Precise magnetometry with a spin squeezed ultracold gas and squeezed light

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1. Introduction

The engineering of the quantum states of matter and light has been an intriguing issue. It is not only of fundamental interests but also is appealing as a tool for realizing better measurement. Such quantum metrology has drawn much attention recently. Atomic gases have been used for precise measurements, including atomic clocks, gyroscopes, and magnetometers. Because the sensitivities in state-of-the-art atomic sensors have reached down close to the standard quantum limit (SQL), beating the SQL in a precise atomic sensor is one of the important goals in recent research.

We are now developing an ultrasensitive magnetometer with a Bose-Einstein condensate (BEC) of ^{87}Rb atoms. The BEC magnetometry can offer an excellent magnetic field sensitivity per unit measurement area (or volume) due to the high density and restricted motion of atoms. Its magnetic field sensitivity has been limited by the quantum noises of atoms and light. We aim to squeeze both of the quantum noises to achieve an unprecedented sensitivity and to explore an open question on the limitation of the magnetic field sensitivity per volume.

2. Results

Our project consists of (i) construction of a sensitive BEC magnetometer, (ii) spin squeezing of a BEC, and (iii) preparation of stable squeezed light at atomic resonant wavelength (795 nm). While our final goal is to combine these, every element itself is of significance for quantum metrology with atoms. We recently complete all of these and introduce them briefly here. The details will be reported in the presentation.

BEC magnetometry has been reported for these two decades. Among of them, a magnetometry by consecutive imaging of a BEC exhibiting the Larmor precession has achieved the best sensitivity [1]. We have found that the magnetic field sensitivity of this type of magnetometry can be improved by careful choice of probe frequency, reducing the optical shot noise [2]. We have attained a magnetic field sensitivity of 6.2 pT $Hz^{-1/2}$ with a measurement area of 28 μm^2. This is the best sensitivity among BEC magnetometers. In addition, it is almost limited by the SQL of comparable atomic spin and photon shot noises.

Our consecutive imaging is quantum nondemolition (QND)-like and measurement-based spin squeezing is expected to naturally occur during imaging. The measurement-based spin squeezing of a BEC, however, has not been reported so far, probably due to severe light-induced atom losses. The probe optimization helps to avoid the losses and we recently realized conditional spin squeezing of a BEC using consecutive imaging.

We generated squeezed light at 795 nm using optical waveguides for second harmonic generation (SHG) and optical parametric amplification (OPA). While the squeezed light at 795 nm has been usually produced using atomic gases or a nonlinear crystal in a cavity, we use optical waveguides for stability and compactness. An obstacle in the optical waveguide scheme was to produce the second harmonics of high power for pumping the OPA. We have used pulsed fundamental light for the SHG and produced UV (397 nm) light of high peak power. By injecting this pulsed UV light into the OPA, we have observed squeezing of the optical quantum noise.

3. Conclusions

We have realized sensitive BEC magnetometry, spin squeezing of a BEC compatible with our magnetometry method, and squeezed light for probing the BEC. These achievements are important constituents for a quantum ultrasensitive magnetometry. We are now in preparation for combining the BEC machine and the squeezed light.

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References

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