Chip-scale atomic magnetometer based on free-induction-decay for ultra-low magnetic field detection

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Sensitive and accurate detection of ultra-low magnetic fields is of prime importance in numerous applications including magnetocardiography, geophysical surveying, and in fundamental science. In particular, chip-scale atomic magnetometers offer significant advantages in power dissipation, cost of fabrication, and size whilst maintaining sub-pT level sensitivities. Here we describe an optically pumped magnetometer utilizing a 1.5-mm thick caesium vapour cell containing N_2 buffer gas to impede atomic diffusion to the cell walls. The thermal cell is operated at 85 °C to improve signal-to-noise ratio (SNR) whilst limiting spin-exchange collisions, both of which increase with atomic density. Many atomic magnetometry schemes operate in a cw regime were the spin preparation (pump) and detection (probe) stages are performed simultaneously with a single laser beam. Here we discuss a pump-probe approach that separates these distinct phases in the time-domain, allowing the prepared atomic polarization to precess freely at the Larmor frequency whilst decaying exponentially as a consequence of various relaxation processes inherent to the vapour cell.

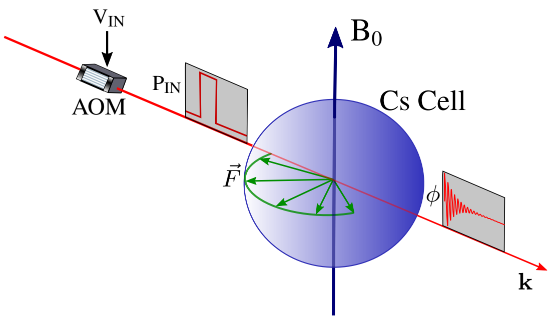

Figure 1: Illustration of the mechanisms behind an amplitude-modulated FID magnetometer. A high power light pulse builds up spin polarization during the pump phase. The spin precession is then monitored through optical rotation during a low-intensity probe stage.

Single-pulse optical pumping can sufficiently polarize the atoms at low precession frequencies with the acquired SNR dependent on the spin decoherence rate [1]. Alternatively, synchronous modulation at the Larmor frequency provides a consistent optical pumping efficiency throughout an extensive range of bias fields. The induced oscillating birefringence of the atomic sample can be monitored using polarimetry to observe the time-dependent optical rotation of the output light. Magnetic field information can be easily extracted from truncated FID signals epitomizing the potential for high bandwidth capability. This technique also provides significant advantages in accuracy over driven magnetometers as the precession is monitored directly and is not subject to systematic frequency shifts imposed by phase errors in the feedback signal [1]; however careful consideration of potential light shifts is required at elevated probe intensities. An optimal sensitivity lower than $4\,\mathrm{pT}/\sqrt{\mathrm{Hz}}$, limited by spin-exchange collisions, within a Nyquist limited bandwidth of 500 Hz has been measured in a shielded environment.

[1] Z. D. Grujic, P. A. Koss, G. Bison, and A. Weis, A sensitive and accurate atomic magnetometer based on free spin precession, Eur. Phys. J. D **69**, 135 (2015).