CHIP SCALE ATOMIC GYROSCOPE

GOVERNMENT SUPPORT

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FIELD

The present invention relates generally to the field of atomic-based sensing devices. More specifically, the present invention pertains to chip-scale atomic gyroscopes and methods for orientation and rate sensing.

BACKGROUND

Gyroscopes are utilized in a wide variety of applications for sensing orientation and/or inertial motion of objects. In the design of navigational and communications systems, for example, such devices are useful in sensing slight variations in linear and rotational motion of an object traveling through space. Navigational grade gyroscopes, for instance, enable desired flight paths to be followed with a high degree of accuracy, particularly in those environments where GPS guidance is unavailable.

The area of gyroscope design has encompassed a vast arena of technologies, including mechanical, fiber optics, and ring laser based designs. More recent trends have emphasized ultra compact, high performance architectures such as microelectromechanical systems (MEMS) based devices, which utilize semiconductor fabrication techniques to form miniaturized components on the surface of a wafer. In one such design often referred to as a MEMS vibratory-rate gyroscope, for example, a resonating structure such as a proof mass is suspended by a flexure anchored to a substrate such as a wafer of silicon or glass. Commonly implemented suspension structures may include interdigitated combs, cantilevered beams, disks, and/or ring structures. To sense displacement or acceleration in response to movement of the device about a rate axis, the proof mass is typically driven into a high-Q resonance state using a number of drive electrodes. Under angular rotation, the Coriolis force resulting from motion of the device about the rate axis induces motion in the direction of a sense axis perpendicular to the proof mass motion, which can then be capacitively sensed and outputted as a rate signal.

Since mechanical gyroscopes such as MEMS vibratory-rate gyroscopes are often operated in high-Q shock environments, such devices are prone to drift over time due to aging, material degradation and stress, leading to scale factor instability in the gyroscope. In some cases, cross-coupling stiffness and damping between the drive and sense directions can affect the performance of the gyroscope, leading to bias drift issues. In addition, the susceptibility of the suspension structures to shock and vibration can further affect the ability of the device to accurately sense subtle changes in orientation and/or angular rotation. Due to the relatively small capacitive sense signals outputted and measured, MEMS vibratory-rate gyroscopes often demand highly stable and accurate sense electronics, resulting in increased power consumption and manufacturing complexity.

To overcome many of the drawbacks associated with mechanical gyroscopes, atomic-based gyroscopes have been proposed which rely on the precession rates of alkali-metal atoms to sense and measure angular rotation. In one illustrative design often referred to as a Larmor precession gyroscope, a vapor cavity filled with an alkali metal and two noble gas isotopes are used to sense rotation. In a non rotating frame, a static magnetic field is applied and the isotopes are spin-aligned using optical pumping. Two perpendicular oscillating magnetic fields are then applied with frequencies near the Larmor precession frequency for each isotope, inducing a precession about the static magnetic field that can be measured using magneto-optical techniques. As the system undergoes rotation, the angular velocity alters the precession frequency, which may then be extracted numerically to determine the rotation rate of the gyroscope.

One significant issue with Larmor precession gyroscopes is that they require the use of two separate isotopes with similar relaxation time constants in order to extract the rotation angle accurately. In some designs, for example, two different nuclei each having a different gyromagnetic ratio can be configured to precess at different rates in an applied magnetic field. The mechanical rotation rate of the gyroscope is then deduced by simultaneously tracking the precession rates of each nuclei, and then subtracting out the magnetic field contribution from the measured angular precession rate. Such proposed designs, however, have been difficult to implement in practice since minor magnetic field gradients can cause the atoms to precess at different rates, causing fluctuations in the output. Moreover, differences in the relaxation rates can cause the isotopes to lose spin coherence at different rates leaving the system in a highly convoluted unknown state. Since such gyroscopes required synchronous precession information from both isotopes, high signal fidelity is also difficult in such designs. These aspects, coupled with the device's high cross-axis sensitivity and extreme sensitivity to magnetic gradients and transients, result in a complex system whose angular rotation is difficult to extract under normal fielded 3-axis rotational motion. Accordingly, there is a need for improved atomic sensors for use in orientation and/or rate sensing.

SUMMARY

The present invention pertains to chip-scale atomic gyroscopes and methods for orientation and rate sensing. An illustrative chip-scale atomic gyroscope can include a vapor cell having a vapor cavity adapted to contain a vaporized source of alkali-metal atoms, noble gas atoms and one or more buffer gasses. The vapor cell can be contained within a packaging structure of the gyroscope by inclusion of a separate enclosed cavity or cavities. In other embodiments, the vapor cell may be defined by a multi-wafer stack. A number of storage chambers for storing a supply of alkali-metal atoms and noble gas atoms may also be defined. In some embodiments, a number of nested shields can be provided about the packaging structure for magnetic and thermal shielding. The packaging structure may further include one or more other elements such as a magnetic field source and a heater source.

A pump laser source adapted to produce a pump laser beam along an optical pumping axis of the gyroscope can be utilized to optically pump the alkali-metal atoms within the vapor cavity to an excited state. In some embodiments, for example, the laser beam outputted by the pump laser source can be maintained at a wavelength corresponding to the carrier wavelength of the alkali-metal atoms, producing an angular momentum in the alkali-metal atoms that induces a nuclear spin polarization in the noble gas atoms. Lock-in of the pump laser source to the carrier wavelength of the alkali-metal atoms can be accomplished, for example, via a