poisson12,13,23	2.78×10^{-1}
G_{12}, G_{13}, G_{23}	7.96×10^{4}

The material of the fix-end beam was polysilicon. When designing crystal silicon models, the crystallographic axis of the crystal silicon material should be aligned with the axis of the global system of reference. The elastic constant of polysilicon is 1.6×10^5 MPa and poisson is 2.2×10^{-1}. The density is 2.23×10^{-15} kg/μm^3 and TCE is 4.7×10^{-6}/K. Thermal conductivity is 1.48×10^2 W/(m·K).

2.2 Solid model construction

Three-dimension solid finite model is constructed on the base of the process and the mask. This sensor is a typical, fix-end beam and piezoresistive sensing element model with a patch displacement boundary condition as shown in Fig. 1 and Fig. 2[4]. The solid model is highly meshed using "Manhattan brick" with element size 10 μm×10 μm×1 μm. The FEM in this analysis was used to model piezoresistive behavior.

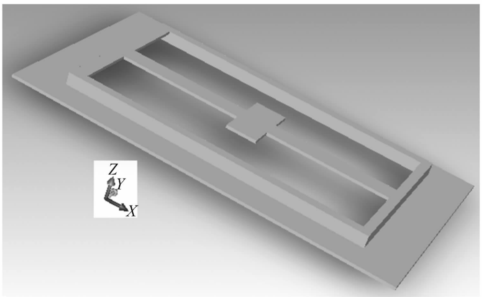

Fig. 1 Solid model

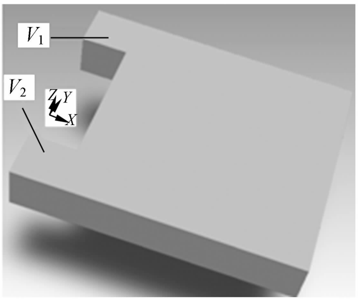

Fig. 2 Piezoresistive sensing element

3 Study of sensing element location

The position of the piezoresistive sensing element in the fix-end beam directly influenced the output i. e. device performance. Therefore, to properly compute the change in sensitivity in a numerical simulation, the piezoresistive sensing element should be correctly positioned in the fix-end beam[5]. CoventorWare is a special software for MEMS device design and analysis. Its MemPZR module is designed to compute the piezoresistive sensor's potential field and the resulting change in current resulting from the applied stress. In this analysis, a parametric study solution set was created that shows the current change as the piezoresistor device was moved longitudinally along the beam. Setting the mass plate had 1 displacement in Z direction. Vary the piezoresistive sensing element position from the fix end of the fix-end beam to the other end at each step of 20 μm. The graphical change in current as the piezoresistor device is stepped along the fix-end beam is obtained as shown in Fig. 3. The fix-end beam stress results from previous simulations confirm that the maximum stress is near the fixed end, with the least amount of stress near the end. The piezoresistor device accurately senses this stress change and converts it into a current that can be measured in an electronic circuit. Current change was shown in Fig. 4. Minimum stress is at the center of the beam.

Thus the two piezoresistive sensing elements were located at the two fix ends of the fix-end beam and mutual perpendicular to each other. Linked the two piezoresistor sensing elements as two vicinage resistances in the wheatstone bridge[3]. For the two sensing elements were subject to the inverse direction stress and vicinage in the wheatstone bridge, the output was

