VOA-Based Optical MEMS Accelerometer

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Abstract— **A novel in-plane double silicon-on-insulator optical MEMS accelerometer based on variable optical attenuator is presented. It is designed for micro-satellite navigation applications and it uses multimode waveguides integrated with MEMS providing a compact and reliable device.**

Keywords-optical accelerometer; microelectromechanical systems (MEMS); silicon-on-insulator; variable optical attenuator

I. Introduction

Optical accelerometers offer higher sensitivity and better reliability compared to capacitive or piezoelectric accelerometers and they are also immune to electromagnetic interferences. A Silicon-On-insulator (SOI) optical accelerometer using a Fabry-Perot (FP) microcavity with two distributed Bragg reflectors (DBR) was recently reported by our group [1]. Optical accelerometers based on intensity modulation were proposed [2], [3], [4]. They have advantages to those based on wavelength detection because no complex source or detector is required and only the intensity of light is measured at the output. Most of the reported devices have low sensitivity [2], [3], [4] and some are unable to detect the acceleration direction [2], [3]. A Variable Optical Attenuator (VOA)-based SOI optical accelerometer composed of optical fiber and MEMS structure has been previously reported [5]. The device is sensitive however it is not fully integrated and has limited reliability because of its misalignment sensitivity from the vibration/shock. In addition, a gold layer deposition is required in order to obtain a high reflectivity for the mirror. The device presented here is fully integrated, robust to vibration and does not require gold coating, providing a higher reliability for the sensor. A double SOI wafer is used in order to provide low loss waveguides.

II. Working Principle

Figure 1 shows the schematic of our proposed optical accelerometer. Light is launched from a single mode optical fiber through an integrated SOI U-groove to a multimode SOI channel waveguide with 12 µm width and then is split by a T-bar waveguide splitter into two arms: sensing arm and reference arm. The light emitted from the sensing arm hits a movable Bragg mirror, which is attached to the sensor proof mass. The position of the mirror edge is designed to be at the center of the waveguide when no acceleration is applied. A similar mirror is placed in the reference arm at the same position as the other mirror in order to have similar optical length. This second mirror is fixed and used as a reference. The displacement of the Bragg mirror (relative to the nominal signal detected by the reference) in the presence of an inertial load modulates the coupled optical intensity from the transmitting multimode waveguide to the receiving multimode waveguide. Finally the output power is detected and the magnitude of the applied acceleration is measured.

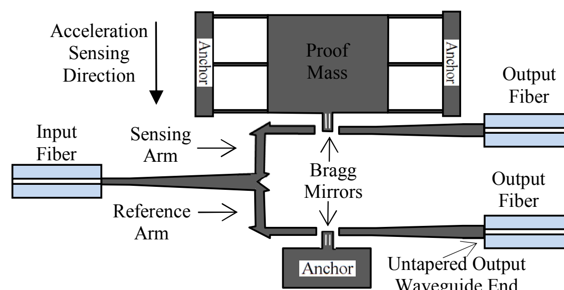

Figure 1. Schematic of the optical accelerometer based on VOA.

III. Design and Fabrication

A finite element method is used to model the mechanical behavior of the device. The accelerometer proof mass (1.32×10^{-7} kg) is suspended by six span beams (Figure 1) having a designed overall stiffness of 2.2 N/m providing 4.1 kHz natural resonance frequency. Figure 2 illustrates the device fabrication process. The device is fabricated using two masks. A double SOI wafer with 15 µm thickness low doped top device layer, 0.3 µm top oxide layer, 32µm middle device layer, 3 µm bottom oxide layer,

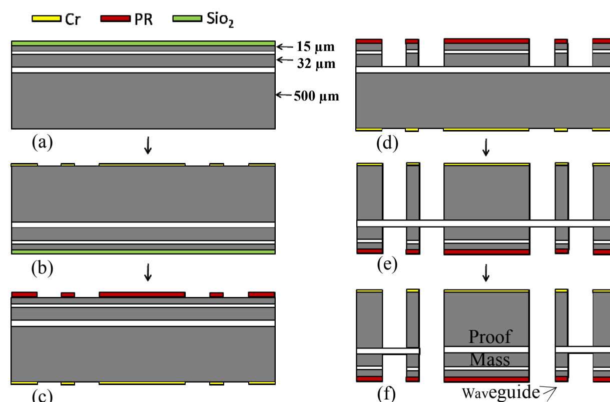

Figure 2. Fabrication process for the optical accelerometer.

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and 500 μm Si-handle layer is used. The proof mass is composed of all five layers. First, 2 μm oxide layer is sputtered on the front side of the wafer (on the top device layer) to protect the front side surface during fabrication (a) followed by Cr deposition and lift-off on the backside (b). The sputtered oxide is then removed followed by photolithography on the front side (device mask was aligned with the Cr mask at this point) (c). Next the patterned device resist mask was deep reactive ion etched (DRIE) all the way to the bottom buried oxide layer (d). Finally DRIE on the backside (e) and releasing the proof mass using vapor HF (f). Waveguides, U-grooves, springs and the device structure are patterned at step (d) and a substrate mass added to the sensor proof mass (providing higher sensitivity) is done at step (f). Double SOI is used to guide the light only inside the top device layer providing thinner waveguides hence lowering optical loss by scattering from the side-walls roughness generated during DRIE process. Also with this configuration the notching phenomenon at the bottom of the waveguides is avoided.

