MODELING OF PIEZORESISTIVE CANTILEVERS FOR CHEMICAL SENSING

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Abstract—This paper presents an analytical model to provide good results for cantilevers with point load at free end and to describe the micro cantilevers with surface stress. It has been shown that the width of the cantilever has to be increased to optimize the sensitivity. The placement of the piezoresistor was found to be in the centre of the cantilevers clamped end and the area of the piezoresistor should be minimized.

Keywords—Piezoresistor, cantilevers, sensitivity, Surface stress

I. INTRODUCTION

In a piezoresistive cantilever the detecting resistors, called piezoresistors, are placed at potentially high-stress points of the cantilever beam; as long as the cantilever deflection is negligible compared to its length, the resistance of piezoresistors changes linearly with the deflection. The considerable advantages of this scheme are the implementation of the detection mechanism within the cantilever, CMOS integration capability, and the possibility of making large cantilever arrays. Piezoresistance is a characteristic of conductive and semi conductive materials, attributed to the change of the electrical resistance with an applied stress (strain). The phenomenon of the resistance change of metallic wires with elastic strain has been investigated since the mid-19th century, after the pioneering works of Thomson followed by, particularly, Bridgman’s works on the Piezoresistance measurements of polycrystalline materials. In the mid-20th century, after the theoretical modelling of the energy level structure in diamond crystals (e.g., silicon and diamond), it was predicted that the energy gap between the valence and conduction bands would increase with the decrease of the atomic spacing and, therefore, with pressure. This prediction was confirmed by observation of the resistance change of p-n junctions with pressure in germanium, and especially by Smith’s work on the Piezoresistance effect in germanium and silicon. Being the dominant material in the semiconductor industry, silicon has been comprehensively studied as a prominent piezoresistive material. Also, besides crystalline silicon, the Piezoresistive properties of other microelectronic materials have been exploited and characterized, such as poly-Si, GaAs, GaN, SiC, poly-C, and amorphous materials. In addition, with the development of non-conventional micro-fabrication techniques, the Piezoresistance effect in carbon nanotubes and thin metal films has been recently investigated. These materials are demonstrated to be viable alternatives in piezoresistive detection.

II. DESIGN OF PIEZORESISTIVE FORCE SENSING CANTILEVERS

The measuring point loads at the free end; design criteria for cantilever sensors are discussed. The design of cantilevers and the analytical models are done using COMSOL Multiphysics software. The cantilever and piezoresistor dimensions are shown in table 1.

|        | Cantilever | Piezoresistor |
|--------|------------|---------------|
| Length | 200 µm     | 50 µm         |
| Width  | 100 µm     | 20 µm         |
| Thickness | 2 µm     | 0.5 µm       |

The schematic of the cantilever with point load at the free end and the analytical model and Finite model are shown in fig a and fig b.

The chosen cantiliver and piezoresistor dimensions for the comparison of different models and the relative resistance change over point force at cantilever free end calculated by three different models are shown in fig a and fig.b.
The deviation of FEM solutions from the linear behaviour is caused by geometric linearities at large tip deflections 47.0µm at 500µN is accounted in this type of analysis. The two FEM solutions differ by no more than 5.3% which indicates that stress difference is good. So the force sensing cantilevers should be made thin and long and the piezoresistior area should be short and thin and as close to the clamped base.

III. DESIGN OF PIEZORESISTIVE SURFACE SENSING CANTILEVERS

The stress distribution in a cantilever with surface stress is similar to that of a cantilever with a given tip deflection. The stress distributions of a cantilever with a point force at free end and surface stress on the top surface are shown in the figs. The two loading cases comparison clearly displays that the stress distributions within the cantilever and thus the piezoresistive output signal are very dissimilar. While the point force causes a stress distribution with a linearly decreasing stress in x-direction and a stress of much smaller magnitude in y-direction, this is not the case for the cantilever surface stress loading. The distribution of stresses closes to the surface in x-and y-direction for different cross sections of a cantilever with surface stress is shown in the figs below.
The stress difference with surface stress loading on the top surface with width 50µm and length 200, 100, 50 and 400µm and the graph of average stress and cantilever length is shown below.

The stress difference with surface stress loading on the top surface with width 50µm and length 200, 100, 50 and 400µm and the graph of average stress and cantilever width is shown below.
The above figure compares the piezoresistor thickness of 0.1 and 0.25µm and the one in which the piezoresistor thickness is one third of the cantilever thickness. The relationship is inversely proportional.

