Atom interferometry with ultra-cold strontium

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We report on the the first realization of an atom interferometer based on alkali-earth atoms, namely strontium, using Bragg diffraction. The present status of the project and future prospects towards high precision tests in gravitational physics are discussed.

1 Introduction

Strontium atoms have interesting features for atom interferometry. In particular for bosonic ^{88}Sr isotope, atoms in the ground electronic ^{1}S$_0$ state has zero spin, making them insensitive to external electric and magnetic fields. Moreover, cold collisions among atoms in this state are very rare. The almost negligible scattering cross section (a=-2a_0) is particularly favorable in order to preserve coherence of the atomic wave function for long interferometric sequences and Bloch oscillations[1]. For these reasons, bosonic ^{88}Sr atoms are considered for testing large momentum transfer (LMT) interferometers by employing two-photon Bragg transitions[2].

Toward this goal, we are performing first tests of Bragg diffraction on ultra-cold strontium samples. Bragg pulses are applied along the vertical direction on a pre-cooled sample of strontium (about 10^6 atoms at μ K temperatures). The Bragg pulses are produced by a secondary 461 nm blue laser frequency offset locked to the primary cooling laser source with a typical frequency offset of $\Delta = 9$ GHz. Two acousto-optical modulators are used to produce two optical beams with the proper frequency detuning $\delta = \omega_1 - \omega_2$ for the Bragg pulses. The different diffraction order n is then selected by choosing the proper $\delta_n = 4n\omega_r$, where $\omega_r = \hbar k^2/(2M)$ is the recoil frequency ($\omega_r = 2\pi \times 10.6$ kHz for strontium). The two frequency components are then coupled into a single mode fiber with mutually orthogonal polarization and sent to the atomic sample; after the atom chamber, the polarization is changed with a quarter wave plate and the beam is retro-reflected by a suspended mirror.

By choosing the proper Bragg pulses parameters (laser intensity, frequency detuning and pulse duration), it is possible to transfer efficiently the atomic cloud in the first diffracted order (π pulse, as shown by Fig.1) with net momentum of $+2\hbar k$. To ensure high efficiency π pulses[3], atoms with lower velocity spread along the vertical direction are selected and launched upward before the subsequent Bragg interaction. About 10^5 atoms are launched upward with an initial

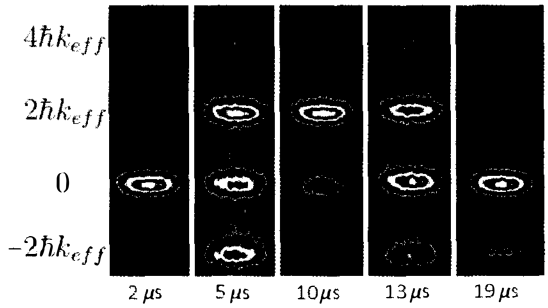

Figure 1 – False colour images of Bragg-diffracted ultra-cold strontium atoms after time of flight $T_{tof} = 20$ ms. On the bottom of each picture is reported the corresponding Bragg pulse duration.

momentum $p_0 \sim 24\hbar k$ and a velocity spread of $\Delta p \sim 0.1\hbar k$. In this condition, the maximum diffraction efficiency we reached for a π-pulse is nearly 90%.

We have also performed first tests on Mach-Zehnder $\pi/2$-π-$\pi/2$ interferometer, obtaining fringes with a contrast $C \sim 50\%$ for an interferometer time $T = 30$ ms. While the total interferometer time is currently limited by the vertical size of the vacuum system, in this configuration, we could perform precision measurements of the local gravitational acceleration g. A detailed study of the sensitivity of the strontium gravimeter, $\Delta g/g < 10^{-7}$ for an integration time $\tau = 400$ s, is currently under study. Meanwhile, to overcome some of the limitation imposed by the current experimental setup, a feasibility study for a 10 m strontium fountain is under way. In conclusion, ultra-cold strontium atoms might represent a valid choice for precision gravimeter and gravity gradiometer, with possible future application to stringent tests of fundamental physics theories [4].

Acknowledgments

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References

1. N. Poli, F.-Y. Wang, M. G. Tarallo, A. Alberti, M. Prevedelli, G. M. Tino, "Precision measurement of gravity with cold atoms in an optical lattice and comparison with a classical gravimete", *Phys. Rev. Lett.* **106**, 038501 (2011)
2. G. M. Tino, "Testing gravity with atom interferometry" in *Atom Interferometry*, Proceedings of the International School of Physics "Enrico Fermi", Course CLXXXVIII, Varenna 2013, p. 457-491, Editor G. M. Tino and M. A. Kasevich, Società Italiana di Fisica and IOS, (2014)
3. S. S. Szigeti, J. E. Debs, J. J. Hope, N. P. Robins, J. D. Close, "Why momentum width matters for atom interferometry with Bragg pulses", *New J. Phys.* **14**, 023009 (2012)
4. M. G. Tarallo, T. Mazzoni, N. Poli, D. V. Sutyrin, X. Zhang, and G. M. Tino, "Test of Einstein Equivalence Principle for 0-spin and half-integer-spin atoms: Search for spin-gravity coupling effects", *Phys. Rev. Lett.* **113**, 023005 (2014)