COMPACT ATOMIC MAGNETOMETER AND GYROSCOPE BASED ON A DIVERGING LASER BEAM

CROSS-REFERENCE TO PROVISIONAL PATENT APPLICATION

This patent application claims priority to U.S. Provisional Patent Application Ser. No. 60/954,555, entitled "Compact Atomic Magnetometer and Gyroscope Based on a Diverging Laser Beam," which was filed on Aug. 7, 2007, the disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

Embodiments are generally related to magnetometers and gyroscope methods and systems. Embodiments are also related to the field of sensing magnetic fields.

BACKGROUND OF THE INVENTION

Magnetometers are used for sensing magnetic fields. Applications include geophysical surveying, nuclear magnetic resonance (magnetic resonance imaging), magneto-cardiography, magneto-encephalography and perimeter surveillance. Gyroscopes sense rotation. These instruments are used in inertial navigation and platform stabilization (anti-roll systems in cars, for example). The implementations described here allow for high sensitivity and simultaneously inexpensive fabrication, small size and low power consumption. These implementations would be suitable for remote deployment that requires extended operation under battery power and integration into handheld, portable systems.

Considerable prior art has been focused on gyroscopes based on polarization of the alkali and noble gas atoms through optical pumping and spin-exchange collisions, which was initially developed in the 1960s and refined considerably throughout the 1970s and 1980s. The work was largely abandoned in the early 1980s with the invention of the ring laser gyroscope and fiber-optic gyroscope, which promised equivalent sensitivity with reduced complexity. Recently, there has been a resurgence of interest in the nuclear magnetic resonance (NMR) gyroscope due to the miniaturization possibilities allowed by micro machined alkali atom vapor cells.

There are various types of commercial magnetometers, each with its own application area. These are summarized in Table 1 below (Table 1 is only provided for exemplary purposes and is not meant to limit the scope for the invention):

TABLE 1

Comparison of commercial magnetometers.

Type	Sensitivity (nT)	Size (cm^3)	Power (mW)	Cost ($)	Comments
SQUID	10^{-5}	$10^{5(*)}$	~1000	10^4	Cryogenic
Coil	0.0001	100	10	100	AC only
Cesium	0.001	100	20,000	10^4	Scalar
Flux gate	0.01	100	50	100	Magnetic
Magneto-resistive	1	0.001	0.01	10	High bw
Hall	100	1	100	10	Very reliable
Expected performance metrics of the diverging beam magnetometer:					
CSAM	10^{-5}	1	50	100	Scalar

(*)Including cryostat

For many years, magnetometers based on superconducting quantum interference devices (SQUIDS) had unsurpassed sensitivities in the range of 1-10 fT/√Hz. These instruments require cryogenic cooling and therefore are large, expensive and difficult to operate. Recently, atomic magnetometers similar to the invention described in this disclosure but larger and without the diverging beam geometry, were shown to achieve a sensitivity of below 1 fT/√Hz. Commercial atomic magnetometers based on Cs are approximately a few 100 cm^3 in volume, run on 20 W of electrical power and achieve sensitivities in the range of 1 pT/√Hz. The cost of Cs magnetometers is higher than all but SQUID-based sensors. Proton magnetometers, another type of atomic magnetic sensor, are less expensive than Cs magnetometers and are also more accurate, but suffer from considerably worse sensitivity, ~1 nT/√Hz.

Search coil magnetic sensors can achieve sub-pT sensitivities at high frequencies (>1 MHz) but are largely insensitive to DC magnetic fields. Search coils have been used for many years as the sensors in magnetic resonance imaging (MRI) instruments. Flux gate magnetometers typically achieve sensitivities in the range of 1-10 pT/√Hz and are fairly small (a few cm^3) but require considerable power (~1 W). They are also magnetic, which makes them difficult to use in arrays. Commercial magneto-resistive sensors are sensitive to ~1 nT/√Hz but are very small (4 mm^3, packaged), and very inexpensive. Finally, Hall probe magnetometers have very poor sensitivity (100 nT/√Hz) but are inexpensive.

An important distinction between atomic magnetometers and most other sensor types is that atomic magnetometers are scalar sensors, which means they sense the magnitude of the magnetic field, rather than the projection along one spatial direction. This is particularly important for applications on moving platforms since platform motion adds considerable noise to a vector sensor as the angle between the field and the sensor axis changes.

One very high performance commercial gyroscope is the hemispherical resonator gyroscope (HRG), which achieves an exceptional angle-random walk (ARW) and bias drift but is very expensive to manufacture. Ring laser gyros (RLGs) and fiber-optics gyros (FOGs) also achieve navigation-grade performance at somewhat reduced cost. MEMS gyroscopes generally have very poor bias stability.

It is therefore believed that a solution to such drawbacks lies in the development of a magnetic field sensing apparatus, such as a gyroscope, and method as presented in this application.

BRIEF SUMMARY

The following summary of the invention is provided to facilitate an understanding of some of the innovative features unique to the present invention and is not intended to be a full description. A full appreciation of the various aspects of the invention can be gained by taking the entire specification, claims, drawings and abstract as a whole.

It is therefore one aspect of the present invention to provide for improved magnetometer methods and systems.

It is another aspect of the present invention to provide for improved gyroscope methods and systems.

The above and other aspects of the invention can be achieved as will now be briefly described. The innovation the present invention brings to the development of gyroscopes and magnetometers is associated with the diverging beam geometry. This geometry allows a simple, highly compact implementation of the NMR gyroscope that could be fabricated at a much lower cost than gyroscopes of equivalent