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Light pulse analysis with a multi-state atom interferometer

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Abstract. We present a controllable multi-state cold-atom interferometer that is easy-to-use and fully merged on an atom chip. We demonstrate its applications as a sensor of the fields whose interactions with atoms are state-dependent.

Keywords: Atom interferometry, Bose-Einstein condensate, Atom manipulation
PACS: 03.75.Dg, 37.25.+k,37.10.De, 37.10.Gh

1. INTRODUCTION

Matter-wave interferometry is a powerful tool for high-precision measurements of the quantum properties of atoms, many-body phenomena and fundamental interactions [1]. Further enhancement of sensitivity and reduction of complexity are crucial requirements for success and widening of their applications. We present a controllable multi-state cold-atom interferometer that is easy-to-use and fully merged with an atom chip.

2. MULTI-STATE INTERFEROMETER ON ATOM CHIP

A typical interferometric sequence is comprised of the initial state preparation, multi-state splitting, phase evolution, remixing of the states and population read-out. The initial state is prepared by condensing ^{87}Rb atoms in a low field seeking ground state $|F = 2, m_F = 2\rangle$ on an atom chip. Coherent transfer of the atoms to other Zeeman states of the same hyperfine state is realized by application of a resonant RF pulse. The interferometer is closed by remixing these states by a second RF pulse after a controllable time delay as in [2]. This second pulse maps the relative phases accumulated between different states during the delay into a population distribution at the output of the interferometer. In the absence of an external field, the relative phases between the states are accumulated due to the presence of the trapping magnetic field B. In this field Zeeman states experience different potentials given by $V = m_F g_F \mu_0 |B|$ where m_F and g_F are the spin and Landé numbers, respectively, and μ_0 is the Bohr magneton. As a consequence, the interferometer output has a form of a finite Fourier series whose terms correspond to the multiples of the energy difference between adjacent Zeeman states. The harmonics cause a fringe narrowing with the total number of states, Fig. 1, which is the basic characteristic of a multi-state interferometer and has been shown for an atom

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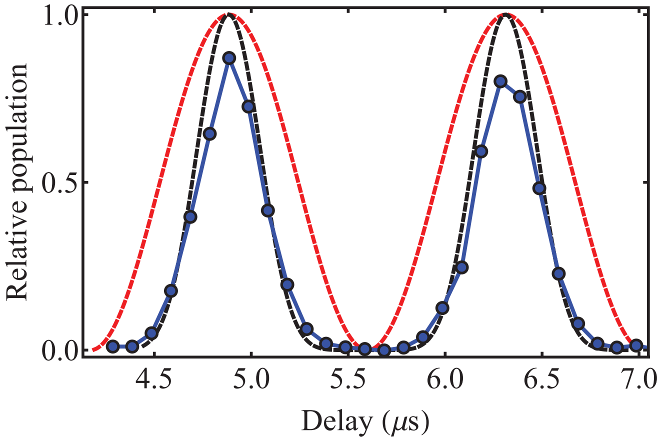

FIGURE 1. Interferometric signals for the $m_F = 2$ state. Blue circles show the best signal obtained in the experiments (the blue solid line serves to guide the eye). This signal was obtained an RF Rabi pulse area of $\Omega\tau = 1.55\ \pi$. The dashed black line shows the corresponding theoretical signal. For comparison, the optimal 2-state interferometer is also shown (red solid line). The realized 5-state interferometer has 1.75 times higher resolution than the ideal 2-state interferometer.

interferometer in [3]. Finally, in order to determine the population of each output state, the states are spatially separated by application of the Stern-Gerlach method[1] followed by a free-fall expansion and the imaging procedure.

3. LIGHT PULSE ANALYSIS

Applications of the proposed interferometer are based on different responses of the Zeeman states to an external field. Due to the simultaneous measurement of multiple state populations, the interferometer can be used in two basic measurement configurations: absolute measurements in which the signal is defined as a shift of fringes belonging to a chosen state, and differential measurements in which the signal is defined as the difference in shifts of fringes belonging to different states. Applications of the absolute measurements are, e.g., the determination of a magnetic field amplitude which directly maps into the periodicity of the fringes or measurements of parameters of light-atom interactions. An example of the latter is shown in Fig. 2 where a response of the $m_F = 2$ state to far-off resonant light pulses with different circular polarizations is shown.

4. CONCLUSIONS

We present a novel multi-state interferometer on an atom chip and demonstrate its applications as a sensor for light polarization. It is based on different responses of the

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[1] A magnetic field gradient is applied causing a spatial separation of the different Zeeman states.

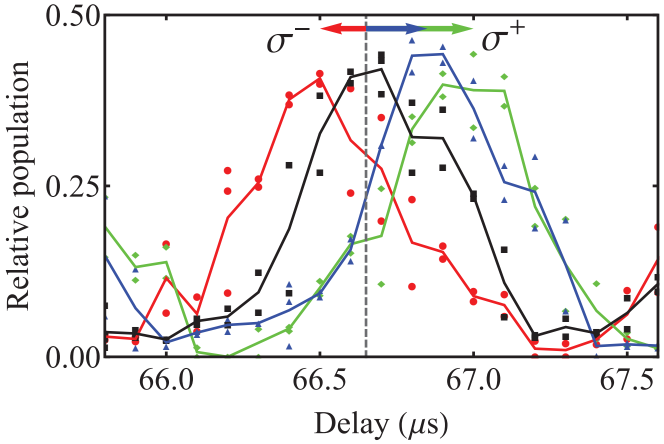

FIGURE 2. Here we demonstrate the sensitivity of the interferometer to a light pulse sent to the BEC during the time interval between the two Rabi pulses. The atoms were illuminated by the $40\ \mu s$ light pulse with the frequency stabilized to 6.568 GHz to the red of the $F = 2 \rightarrow F' = 3$ Rb D2 transition. The pulse was focused along the longer axis of the BEC and its beam waist at the condensate was $100\ \mu m$. The black squares shows the reference fringe without light,the red circles corresponds to σ^- light pulses with a power of 86 nW, blue triangles and the green diamonds correspond to σ^+ light pulses with powers 86 nW and 176 nW, respectively. All fringes are of the $m_F = 2$ state. To facilitate the analyses we have plotted the median (full lines) of the experimental data. The polarisation of light determines the sign of the fringe shift, σ^- advances and σ^+ delays the fringe pattern.

Zeeman states to external fields. Simultaneous measurement of all state signals at the output enables a range of advanced sensing applications in atomic physics and optics, e.g. multi-parameter sensing, while the integration of the interferometer with a chip puts it into consideration for future portable cold-atom based measurement apparatuses.

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REFERENCES

1. A. D. Cronin, J. Schmiedmayer, and D. E. Pritchard, *Rev. Mod. Phys.* **81**, 1051 (2009).
2. F. Minardi, C. Fort, P. Maddaloni, M. Modugno, and M. Inguscio, *Phys. Rev. Lett.* **87**, 170401–4 (2001).
3. M. Weitz, T. Heupel, and T. Hänsch, *Phys. Rev. Lett.* **77**, 2356–2359 (1996).