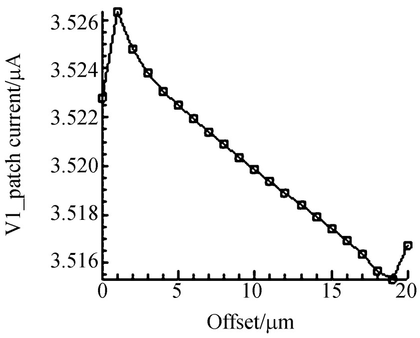

Fig. 3　Output current

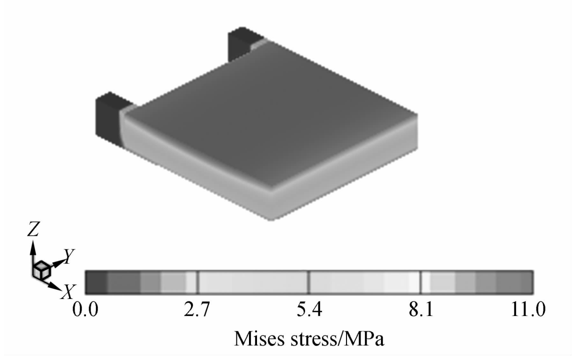

Fig. 5　Piezoresistor stress results

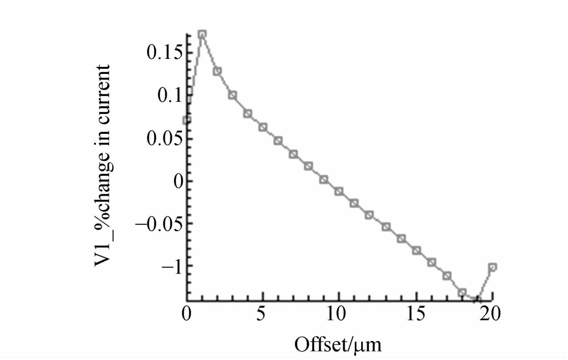

Fig. 4　Minimum stress at beam center

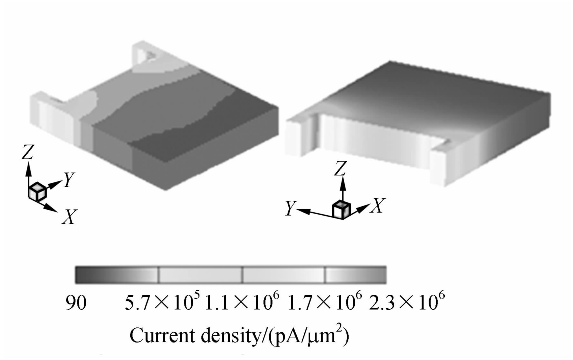

Fig. 6　Current density after input 1 V

augmented.

4　Simulation analysis

When the high g acceleration is inputted, the displacement moves a single patch in a vector direction, creating an internal larger stress on all the internal nodes in the model. The piezoresistive sensor's potential field and the resulting change in current are due to applied stresses.

The piezoresistive sensing element created as a separate piezoresistive model is initialized with a potential across its terminals, with the problem set up to sense current through the same terminals.

Set the potential across the piezoresistor device terminals V1 and V2. When 20 kilo g acceleration is inputted and one volt is applied, the piezoresistor stress location is shown in Fig. 5 and the current density is shown in Fig 6.

The displacement moves a single patch in a vector direction, creating an internal stress on all the internal nodes in the model.

A parametric study solution set is created that shows the current change as the piezoresistor device moves longitudinally along the beam.

The conductivity of the piezoresistive sensing element is critical for the amplitude of the output. How a variation in the electric conductivity for the piezoresistor material affects its resistivity and its ability to convert the beam stress results into a current were investigated. The electric conductivity is allowed to vary ±10% during the simulation. The results for −10% and +10% variation in conductivity were contrasted. The results showed the current changed by the same percentage when electric conductivity changes as shown in Fig. 7, so the material property variation make the piezoresistor device conversion capability relatively insensitive to this parameter.

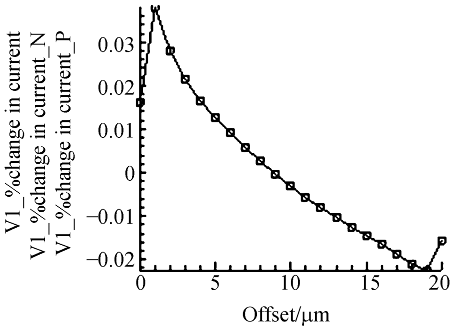

Fig. 7 Sensitivity changes *vs.* electric conductivity changes

Crystal silicon is a brittle material, so the reliability is also considered under over loading[7]. When input 20 kg acceleration, the maximum stress in the fix-end beam is smaller than the yield strength as shown in Fig. 8.

