Squeezed-light enhancement of sensitivity and signal bandwidth in an optically-pumped magnetometer

Charikleia Troullinou, ICFO-The Institute of Photonic Sciences, charikleia.troullinou@icfo.es
Ricardo Jiménez Martínez, ICFO-The Institute of Photonic Sciences, ricardo.jimenez@icfo.es
Jia Kong, Department of Physics, Hangzhou Dianzi University, jia.kong@hdu.ch
Vito Giovanni Lucivero, ICFO-The Institute of Photonic Sciences, vito-giovanni.lucivero@icfo.es
Morgan W. Mitchell, ICFO-The Institute of Photonic Sciences and ICREA Institució Catalana de Recerca i Estudis Avançats , morgan.mitchell@icfo.es

Topic(s)

“quantum sensing/metrology”, “quantum basic science”

Background

Optically-pumped magnetometers (OPMs) [1], in which an atomic spin ensemble is optically pumped and its spin-dynamics optically detected, are a paradigmatic quantum sensing technology with applications ranging from geophysics [2] to medical diagnosis [3] to searches for physics beyond the standard model [4]. OPMs are also a useful proving ground to test sensitivity enhancement techniques that may someday be applied to atomic clocks, atomic gyroscopes, and atomic co-magnetometers. In these sensors two quantum systems – atoms and light – interact to produce the signal. Understanding and controlling the quantum noise in this interacting system is an outstanding challenge.

Presentation

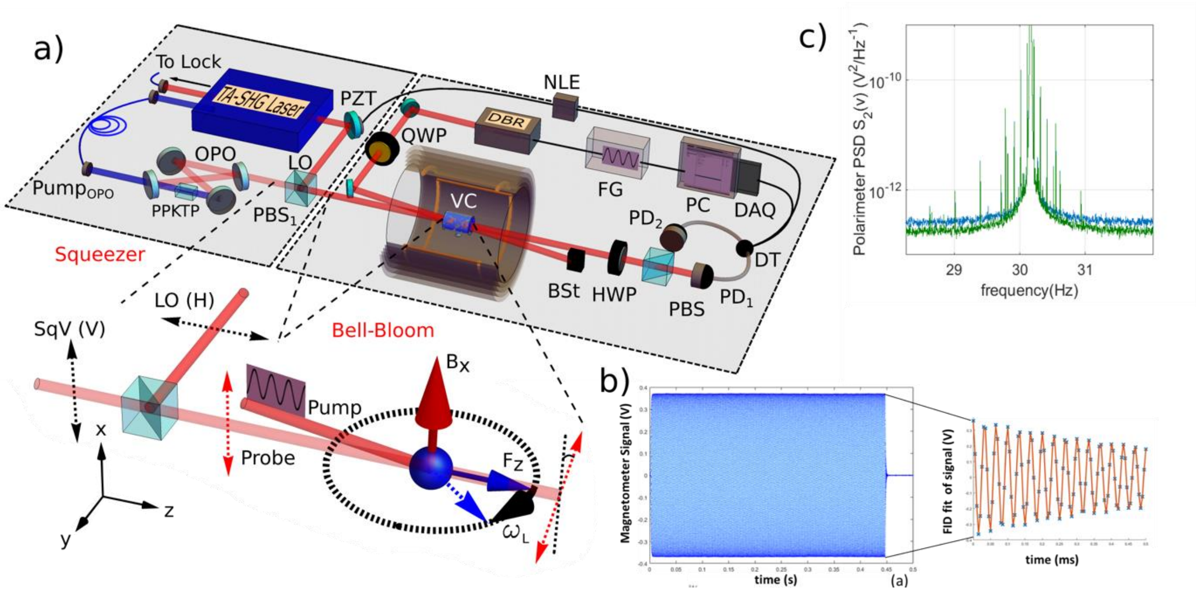

Figure 1. Squeezed-light Bell-Bloom OPM. a) Experimental schematic. TA-SHG, Tapered Amplified Second Harmonic Generator; OPO, Optical Parametric Oscillator; PPKTP, Nonlinear crystal; LO, Local Oscillator; PBS, Polarizing BeamSplitter; QWP - Quarter Wave-plate; VC - Vapor Cell; BSt - Beam stopper; HWP - Half Wave-Plate; PD - Photodiode; DTIA- Differential Transimpedance Amplifier; DAQ - Data Acquisition; FG - Function Generator; NLE - Noise Lock Electronics."Bell-Bloom" Inset: Due to the magnetic fieldBxatomic spins precess at the Larmor frequencyωLin the transverse plane.Synchronously modulated optical pumping maintains the atomic spin polarization. A linearly polarized cw probe undergoes paramagnetic Faraday rotation."Squeezer" Inset:Vertically-polarized squeezed vacuum is combined with horizontally-polarized LO on a polarizing beam splitter to generate a polarization squeezed probe. b) Power Spectral Density (PSD). Power spectrum of the BB signal for coherent and squeezed-light around the Larmor frequency. The spectra are averages of 100 measurements, each one with duration of 0.5 sec. c) Polarimeter signal under continuously modulated optical pumping (left) and free-induction decay (right).

Here we study how squeezed-light probing affects the sensitivity spectrum of a high-density quantum-noise limited OPM with 300 fT/√Hz sensitivity. In contrast to previous squeezed-light magnetometers, based on spin-alignment [5-7], we use a magnetometer architecture based on spin-orientation of the atoms and use phase-sensitive detection to extract the magnetometer signal. This approach allows us to implement features not found in previous squeezed-light magnetometers: We probe the spin orientation of the atomic ensemble via the optical Faraday effect, which is an efficient technique for quantum non demolition (QND) measurements, and employ Bell-Bloom (BB) excitation, which allows us to work at frequencies of 10s of kHz where detectors and squeezed-light sources can easily be shot-noise limited. This simple magnetometer architecture is amenable to off resonant squeezed-light probing that can be independently tuned. Polarization squeezing is generated in a subthreshold optical parametric oscillator achieving up to 3.2dB of photon shot noise suppression beyond the standard quantum limit. [8]. This use of squeezing is compatible with sub-fT methods including high-density [2], multi-pass [9] and with pulsed gradiometry [10]. The BB technique also gives a clear view of the relationships among different noise sources. We show in theory and observe in experiment that it is possible to improve the high-frequency sensitivity as well as the signal bandwidth of the OPM using squeezed probe light, while also evading measurement back-action noise [11–12]. The results provide experimental input to the much-discussed question of whether squeezing techniques can in practice improve the performance of atomic sensors.

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