Atomic Gyroscope for Enhanced Navigation

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Progress towards miniature atomic gyroscope with navigation grade performance based on a MEMS fabricated Rb vapor cell is reported. The gyroscope utilizes moderate pressure cell containing several hundred torrs of Xe and N_2 buffer that yield strong overlap of hyperfine absorption lines in Rb. Nevertheless we find that magnetic precession reveals large sensitivity to the pump-probe laser frequency. To overcome it, a dual frequency (DF) spin-polarized optical pumping for reduction of the laser frequency sensitivity is proposed. In addition, DF interrogation narrows the width of magnetic resonance and reduces bias.

Within the framework of the research project GYROCELL, we continue our efforts to establish a concept for low-cost navigation grade atomic gyroscope named AGEN (Atomic Gyroscope for Enhanced Navigation). Such micro-gyroscope has clear market prospects for small-size aircrafts and unmanned airborne vehicles.

Low manufacturing cost is inherent to wafer scale MEMS fabrication technique, which is envisioned as a key element of the gyroscope, a cell filled with noble gas and alkali metal atoms. Navigation performance is provided by measuring magnetic precession of nuclear spin in noble gas atoms. For operation of the gyroscope, the noble gas atoms have to be polarized in spin-exchange collisions with alkali atoms, which are under optical pumping with the circularly polarized light. Efficient and stable spin-exchange-optical pumping is vital for reaching navigation grade performance of such micro gyroscope. Here, we report on progress made in understanding the effects of optical frequency detuning from the absorption resonance and propose novel approach to reduce such sensitivity. Our optical test setup mimics the architecture of micro gyroscope physics package with a single frequency (SF) narrowband optical source. It consists of a 45° crossed circularly polarized pump and probe beams diverted from a DFB laser. Three-axis Helmholtz coil system provides a steady holding field in the pump beam direction and a second alternating magnetic field to drive the coherent spin precession in the orthogonal plane. We use a representative cell containing several hundred torrs of Xe and N_2 buffer and heated to 110°C to reach sufficiently high density of Rb vapor (Rb with natural isotopic abundance is used). The hyperfine features in the absorption line are strongly collision broadened and overlap (Figure 1, red curve). Once on resonance, one would expect no large sensitivity to small variations in laser optical frequency. Fixing the frequency of coherent magnetic field (120 kHz in Figure 2, red curve) and scanning the amplitude of the holding field, we recorded the electron spin resonance (ESR) curve for the two Rb isotopes in the cell. Under SF interrogation, ESR curve reveals bias, which can be attributed to the light shift effect. Fixing then both the frequency of coherent magnetic field and the amplitude of the holding field, we measured the impact of the laser frequency detuning on the amplitude of ESR (Figure 3). Surprisingly, despite smooth profile of the absorption spectrum in Figure 1, hyperfine ground state lines in Rb reappear in the ESR spectrum (Figure 3, red curve shows example for ^{85}Rb isotope). These features indicate that the laser frequency stabilization with MHz precision is required for navigation grade performance. This requirement implies an additional low-pressure reference cell in the architecture of such micro gyroscope.

We find what we believe a pioneering solution enabling us to avoid such tight stabilization of the laser frequency. It consists in modulating the laser drive current so as to produce a two sidebands in the optical spectrum on resonance with the two hyperfine absorption lines in Rb. Dual frequency (DF) pumping and interrogation scheme flattens the ESR spectrum, reducing sensitivity to the carrier frequency detuning (Figure 3, blue curve). It also reduces the bias and the width of ESR resonances (Figure 2, blue curve). These findings will be crucial for the design of our micro gyroscope. They are also important for other miniature atomic sensors e.g. for chip-scale atomic magnetometers.

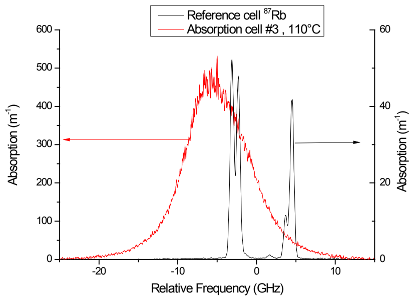

Figure 1: Measured absorption spectra of representative Rb-Xe-N2 cell at 110°C (red curve) and of the reference cell with ^{87}Rb and no buffer (black curve).

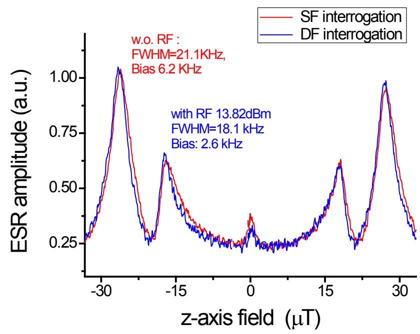

Figure 2: ESR amplitude vs holding field in a cell with natural abundance Rb. Coherent magnetic field oscillates at 120 kHz. Data are taken under SF (red curve) and DF (blue curve) interrogation.

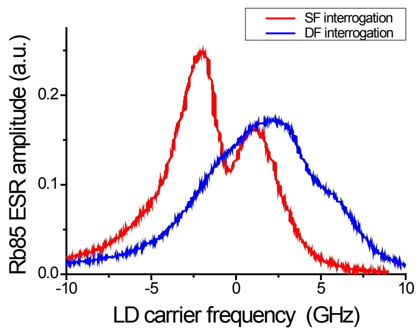

Figure 3: ESR in ^{85}Rb atoms at 145 kHz (B_z=31μT) vs carrier optical frequency under SF (red curve) and DF (blue curve) interrogation.

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