IV. CONCLUSION

Thus this paper presented the process for understanding the micro cantilevers for chemical sensing was familiarized. In many cases, the piezoresistor thickness is constrained by the fabrication process. In this case, the cantilever thickness should be chosen so that the piezoresistor is about two thirds of the cantilever thickness. In contrast to the case of a cantilever with a point load at the free end, when the piezoresistor thickness is close to the total thickness of the cantilever the sensitivity does not decrease intensely.

V. REFERENCES

[1]. Akeel Shebeeb and Hanim Salleh, Effect of cantilever Shape on the power output of a piezoelectric bimorph Generator ICSE2010 Proc. 2010, Melaka, Malaysia.

[2]. MoYang, Xuan Zhang, KambizVafai and CengizS Ozkan, High sensitivity piezoresistive cantilever design and Optimization for analyte-receptor binding!, IOP Publishing, J. Micromech. Microeng. 864–872, 2003.

[3]. Ibrahim Ethem SACU, Mustafa ALCI, —Design of a Basic Piezoresistive Microcantilever Biosensor, IJ- Journal of Electrical and Electronics Engineering Vol. 13(2), (2013), 1641-1645.

[4]. Ribu Mathew and A Ravi Sankar, —Design of a triangular platform piezoresistive affinity microcantilever sensor for biochemical sensing applicationsl, IOP Publishing, J. Phys. D: Appl. Phys. Vol. 48 205402 (14pp), 2015.

[5]. Joseph C. Doll, Sung-Jin Park, and Beth L. Pruitt, Design optimization of piezoresistive cantilevers for force sensing in air and waterl, American Institute of Physics, Journal of Applied Physics Vol. 106, 064310, 2009.

[6]. Hidetoshi Takahashi, Tetsuo Kan, Kiyoshi Matsumoto and Isao Shimoyama, —Simultaneous detection of particles and airflow with a MEMS piezoresistive cantileverl, IOP Publishing, Meas. Sci. Technol. Vol. 24, 025107 (7pp), 2013.

[7]. J. A. Harley and T. W. Kenny, —1/fNoise Considerations for the design and Process Optimization of Piezoresistive Cantileversl, J. Micromech. Microeng. Vol. 27, 105005 (7pp), 2017.

[8]. MohdZahid Ansari and Chongdu Cho, —High S/N Ratio Slotted Step Piezoresistive Microcantilever Designs for Biosensorsl, Journal of Sensors, by MDPI, 2007.

[9]. Johnny H. HE and Yong Feng LI, —High sensitivity piezoresistive cantilever sensor for biomolecular detectionl, Journal of Physics: Conference Series 34, 429–435, 2006.

[10]. Sung-Jin Park, Joseph C. Doll, Ali J. Rastegar, and Beth L. Pruitt, —Piezoresistive Cantilever Performance—Part II: Optimization‖, Journal Of Micro Electro Mechanical Systems, IEEE, Vol. 19, No.1, February 2010.

[11]. RosminazuinAb Rahim, BadariahBais, Burhanuddin Yeop Majlis, and Sheik Fareed, —Design Optimization of MEMS Dual-Leg Shaped Piezoresistive Microcantileverl, IEEE Micro and nanoelectronics symposium, 978-1-4799-1183-7, 2013.

[12]. Mo Yang, Xuan Zhang, KambizVafai and Cengiz S Ozkan, —High sensitivity piezoresistive cantilever design and optimization for analyte-receptor bindingl, J. Micromech. Microeng., Vol.13, 864–872, 2003.

[13]. L.G. Villanueva, G. Rius, F. Pérez-Murano, J. Bausells, Piezoresistive cantilever force sensors based on polycrystalline siliconl, IEEE, doi:978-1-4799-8108-3/151, IEEE, 2015.

[14]. T. Chu Duc, J. F. Creemer, and Pasqualina M. Sarro Piezoresistive Cantilever Beam for Force Sensing in Two Dimensionsl, IEEE Sensors Journal, Vol. 7, No. 1, January 2007.

[15]. Gholamzadeh, Ebrahim Ghafar-Zadeh, Falah Awwad and Mohamad Sawan, —Piezoresistive Cantilever Platform for Label-free Detection of Moleculesl, doi: 978-1-4799-2507-0/14, IEEE, 2014.