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Concept of MEMS Ring Laser Gyroscope with Movable Optical Parts

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Abstract

In this paper, we present the concept of a microelectromechanical systems ring laser gyroscope (MEMS-RLG) and its optical components. MEMS-RLG has a semiconductor optical amplifier (SOA) enclosed with mirrors that form an optical loop for an external laser oscillator in free space. To confirm the feasibility of MEMS-RLGs, we constructed an experimental device with commercially available SOA and mirrors for external oscillation. We also show the fabrication and characteristics of optical components such as movable mirrors and a lens-positioning device, which are required for a miniaturized MEMS-RLG.

Keywords: Ring laser gyroscope; RLG; Comb drive actuator; External oscillation

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1. Introduction

Microelectromechanical systems (MEMS) gyroscopes, which are almost all of the vibratory type, have been widely used for many products because of their small size and inexpensive cost. Recently, there has been demands for MEMS gyroscopes with good zero-point stability and high sensing resolution for inertial navigation systems. The use of a ring laser gyroscope (RLG), which is a type of optical gyroscope, can satisfy such requirements. Conventional RLGs have extremely high stability of about 0.01 deg./h; however, they are very large with special glasses that have no thermal expansion and they consume large amounts of power because of the use of He-Ne gas laser. To solve these problems, miniaturized RLGs using ordinary materials and a semiconductor optical amplifier (SOA) have been reported, including one combining an SOA as the light source and a long optical fiber loop as the optical path [1] and the other with a ring-shaped solid optical waveguide formed inside of an SOA [2].

We previously suggested a preliminary concept of an MEMS-RLG that operates with an SOA and a silicon optical loop [3]. The optical loop is made of a silicon single crystal using MEMS fabrication technology and acts as an external laser oscillation cavity in free space. To confirm the feasibility of our MEMS-RLG, we constructed a trial model device to verify this external oscillation using a commercially available SOA and mirrors. We also show the fabrication and characteristics of optical components that compensate for some optical alignment errors.

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2. Confirmation of external oscillation

Ring laser oscillation is essential for RLGs because clockwise (CW) and counterclockwise (CCW) laser waves are origin of the Sagnac effect, which is the basic operating principle of RLGs. External oscillation using an SOA and optical fiber as an optical loop have been reported [1]. However, these systems have disadvantages such as complex alignments, high insertion loss in the long fiber, and undesirable resonation modes [2]. When external oscillation is realized in free space without fibers, we can gain an ideal lossless system. To confirm this, an RLG optical path is formed by a commercial SOA and mirrors. A top view diagram of the RLG is shown in Fig. 1. It includes the SOA combined with two collimation lenses (A230TM-B; Thorlabs, USA), two mirrors (58853-j; Edmund Optics, USA), and a beam splitter (OPB-15S05-10-5; SIGMA KOKI, Japan). The total floor size is 180 × 180 mm^2 and the optical loop is 360 mm long. Since both sides of the SOA (oscillation wavelength, 850 nm) have antireflection (AR) coating, it has less than 3% reflectance. The aspherical collimation lenses measuring ϕ9.24 mm in diameter have 0.5% AR coating. The mirrors, which are coated with gold, measure ϕ12.5 mm in diameter, exhibit $\lambda/10$ surface flatness, and have 97% reflectance for 850 nm laser beams. The beam splitter, with aluminum coating, measures 15 × 15 mm^2 and has $\lambda/10$ surface flatness, 85% reflectance, and 5% transmittance.

The lights from both sides of the SOA are collimated by lenses and reflected by mirrors at the corners. When the optical path is suitably aligned, external oscillation begins and circular laser beams are obtained. Two laser beams propagate in opposite directions (CW and CCW) simultaneously. When angular velocity is applied to the device (shown in Fig. 1), the oscillation wavelengths for the CW and CCW beams are differentially changed by the Sagnac effect. The wavelength of the CW beam becomes long and that of the CCW beam becomes short. To form a fringe pattern at the detector by a prism whose corner slightly different from 90 deg. behind the beam-splitter, movement of the fringe pattern according to the CW and CCW wavelengths is generated at the detector. The velocity of movement of the fringe pattern is proportional to the applied angular rate, and this is the output of the device.

The light intensity-injection current-supply voltage (L-I-V) characteristics of the SOA are shown in Fig. 2. When the lenses and mirrors are aligned suitably, external oscillation is generated at a threshold current of 75 mA. Figure 3 shows a wavelength spectrum of about 851 nm for an injection current of 100 mA. Generation of oppositely directed (CW and CCW) lasers was confirmed by observation of the spot pattern at the detector.

