A microfabricated photonic magnetometer

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An integrated optically-controlled sensor, suitable for remote, high-sensitivity detection of magnetic fields is presented. The sensor head is free of electrical currents or metal parts, which largely eliminates any spurious fields created by the sensor itself. We demonstrate the operation of the sensor both in earth field in a Bell-Bloom type configuration [1] as well as in a spin-exchange relaxation-free mode (SERF) and reach sensitivities better than 500 fT/√Hz at 10 Hz.

Many magnetometer applications are limited either by the size and power consumption of the sensors (e.g.: remote field or space applications) or by the cost and complexity of operation (medical, SQUIDs). Sensors based on chip-scale atomic magnetometers allow both high sensitivity and low cost in a small integrated device. By operating an atomic magnetometer in the SERF mode sensitivities can be achieved that are comparable with those of high-temperature SQUID devices [2]. However, without the necessity of cooling, the atomic magnetometers are both easy to use and inexpensive to operate.

We present the design and initial measurements of a small atomic magnetometer that has no electrical connections near the sensor head. This also makes the sensor itself non-magnetic and avoids degradation of its performance due to internal magnetic fields. The sensor is fabricated by use of methods derived from microelectromechanical (MEMS) systems and integrated with off-the-shelf micro-optical components. Light is coupled through fibers to and from the sensor head for interrogation of the atoms. Heating of the atomic vapor is achieved by a second fiber-coupled laser source, utilizing the absorption properties of the vapor cell.

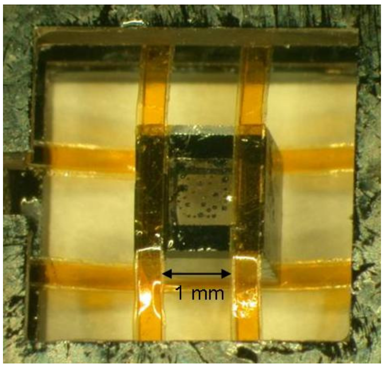

Fig. 1 Vapor cell, suspended by polyimide tethers.

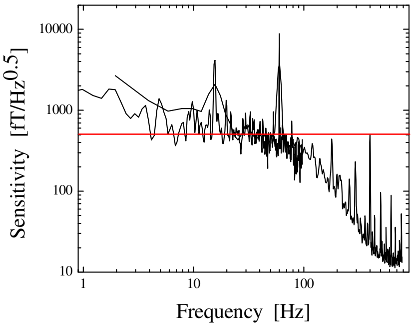

Fig. 2 Magnetometer sensitivity

The magnetometer is based on an alkali vapor cell, filled with ^{87}Rb and about 1 atmosphere of nitrogen as a buffer gas. The magnetically sensitive volume is 1 mm^3 and shown in figure 1. The cell is suspended on polyimide tethers for thermal isolation and enclosed by a stacked silicon frame. Also attached to this frame are the optical fibers and micro-optical components, such as prisms and polarization optics.

The magnetometer can be operated in several different modes. For operation in earth field, a spin precession can be driven with modulated laser light at the Larmor frequency of the atoms. The detected modulation, modified by the response of the atoms is a direct measure of the ambient magnetic field. Sensitivities around 5 pT/√Hz have been measured, limited by spin exchange collisions between the atoms. These collisions however, can be suppressed when operating the magnetometer at high cell temperatures and in very low magnetic fields [3]. This enables much higher sensitivities at the expense of higher power consumption and shielded environment. First measurements show sensitivities of 500 fT/√Hz over a frequency range of 10 to 100 Hz (figure 2).

[1] W. E. Bell and A. L. Bloom, “Optical detection of magnetic resonance in alkali metal vapour”, Phys. Rev., **10**, 1559 (1957)

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[3] W. Happer and A. C. Tam, “Effects of rapid spin exchange on the magnetic resonance spectrum of alkali vapors”, Phys. Rev. A., **16**, 1877 (1977)