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System modeling of microaccelerometer using piezoelectric thin films

Jyh-Cheng Yu*, Chin-Bing Lan

Department of Mechanical Engineering, National Taiwan University of Science and Technology, 43 Keelung Road, Section 4, Taipei 106, Taiwan, ROC

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Abstract

This paper addresses the system modeling of a novel design of microaccelerometer. The proposed microaccelerometer consists of a quadri-beam suspension, a seismic mass, and the displacement transducers using piezoelectric thin films. The derivation of the electromechanical system function illustrates the interactions of the material characteristics, the amplification circuit design, and the microstructure geometry. The dynamic response and the trade-off between several design considerations are discussed. The theoretical model is verified by the finite element analysis of the resonance frequency, the dynamic response of the microstructure, and the sensor sensitivity. The good coincidence of the results demonstrates the validity of the modeling assumptions. The analytical model can be readily applied to performance trade-off and design optimization. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Relevant researches of micro-electromechanical systems (MEMS) have emerged in recent years as a result of the urge of product miniaturization. Microsensors are essential to the integration of electric and mechanical systems, and are the first commercialized MEMS products. The advance of micromachining has made possible the production of three-dimensional dynamic microstructures on a silicon wafer. Microsensors consist of microstructures, displacement transducers, and signal amplifiers, which can then be easily integrated into a single chip using existing integrated circuit manufacturing processes. The miniaturization of sensors not only reduces the manufacturing cost but also improves the operational bandwidth and reliability. The integration of electric and mechanical components facilitates the applications with space constraints. Successful applications in automotive engineering include pressure microsensors in combustion control, microaccelerometers in airbags and suspension systems [1], and micro-gyroscopes in navigation and guidance. Potential markets also exist in biomechanics and aerospace technology.

Accelerometers can be classified into the following categories according to the forms of transduction mechanism [2]: piezoresistive [3]; capacitive [4]; resonant [5]; tunneling [6]; thermal [7]; optical [8]; piezo-MOS [9]; and piezoelectric [10] devices. Piezoresistive and capacitive based transducers are most popular in micromachined silicon accelerometers. One of the first commercialized microaccelerometers was piezoresistive. The main advantage of piezoresistive accelerometers is the simplicity of their structure, fabrication process, and read-out circuitry. However, piezoresistive accelerometers show high temperature dependence and a great influence of mounting stress. Capacitive accelerometers have good dc response and noise performance, low temperature sensitivity, and low drift, but have problems with electromagnetic interference. In another way, novel deigns, such as those based on tunneling current or optical read-out, can achieve high sensitivity with a small size; however, none of these has been commercialized to date. Piezoelectric accelerometers have the advantages of easy integration in existing measuring systems. Due to their excellent dynamic performance and linearity, they have been widely used in condition monitoring systems to measure machinery vibration [11].

Piezoelectric materials have the interchangeability of electrical and mechanical energy. The most widely used piezoelectric ceramics are $PbZrTiO_6$ solid solutions (PZT). Because of the advantages of their high electro-mechanical coupling factors, high electric impedance, and temperature stability, piezoelectric transducers are very promising in sensor and actuator applications [12]. Piezoelectric thin films keep the characteristics of bulk materials, but are more compact and less costly. The quality of thin films used to be a

* Corresponding author. Tel.: +886-2-27376499; fax: +886-2-27376499.
E-mail address: jcyu@mail.ntust.edu.tw (J.-C. Yu).

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