Microelectronics and Microsystems
Photonics

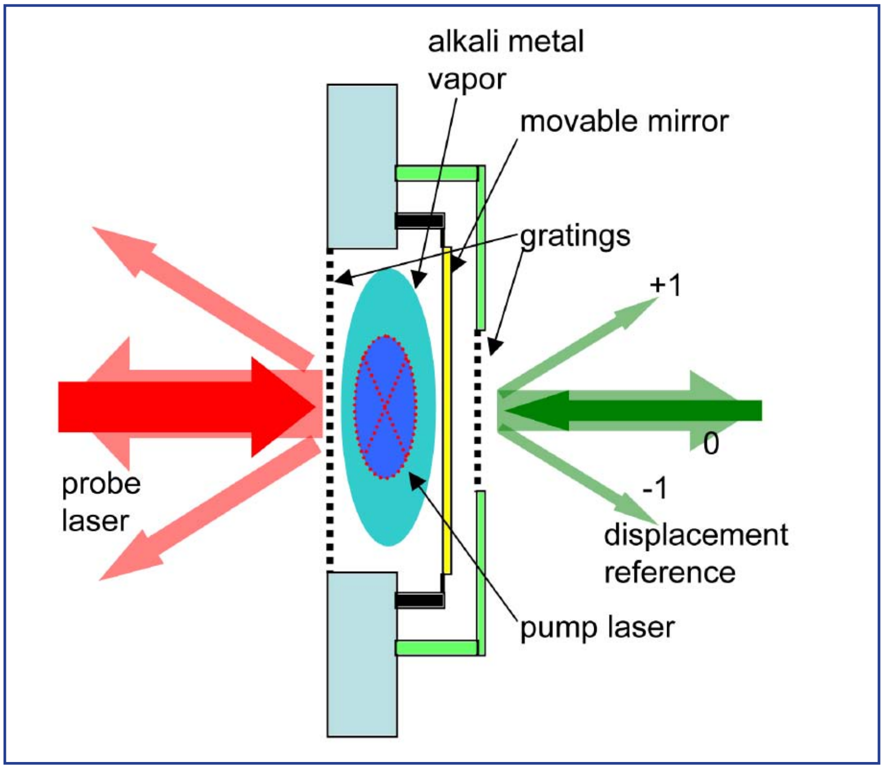

Figure 1: Schematic of the atomic magnetometer micro-cavity. A movable mirror and a grating are placed on either side of the atomic vapor cell. A pump laser (blue) orients the atomic spins. A probe laser (red) passes through the grating and the atomic vapor before reflecting off the mirror. The reflected light then passes through the grating again and interferes with light that is reflected directly from the grating. As the atoms respond to a magnetic field, their index of refraction changes, causing the interference pattern from the grating to shift. The displacement reference beam (green) precisely locates the movable mirror.

Atomic Magnetometers

Atomic magnetometers offer low power and high sensitivity in a small package.

High sensitivity detection of magnetic fields is a fundamental capability that enables a large number of diverse applications, from locating unexploded ordnance and underground structures, to the detection of biomagnetic fields associated with heart and brain activity. Superconducting magnetometers have long been the only practical option for high sensitivity magnetic field detection. However, they require bulky and expensive cryogenic cooling. Recent advances in atomic magnetometry have allowed world-record sensitivity (less than one femtotesla) to be achieved without the use of cryogenic cooling, thus drastically reducing the size and operating expense of a magnetometer. At Sandia, researchers are applying their photonics expertise to advance this new technology.

Atomic magnetometers rely on the fact that an alkali atom has an unpaired electron in its outer shell whose spin rapidly precesses in an external magnetic field. In Figure 1, a resonant (pump) laser beam shines through an atomic vapor cell to orient the atomic spins, and a second (probe) laser beam passes through the vapor to detect how the spins react to the magnetic field. The highest possible sensitivity is achieved when the magnetometer is operated at a low magnetic field. In this regime, atom-atom collisions in the atomic vapor are no longer a source of decoherence, and thus the number of atoms participating in the magnetic field measurement can be dramatically increased.

One aspect of Sandia's effort in atomic magnetometry focuses on miniaturization. To maintain high sensitivity at small sizes, a tunable micro-cavity is being developed for improved optical detection of the atomic response to a magnetic field (Figure 1). The tuning element in the cavity is a moveable microelectromechanical (MEMS) mirror (Figure 2). To contain the atoms in a small volume that also allows good optical access for the

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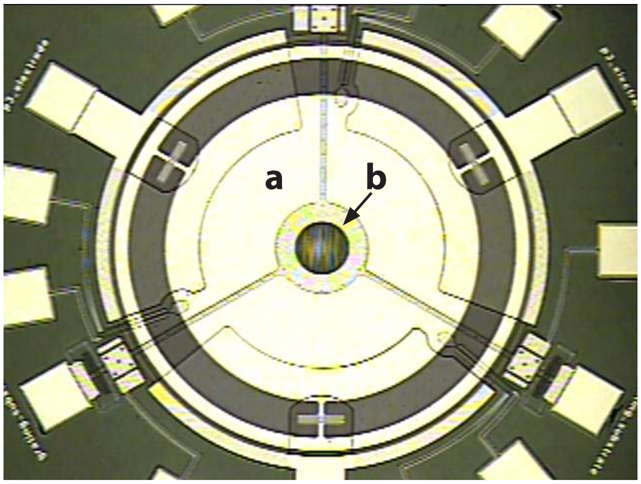

Figure 2: Photo of the movable MEMS silicon mirror and grating structure. (a) indicates the mirror (~1 mm diameter) and (b) indicates the grating.

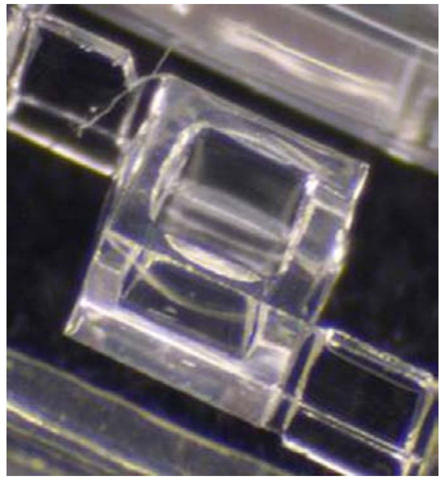

Figure 3: Photo of the patterned glass cell prior to filling with the alkali metal vapor.

lasers, a 1 mm^3 vapor cell is being developed using a photo-patternable glass (Figure 3).

In another effort, an atomic magnetometer is being developed for magnetoencephalography (MEG), the detection of the extremely weak magnetic fields produced by the brain. MEG data is collected by surrounding the head with an array of magnetometers and is then used to infer the location of neural currents inside the brain. Being one of the few non-invasive techniques for measuring brain activity, both spatially and temporally, MEG is a critical tool for furthering our understanding of the physiology underlying human cognitive processes.

The design challenge is to attain high sensitivity while keeping in mind the requirements of the human subject. A major component of the effort will be to collaborate with MEG experts at the Mental Illness and Neuroscience Discovery (MIND) Institute and the University of New Mexico to provide us guidance in the design and use of the device for use with animal models and human subjects. The high spatial resolution of MEG comes from using multiple sensors around the head. Because the atomic magnetometer reads out the atomic response to a magnetic field via optical interrogation, we can readily achieve multi-channel operation by simply detecting separated regions of the probe laser beam. Techniques developed in these research efforts will push the state of the art in atomic magnetometry, and, when combined, will enable many strategic applications, including underground structure mapping, remote sensing for boarder security, and MEG.

Sandia National Laboratories

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