Advanced atom interferometry techniques for high-sensitivity sensing using ^{88}Sr atoms

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In the past few years, atom interferometers have evolved dramatically and are now used as state-of-the-art quantum sensors for fundamental physics [1]. In gravitational physics, their ability to accurately measure acceleration allows for precise measurements of gravity [2,3], gravity gradients [4,5], gravity curvature [6] and the gravitational constant [7]. Furthermore, their high precision makes atom interferometers ideal candidates for gravitational wave detection. Important advances in atom interferometry focus on increasing their sensitivity as well as demonstrating high sensitivities with atomic species other than alkali-metal elements commonly used.

Specific interest has centred around the use of alkaline-earth-metal and alkaline-earth-metal-like atoms, such as Ca, Sr and Yb [8-10], as they possess several characteristics that make them well-suited for high-precision measurements. Their zero electronic angular momentum in the $^1S_0$ ground state makes them less sensitive to electronic perturbations and the presence of dipole-allowed transitions as well as narrow intercombination transitions allows for efficient multiphoton Bragg diffraction [11] and single-photon interferometry schemes [12].

We report on two high-sensitivity atom interferometry experiments using the ^{88}Sr isotope, which due to a nuclear spin of zero in the ground state makes it insensitive to stray magnetic fields and further, suffers little from decoherence resulting from cold collisions due to a small scattering length $a = -2a_0$ [13]. The first experiment is a demonstration of atom interferometry using large-momentum-transfer Bragg diffraction in a fountain of ^{88}Sr atoms [14]. We use a 461 nm blue laser detuned 8 GHz from the $^1S_0 - {}^1P_1$ to apply a Bragg momentum transfer via light pulses to the atomic cloud, both launching it from an initial red MOT and then separating and recombining the atomic cloud in a typical Mach-Zehnder interferometric scheme. Each Bragg interaction imparts a momentum transfer of $2n\hbar k$ where k is the wavevector of the Bragg laser and n is the Bragg order. This results in the total phase accumulation of the interferometer becoming $\Phi = 2nk \cdot gT^2 + n(\varphi_1 - 2\varphi_2 + \varphi_3)$, where T is the total interferometer time, g is the acceleration due to gravity and φ_n is the phase of each Bragg pulse. A higher Bragg order allows higher sensitivities in the phase detection, which translates into higher sensitivities in gravity measurement. With fourth order Bragg pulses, the total momentum transfer can be as high as 8 photon recoils, resulting in a sensitivity to gravity $\delta g/g$ of up to 4×10^{-8}. Aside from typical noise contributions, the limitations on this experiment are the small size of the experimental cell, which limits the maximum initial launch distance of the atomic cloud and therefore the total momentum transferred to the atoms, which in turn limits the sensitivity.

The second experiment aims to increase the interferometer sensitivity by increasing the total interferometer time T [15]. Due to the long coherence time of ^{88}Sr, it is possible to observe long-lived Bloch oscillations when the atoms are trapped in a potential well [16]. We exploit this property by using an optical lattice to trap the atoms at their apogee position during a typical interferometer sequence, extending the total time T of the interferometer and therefore it's final sensitivity. This experiment is the first realisation of an atom interferometer using Bragg pulses and Bloch oscillations, as we use the principles of the previous experiment to apply the Bragg pulses of the interferometer sequence. Unlike the previous experiment, an initial launch momentum is imparted onto the atomic cloud from the red MOT using an optical lattice driven by a 532 nm source, instead of the Bragg pulses. A series of Bragg pulses then narrows the momentum selection of the cloud, and further Bragg pulses split the atomic cloud in a typical Ramsey-Bordé interferometer scheme. At the apogee of the interferometer, the atomic clouds are further trapped in the optical lattice, which due to its far detuning (~70 nm) from the strong atomic transition, allows a Bloch oscillation time of up to 1.4 s, which is comparable to the total interferometer time of a launched interferometer in a 10 m fountain. Measurements of the interferometer fringe contrast show negligible decay of the fringe for up to 1 s evolution time in the lattice, with the limitation coming mainly from the lattice lifetime in the current system. Current work is focused on characterising the Bloch evolution in the lattice and contrast decay as a function of the Ramsay time (time between each Bragg pulse in the interferometer sequence) as opposed to the Bloch evolution time. Upon completion of this part of the experiment, future work will be to move to Bragg pulses using the narrower red transition at 689 nm to obtain higher-order Bragg diffraction with lower laser power, allowing for further increase in sensitivity. The red laser can also be used as the lattice laser, and faster detuning of this laser can more easily compensate for contrast decay induced by light-shift inhomogeneity, which is highly apparent when using the far-detuned green laser source.

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