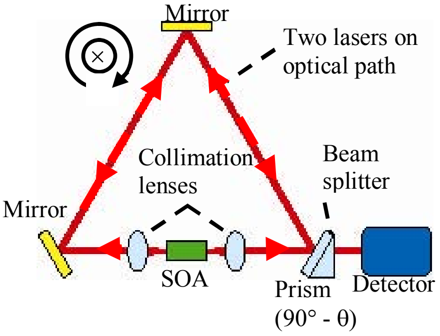

Fig. 1 Measurement apparatus of the RLG with the SOA.

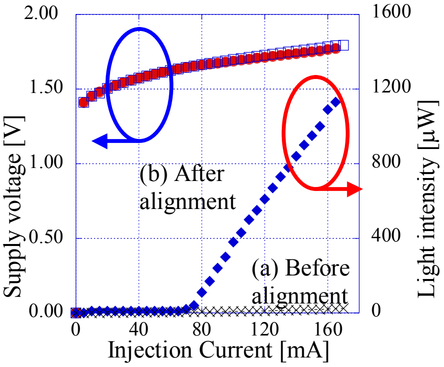

Fig. 2 L-I-V characteristics

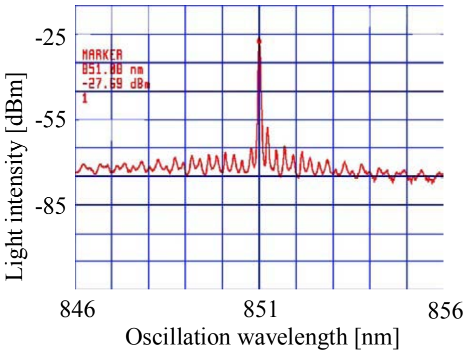

Fig. 3 Wavelength spectrum of oscillation.

3. Design and fabrication of optical loop with movable optical parts

3.1. Movable optical parts for alignment control

External oscillation using non-MEMS optical components was confirmed above. To reduce the device size and avoid any complex alignment technique, we fabricated a monolithic silicon MEMS-RLG for trial use. The MEMS-RLG employs silicon mirrors prepared by anisotropic wet etching, where the mirror angles are defined by crystalline direction. Thus, the mirror can be aligned with an accuracy of 0.001 deg., which is the orientation error of commercially available silicon wafers.

Unfortunately, with current MEMS techniques, the SOA and collimation lenses will need to be installed manually or integrated using a hybrid technique after mirror fabrication. Thus, adjustment mechanisms for the SOA and lenses are necessary to compensate for production errors, such as length errors in the SOA's cavity or lens diameter and position errors during installation. Furthermore, if additional errors in the optical path length occur, they must be compensated for suitable external laser oscillation. To compensate for these errors, we designed and fabricated movable components with comb drive actuators.

The conceptual diagram of the MEMS-RLG is shown in Fig. 4. To design the device, first, each element's size is determined. The SOA measures 300 × 300 × 120 μm^3 for an oscillation wavelength of 650 nm, and the SOA chip will be clamped by the fixture mechanism as shown in Fig. 4. Collimation ball lenses made from BK7 (diameter, ϕ300 μm) are laid on both sides of the SOA. The distance from the SOA to the lens is 70 μm, which is the focal length of the ball lens. In this study, we used ball lenses; however, in future we plan to use an aspherical lens or combination of ball and rod lenses for more accurate collimation [4].

All movable parts are fabricated from a 300 μm thick silicon wafer. After performing backside etching of the silicon wafer to secure a gap between the movable structure and glass substrate, the wafer is anodically bonded to a Pyrex glass wafer. The gap between the substrate and movable structure is about 10 μm. The comb electrodes are separated by 15 μm, and the etching aspect ratio is about 20. Springs that support movable parts have 8-turn meander-shaped beams with a width of 15 μm and length of 2 mm. At these design dimensions, the comb drive actuators with an applied voltage of 200 V will move the collimation lens about ±35 μm and the mirrors about ±5 μm.

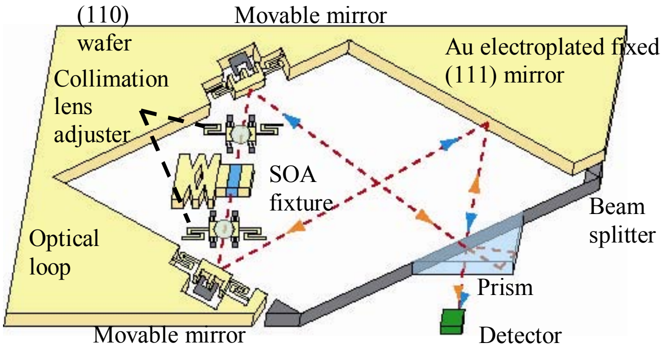

Fig. 4 Conceptual diagram of the MEMS-RLG.

