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A micromachined differential resonant accelerometer based on robust structural design

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ABSTRACT

This paper describes design, fabrication, and testing of a micromachined differential resonant accelerometer (DRA), which is one of the most common solid proof mass accelerometers; it exploits a correlation between acceleration and shifts in the resonant frequency of oscillating beams loaded axially. The effective and simplified structure of the DRA amplifies the induced inertial force resulting from applied acceleration, while retaining structural stability and robustness. Mathematical and numerical analyses were conducted to optimize the detailed structures of the DRA under appropriate operating conditions. An experimentally measured differential scale factor of 188.5 Hz/g showed good agreement with the results of the analysis. Utilizing a silicon-on-insulator wafer provided uniform material properties and thickness of the structural layer, resulting in bias stability of 100 μg and a Q factor of 0.37×10^6.

1. Introduction

A resonant accelerometer is a device that exploits shifts in the resonant frequency of an oscillator to measure linear acceleration [1,2]. The main advantage of a resonant accelerometer is its inherently digitized output; it does not need analog-to-digital conversion, which is a potential source of errors. Because a resonant accelerometer is an open-loop system, it has lower power consumption than a closed-loop accelerometer with a servo system. The proof mass of a resonant accelerometer is always constrained even when unpowered, so resonant accelerometers are rugged and can tolerate high levels of handling and storage shocks [3].

Micromachining allows miniaturization of traditional electromechanical sensors, including resonant accelerometers. This possibly ensures the advantages of low cost, low power consumption, small size, and high shock tolerance. However, the reduction in size of sensing elements creates challenges for attaining good accuracy. In general, as size decrease, the scale factor *SF* decreases, noise increases, and driving force decreases. Although high-precision accelerometers have been already developed, most have not yet been evaluated completely as strategic and navigation grade [2].

Therefore, resonant accelerometers based on micro-electro-mechanical systems (MEMS) have been widely studied to improve their accuracy, and finding ways to increase *SF* has become the priority in many of these research efforts since the feasibility and operations of a MEMS resonant accelerometer have been successfully demonstrated [4].

SF can be increased by two basic approaches: (1) enlarging the area of a proof mass to increase the inertial force at a given acceleration and (2) narrowing and lengthening oscillating beams to increase their frequency shift at a given inertial force. In addition, another method was used to increase SF even in a device of limited size; micro-levers were designed to amplify an inertial force at a given acceleration. Micro-leverage mechanisms have been adopted in many devices [5–8] and systematically analyzed [9]. To further increase *SF*, a multistage micro-leverage mechanism has been designed [10].

However, although micro-leverage mechanisms effectively amplified the inertial force in previous research, they increase the complexity of the manufacturing process, and decrease the device's structural stability. Therefore this report proposes a micromachined differential resonant accelerometer (DRA) that does not incorporate complicated leverages, and that maintains its structural stability and robustness. Mathematical and numerical analyses were conducted to optimize the DRA's structures under

