Manipulation and Transport of Cold Atoms Using an Adaptable Magnetic Grating

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Adaptive optics for cold atoms has been experimentally realized by applying a bias magnetic field to a static magnetic mirror. The mirror consists of a 12 mm diameter piece of commercial videotape, having a sine wave of wavelength 25.4 mm recorded in a single track across its width, curved to form a concave reflector with radius of curvature R=54 mm. We have studied the performance of the mirror by monitoring the evolution of a $24\mu K$ cloud of ^{85}Rb atoms bouncing on it. A uniform static external magnetic field was added to the mirror field causing a corrugated potential from which the atoms bounce with increased angular spread. The characteristic angular distribution of the surface normal is mapped at the peak of the bounce for atoms dropped from a height of R/2 causing the atom cloud to split into two. The splitting of the reflected cloud is proportional to the external field, apart from a slowly varying factor (Figure 1).

In a second experiment an AC magnetic field was applied and the angular distribution of the cloud was measured as a function of frequency. In this scheme we demonstrate a corrugated potential whose time dependent magnitude behaves like a diffraction grating of variable depth. Three characteristic frequency ranges were observed. Firstly at oscillation frequencies lower than 50Hz the cloud shape is the same as that from a static grating. Secondly for frequencies higher than 1/(2 x 10ms) the reflected cloud takes a triangular shape. Since 10ms is the time the whole cloud needs to be reflected, this is caused by different parts of the falling cloud experiencing a static grating with different corrugation strength. The reflected cloud shape does not change again with frequency until 15kHz where the mirror appears perfectly flat. This is because each individual atom takes $67\mu s$ to proceed through the mirror potential and therefore experiences equal amounts of positive and negative corrugation force.

Finally a rotating field was added to generate a corrugated potential that moves with a velocity given by the product of the external field rotation frequency and the wavelength recorded on the videotape. The reflected atom cloud has the split shape seen in the case of static corrugations, proving that the corrugation depth is now constant in time and only its position varies. The reflected cloud is displaced in the direction of motion of the grating. We observed the displacement of the center of mass after reflection from left and right moving gratings for a range of grating speeds and corrugation depth. Experimental limitations limited the displacement to 1.5mm. This traveling grating demonstrates a new method of manipulation as the cold atoms are transported across the surface by surfing along the moving wave.

Two theoretical methods have been developed to predict the behaviour of atoms reflecting from these stationary, variable magnitude and moving corrugated potentials. A simple analytic theory provides excellent agreement for reflection from a stationary corrugated potential and gives good agreement when extended to the case of a travelling grating. A Monte Carlo simulation was also performed by brute force numeric integration of the equations of motion for atoms reflecting from all three corrugated potential cases.

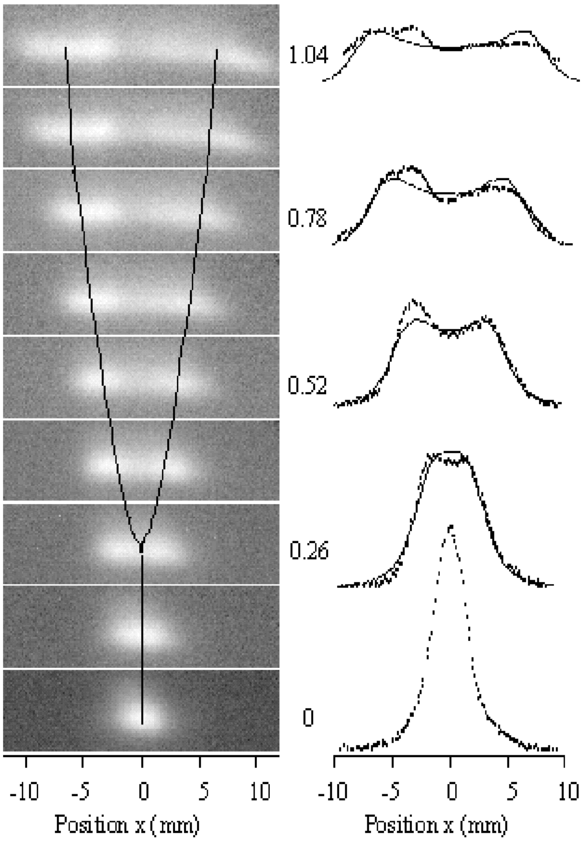

Figure 1: Left: atom clouds split by bouncing on a static corrugated reflector. Black lines show the positions of peaks predicted by our theory. Center: values of corruagting field in gauss. Right: intensity pofiles. Solid lines show theory, dots are experimental data. Normalization is the only fitting parameter.

[1] P. Rosenbusch, B.V. Hall, I.G. Hughes, C.V. Saba and E.A. Hinds, *Phys. Rev. A* **61** R31404 (2000).