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D2.4 Quantum noise measurement and demonstration of an entangled state of two microcells and its application

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D2.4 Quantum noise measurement and demonstration of an entangled state of two microcells and its application

The UCPH team has developed the next generation of 220 µm x 220 µm x 1 cm microcells and performed the first quantum noise measurements on it by optical readout of orientated collective atomic spin. Fig.1 presents the measurement setup. The power spectra density of the magnetometer is shown in Fig. 2. The power spectral density consists of white shot noise background, and a Lorentzian profile, which includes the contribution of the probe back-action and the spin noise associated with the quantum state prepared by optical pumping. The sensitivity is mainly limited by the light shot noise, with a 30% contribution from the spin quantum state and 10% from the back-action of the light probe. By mapping the radio-frequency resonance curve at large magnetic fields, the degree of spin orientation can be found. Spin orientations >90 % were achieved; for the continuous pump operation, the highest magnetic sensitivity was realized for spin state corresponding to ~85% orientation. The setup has been used to demonstrate a sensitive quantum magnetometry. Under continuous optimized pump and probe operation, a magnetic sensitivity ~4 pT/sqrt(Hz) was achieved with ~2x10^6 atoms and coherence lifetime T2~0.5 msec.

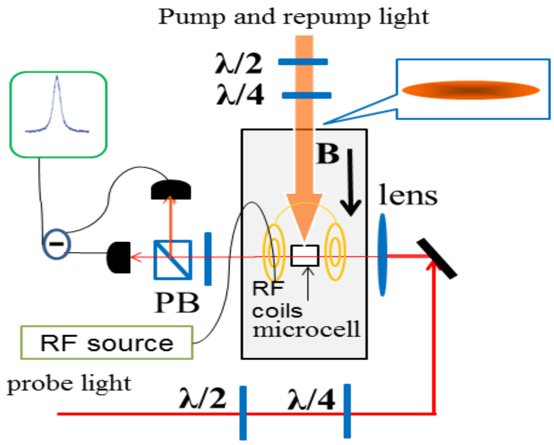

Fig. 1: Optical setup for magnetometery. Circularly polarized pump and repump beams orient the atomic spins in the direction of a holding field. A linearly polarized beam perpendicular to the holding field measures spin precession.

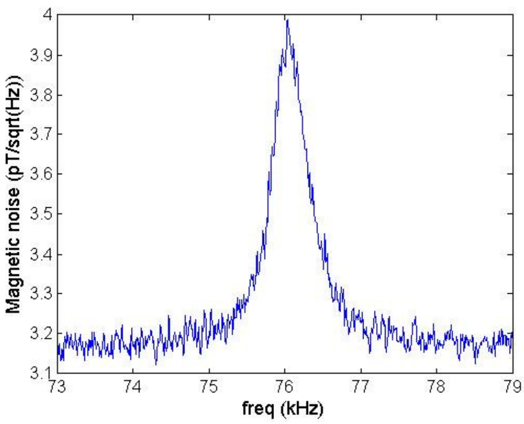

Fig. 2: Power spectral density of the quantum noise from a microcell.

The feasibility of the setup for entanglement generation will be improved by implementing a pulsed pump and probe scheme, in a fashion similar to Ramsey spectroscopy. This will result in an increased atomic coherence time and a preparation of almost fully oriented spin state with the corresponding projection noise limited performance. In addition, the microcell will be placed inside a low finesse cavity, which will enhance the light atom coupling with a corresponding increase of the spin state quantum noise with respect to light shot noise. The UCPH team has already started implementing the pulsed scheme and the cavity.