3.2. *Experimental results of movable parts*

The fabricated optical loop structure including some optical parts is shown in Fig. 5. The hourglass-shaped optical path and collimation lens adjusters, three movable mirrors, the beam splitter, and some test patterns are fabricated on a silicon wafer measuring 38 × 28 mm^2. SEM images of movable optical parts, such as the movable mirror, the collimation lens adjuster, and comb drive actuators, as well as support springs are shown in Figs. 6–8.

The experimental results of displacement versus applied voltage for the collimation lens adjuster and movable mirror are shown in Figs. 9 and 10, respectively.

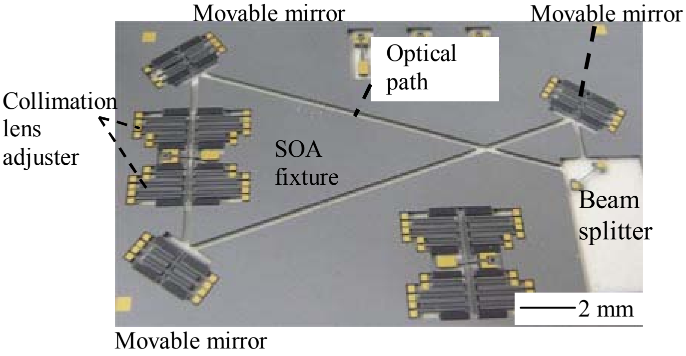

Fig. 5 Fabricated optical loop.

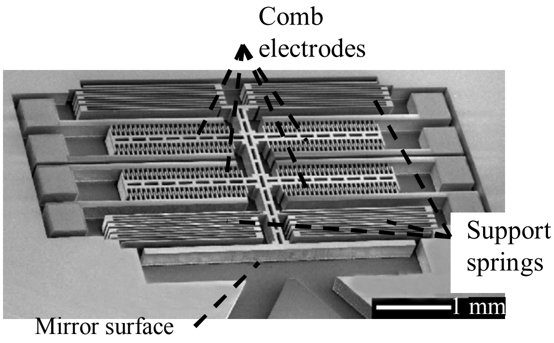

Fig. 6 SEM image of the movable mirror.

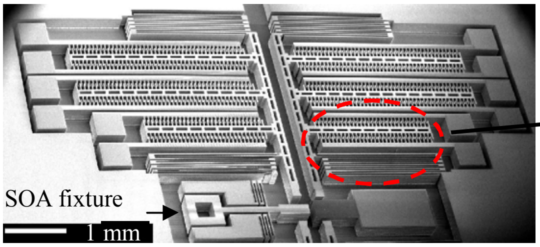

Fig. 7 Collimation lens adjuster.

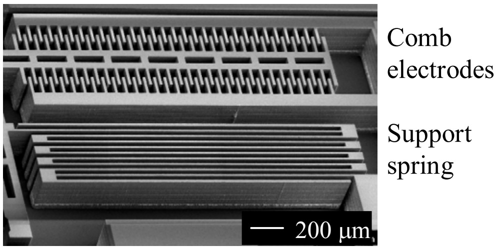

Fig. 8 Comb electrodes and support spring.

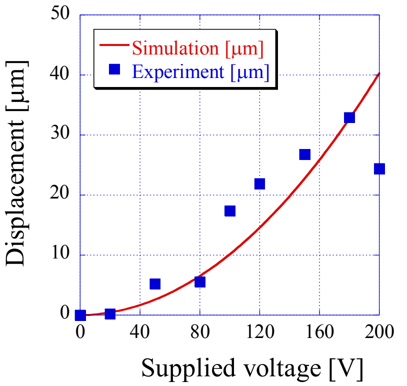

Fig. 9 Displacement of the collimation lens adjuster.

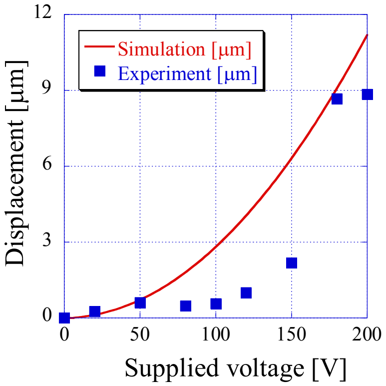

Fig. 10 Displacement of the movable mirror.

These results are somewhat different from the designed values; however, the displacements can be completely corrected by feedback control.

4. Conclusion

Ring laser oscillation using an SOA as the light source and commercial mirrors was demonstrated using a large-scale model. The concept of miniaturized MEMS-RLGs was suggested, and an optical loop with movable optical parts made of silicon was fabricated for their realization. Displacements of movable parts were observed by applying voltage to the comb actuators. We plan to perform feedback control for precise actuator control. These results show the feasibility of external oscillation in an optical loop with feedback-controlled movable parts for MEMS-RLG.

Acknowledgments

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