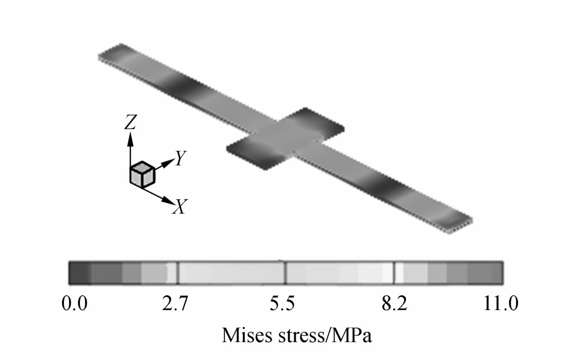

Fig. 8 Fix-end beam stress location

5 Conclusions

A piezoresistive micro-accelerometer was design and analyzed in this article. The location of the piezoresistive sensing element in the fix-end beam was studied in MemPZR module of the CoventorWare. The two piezoresistive sensing elements were located at the two fix ends of the fix-end beam where the stress was the maximum and mutual perpendicular to each other to get maximum output. The current density in the sensing element were obtained when input 1 voltage. The current changed by the same percentage when the electric conductivity was allowed to vary ±10%. It is testified that the sensitivity was insensitive to the electric conductivity. While 20 kg acceleration was input, the corresponding stresses in the fix-end beam were obtained, which testifies the piezoresistive micro-accelerometer can endure such over loading.

References:

[1] RUBIO W M, SILVA E L C N, NISHIWAKI S. Static and Dynamic Response of a Multiplexed-array Piezoresistive Contact Sensor [J]. *Struct Multidisc Optim*, 2008,36:571-583.

[2] CHE L F, LU Y, XU ZH N. Finite element simulation on packaging of hinged high-g micromachined accelerometer [J]. *Opt. Precision Eng.*, 2007, 15 (2):199-205. (in Chinese)

[3] RAVI SANKAR A, DAS S, LAHIRI S K. Cross-axis sensitivity reduction of a silicon MEMS piezoresistive accelerometer [J]. *Microsyst. Technol.*, 2009,15:511-518.

[4] YAZDI N, AYAZI F, NAJAFI K. Micromachined Inertial Sensors [J]. *Proc. IEEE*, 1998, 86:1640-1659.

[5] MIN H B. Micro mechanical transducers-pressure sensors, accelerometers and gyroscopes [J]. *Handbook of Sensorsand Actuator*, *Amsterdam*, *Elsevier*, 2000:281-285.

[6] HUANG SH S, LI X X, WANG Y L, *et al.*. A piezoresistive accelerometer wit haxially stressed tiny beams for both much increased sensitivity and much broadened frequency bandwidth [C]. *The 12th International Conference on Solid State Sensors*, *Act. Proc. Transducers*, 2003:91-94.

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●下期预告

分布式 Unscented 粒子滤波跟踪

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提出了一种新的分布式粒子跟踪算法。本算法主要考虑到传感网络的能量受限、通信受限等特性，改善了通常的分布式粒子滤波粒子数目大、节点间信息交换多的弊端，能够用较少的节点计算得到对机动目标更好的跟踪结果，实现一种改进分布式粒子滤波（DUPF）。DUPF 算法其主要思想是利用 unscented 卡尔曼滤波改进分布式粒子滤波算法形成一个建议分布，用来生成粒子分布，在这个基础上，通过分布式粒子滤波实现目标的在线跟踪。仿真实验表明，DUPF 和分布式粒子滤波相比只需要后者 25％的粒子数目，就能达到同样的跟踪精度，可以用较少的节点和通信消耗，实现很高精度的目标跟踪。