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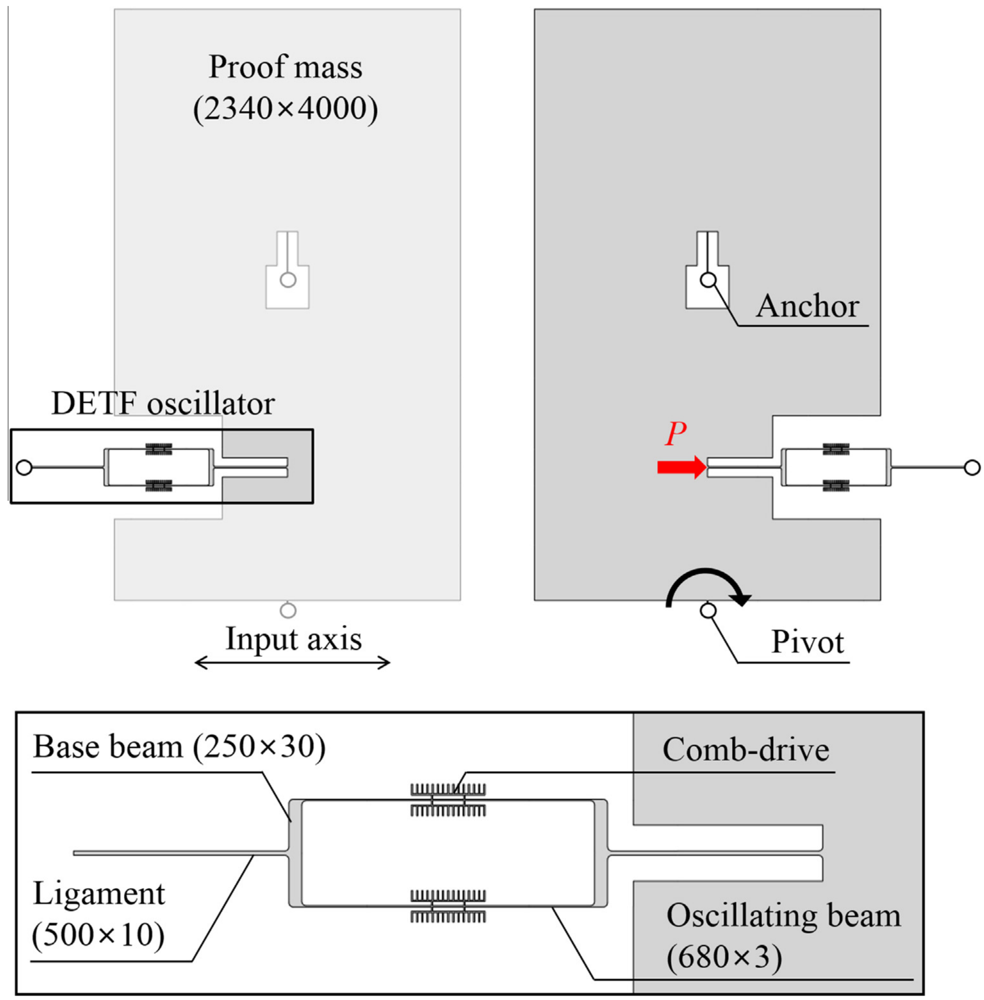

Fig. 1. Schematic of the proposed accelerometer. Horizontal × vertical dimensions are in micrometers. (○: fixed points).

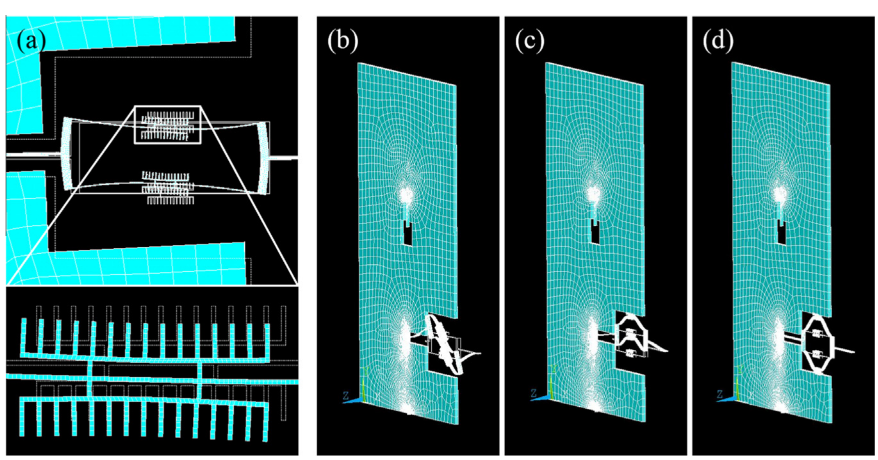

Fig. 2. (a) Exaggerated displacement of com-drive under input acceleration and (b) 6th resonance mode (c) 7th resonance mode (in-phase mode), (d) 8th resonance mode (out-of-phase mode) of the accelerometer.

appropriate operating conditions. A specialized fabrication process developed to realize the proposed accelerometer is presented; this process considers high-aspect-ratio structures for a large area, decreases cross-axis sensitivity, and increases structural stability, robustness, and *SF*. Resonance characteristics, the performance and noise characteristics of the fabricated accelerometer were measured and analyzed using numerical simulation.

2. Design analysis

2.1. Device configuration

The proposed accelerometer is configured with a symmetrical pair of parts that consist of a proof mass and an attached double-ended tuning fork (DETF) oscillator which are driven