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Development of a Spin-Squeezed Scalar OPM in Pursuit of Practical Entanglement Advantage

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Optically pumped magnetometers (OPMs) utilizing entangled spins offer the promise of sensing performance beyond the standard quantum limit (SQL). Unfortunately, realizing this advantage has proven exceedingly difficult. Entangled states are inherently tricky to create and maintain. It is often better to simply use many unentangled atoms rather than entangling far fewer of them. Nevertheless, recent work by the Polzik group has shown promising progress in the generation and utilization of spin-squeezed states in pulsed radiofrequency OPMs that can surpass the SQL (1).

Inspired by this approach, we are developing a scalar OPM that utilizes a similar pulsed interrogation methodology. The key is a stroboscopic interrogation sequence that is pulsed at twice the Larmor frequency to implement a quantum nondemolition (QND) measurement of the spins. To implement squeezing, this method is used to measure the spins both before and after a free evolution period in which the spins interact with external magnetic fields. Conditioning the final uncertainty in magnetic field on information obtained via the pre-interaction measurement can reduce the final uncertainty below the SQL; the spin ensemble has been put into a squeezed state through a process known as conditional squeezing.

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This project has two aims: development of a strong theoretical model to explore the underlaying dynamics of the hot vapor cell on which the OPM is based so we may best predict and optimize squeezing performance and building an experimental platform to test these predictions. Based on the foundation laid by the Romalis group(2) , we are working to implement multiple passings of the probe beam through the vapor cell via a collaboration with Opto-Assembly Inc. Such a multi-passed design leads to a much greater effective optical depth experienced by the probe beam, which can greatly improve the SNR of detection that relies on optical Faraday rotation. This reduces the magnetic field uncertainty stemming from photon shot noise in comparison to the spin-projection noise. Since spin-squeezing can improve only the latter, this architecture should help us realize greater benefits from spin-squeezing.

References

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