The fabricated device is shown in Figure 3. The width of the input silicon waveguide is chosen to be 12 μm to ensure a good core match with the optical fiber core resulting in low misalignment coupling loss. The waveguide collimators are used to reduce the divergence within the silicon waveguides. The added Si-handle mass can be seen in the picture.

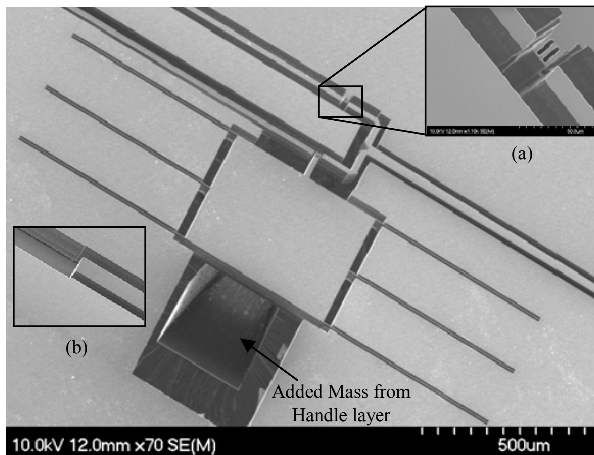

Figure 3. SEM photograph of the fabricated VOA-based optical accelerometer. Inset: (a) close up view of the Bragg shutter and (b) close up view of the integrated output U-groove.

IV. CHARACTERIZATION

Light (λ=1550 nm) from a 4 mW laser source is transmitted using input U-groove into the input waveguide through an 80 μm diameter single mode optical fiber. The transmitted light is collected by the second optical fiber, which is coupled to the untapered end of the output waveguide (Figure 1) at one end and to a photodetector at the other end. Fibers were bonded to the U-grooves using UV-curing optical adhesives. The whole setup is attached to an inclinable board that can be tilted [1]. Acceleration is applied to the device as a consequence of gravity by tilting the board ($g \sin\theta$). Figure 4 shows the detected output power versus the applied acceleration. Due to coupling loss from optical fibers to waveguides and from waveguides to waveguides, the measured output power is low. Power decreases, as the angle of inclination increases while the acceleration is applied towards the fixed Bragg mirror as indicated in Figure 1 (more light is blocked by the Bragg shutter). Sensor response repeatability is checked for three different accelerations. Slight fluctuations at the output power were observed for each of the applied accelerations. The error arising from the board height measurement (reading error) and the deviation of the output power are indicated in this graph. The sensor response to the acceleration ranging from 0 to 0.7 g is approximately linear. 1.6 dB/g sensitivity is extracted from this curve. Sensitivity can be improved by using bigger proof mass and softer springs.

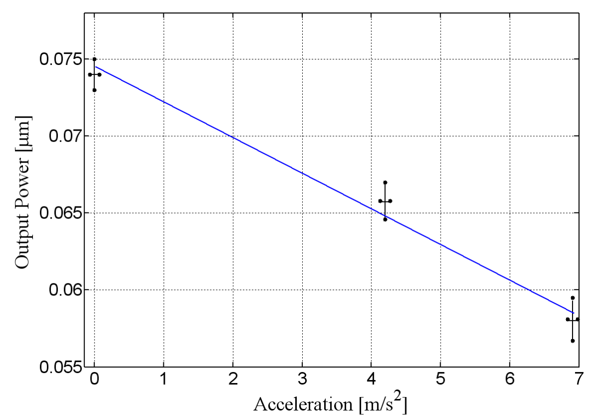

Figure 4. Sensor response to the applied acceleration.

ACKNOWLEDGMENT

The authors would like to acknowledge the constructive suggestions of Philip Melanson and Linh Ngo-Phong from the Canadian Space Agency as well as the financial assistance of the Canadian Space Agency for this work.

REFERENCES

[1] K. Zandi , B. Wong, J. Zou, R. V. Kruzelecky, W. Jamroz, and Y.-A. Peter, "In-Plane Silicon-On-Insulator Optical MEMS Accelerometer Using Waveguide Fabry-Perot Microcavity With Silicon / Air Bragg Mirrors," in *23rd IEEE Intl. Conf. on Micro Electro Mechanical Systems*, Hong Kong, pp. 839-842, 2010.

[2] D. Uttamchandani, D. Liang, and B. Culshaw, "A micromachined silicon accelerometer with fiber optic integration," in *Proc. SPIE Integrated Optics and Microstructures*, vol. 1793, pp. 27–33, 1992.

[3] K. Burcham, G.N. De Brabander and J.T. Boyd, "Micromachined silicon cantilever beam incorporating an integrated optical waveguide", in *Proc. SPIE Integrated Optics and Microstructures*, vol. 1793, pp. 12-18, 1992.

[4] J. Marty et al., "Fiber-Optic accelerometer using silicon micromachined techniques," *Sensors and Actuators A*, vol. 46-47, pp. 470-473, 1995.

[5] B. Guldimann, P. Dubois, P.-A. Clerc, N.F. de Rooij, "Fiber Optic–MEMS Accelerometer with high mass displacement resolution," in *11th International Conference on Solid-State Sensors and Actuators*, vol. 1, pp. 438-441, 2001.