An On-chip Optical Brillouin Gyroscope with Earth-Rotation-Rate Sensitivity

K. Vahala, Y. H. Lai, M. G. Suh

Thomas J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, California

vahala@caltech.edu

Abstract: A chip-based gyroscope is demonstrated that uses counter-propagating Brillouin lasers to measure rotation as a Sagnac-induced frequency shift. Demonstration of rotation measurement below the Earth rotation rate is presented. Prospects for improved performance are discussed.

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Lightweight and compact rotation sensors (gyroscopes) are required in many applications. Micro-electro-mechanical-systems (MEMS) rotation sensors are used widely in consumer electronics, however, their sensitivity and bias stability does not compete with optical gyroscope systems based on the Sagnac effect (ring-laser gyroscopes [1] and fiber-optic gyroscopes [2]). Also, MEMS devices rely upon a suspended mechanical structure for rotation measurement and can be sensitive to shock and vibration [3]. For these reasons there has long been interest in the possibility of a chip-based analog to a ring laser or fiber-optic gyroscope. Being lightweight with no moving parts, such micro-optical gyros [4] would be highly insensitive to shock and vibration. Their reliance on the Sagnac effect could also potentially allow them to out-perform MEMS devices. However, until recently, the performance of micro-optical devices has lagged far behind MEMS devices on account of difficult-to-achieve requirements for high optical-Q-factor chip-based optical resonators. Recent demonstrations using ultra-high-Q whispering-gallery resonators have provided encouraging results [5, 6] that approach sensitivities needed to observe the Earth rotation rate. Here, a monolithic optical gyroscope is described that uses counter-propagating Brillouin lasers to measure rotation through a Sagnac-induced frequency shift. Demonstration of rotation measurement below the Earth rotation rate is presented.

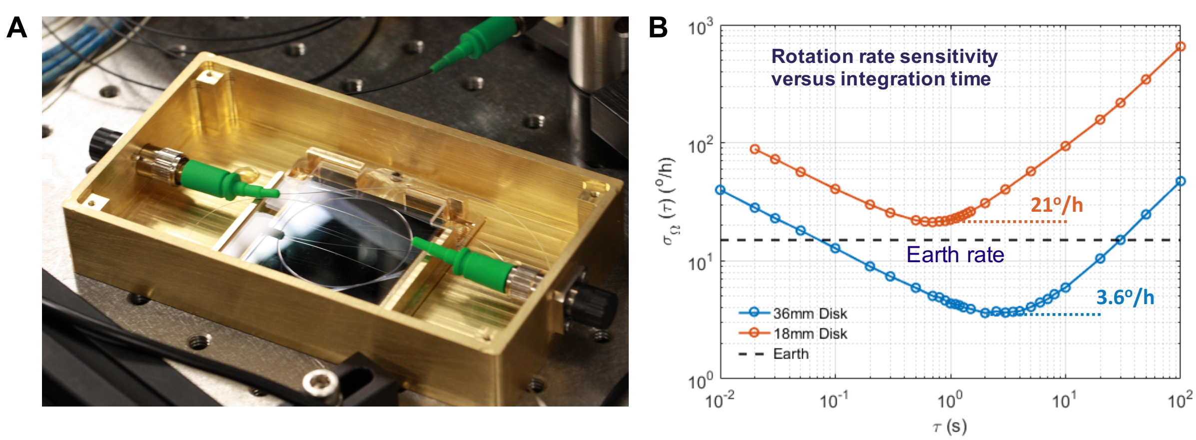

Figure: **A.** Photograph of a 36 mm resonator gyro packaged in a brass box with fiber connectors. B. Allan deviation measurement performed on two disk resonator devices having different diameters (see legend).

Brillouin scattering has been intensely studied in silica optical fiber [7] and it results from the interaction of an optical pump wave with microwave-rate phonons. The application of this process for rotation sensing was demonstrated using optical fibers in the 1990s [8]. As shown in the figure (panel A), the current work uses a silicon-chip-based ultra-high-Q disk resonator [9] to generate counter-propagating Brillouin lasers [5]. When the resonator is rotated about an axis perpendicular to the plane of the disk, the counter-propagating Brillouin lasers experience opposing Sagnac frequency shifts. Detection of their beat frequency therefore provides a rotation readout. The sensitivity of this method of rotation measurement depends upon the linewidth of the beat note. Here, the ultra-high-

Q systems enables sub-Hertz fundamental laser linewidths [10]. Additionally, because the counter-propagating Brillouin lasers are co-lasing within the same cavity, the technical noise contributions to their respective linewidths are largely common-mode-noise. As a result, heterodyne detection of the Brillouin laser waves produces a sub-Hertz linewidth beat frequency [10]. Initial work on this device was able to measure rotations rates as low as 22 degrees/hour [5]. Improvements to the system have now boosted the bias stability to around 3.6 degrees/hour using a 36 mm ultra-high-Q chip resonator (see figure panel B).

The physics of high-coherence Brillouin laser action in the ultra-high-Q resonator system will be reviewed. Both single pump and dual pump configurations of the rotation sensor will be described along with ways to further improve the rotation sensor performance.

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