Entanglement between two different microcells and associated applications have not yet been demonstrated. We have spent a large time and effort towards fabrication and testing of the microcells. This fabrication which involves making a microcell, attaching the AR coated windows and the stem, coating the cell with spin-preserving coating and filling them with Cs is a very complex process. After several fabrication rounds the UCPH team has demonstrated the ground state spin decoherence time of T2=4msec. This result is quite competitive with the T2 times observed for much more complex systems, such as cold atoms and solid state ensembles. Currently, a new way for constructing the microcells by laser bonding windows on commercially available microtubes is explored. Furthermore, it is expected that the use of higher temperatures in the deposition phase of the anti-relaxation coating should result to a better functioning coating. We are positive that in the coming months we should be able to observe projection noise limited measurements and proceed to the two-cell experiment on the way towards demonstration of the entanglement.

In a parallel line of work, the UCPH team has successfully realized the first deterministic cv teleportation experiment between two macroscopic ensembles of Cesium atoms. As shown on Fig.3, the entanglement is generated between the receiver Bob holding ensemble B and a pulse of light propagating from B to the sender Alice holding the ensemble A. Then, quantum teleportation can be performed by a joined measurement on the system formed by the input state of A and the light pulse, followed by classical communication and the corresponding local transformation on Bob's system.

The two ensembles are placed in a bias magnetic field and oriented along the x direction. The atoms are optically pumped into the m=4, F=4 ground state. This coherent spin state is a minimum uncertainty state for the collective ground state spin. To generate distributed entanglement a strong light beam polarized in the y direction is sent through ensemble B. An entangling interaction occurs where one atomic excitation is accompanied by the creation of a photon in the upper sideband of the x-polarization mode. The light, now entangled with the atoms of ensemble B, continues onto Alice's site and is directed through ensemble A.

The state to be teleported is encoded in the collective spin state of ensemble A. Here, a joined measurement comprising the dispersive interaction and a measurement of one of the quadrature operators in the x-polarization mode of the ingoing light via polarization homodyning is performed. Feedback via a magnetic RF pulse onto the atomic spin of ensemble B, according to the measurement outcome on light, completes the teleportation.
The teleportation is successful for every attempt. This is ensured by the deterministic character of the homodyne process. The performance of the experiment is then evaluated by comparing the fidelity of the process to the limit set by classical teleportation. This limit was surpassed for small displacements by different sets of state inputs with a certain mean number of excitations.

The experience and techniques developed for the macrocells here should be readily transferred to microcells.

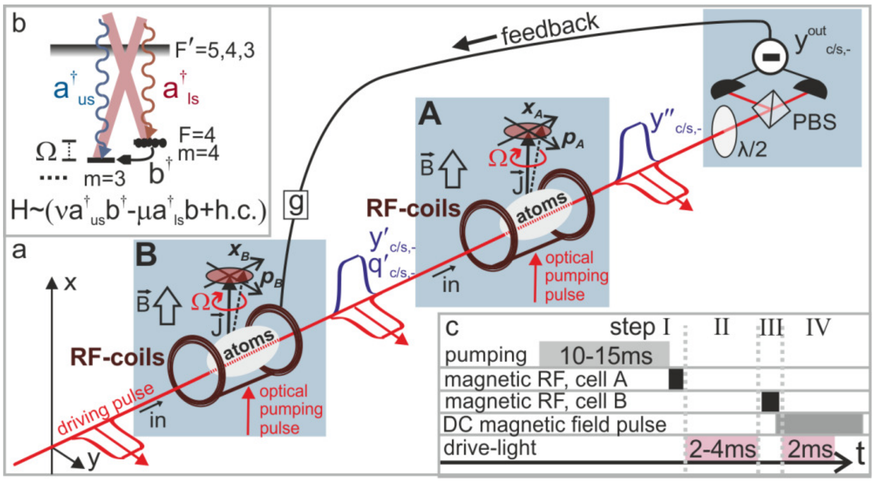

Fig. 3: a) Scheme of the teleportation experiment with ensembles A and B in a bias magnetic field oriented along x. b) Level scheme illustrating the dispersive interaction. c) The steps of the experiment: I. Preparation of the input state, II. Entanglement and joined measurement, III. Feedback, IV. Verification of teleportation success.