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High order Laguerre-Gaussian light beams for studies of cold atoms

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The magneto-optical trap (MOT) has become the workhorse in many laboratories around the world for studies of trapped atoms. To slow the atoms a high intensity is needed but is not required to trap atoms that have been cooled. Low light intensity at trap centre is desirable as collisions between ground-state and excited state atoms is a major route for trap loss. Thus, a cooling beam that has a high intensity away from trap centre but has a low intensity at trap centre would trap more atoms. By excluding the repumping light from the centre of a MOT a dramatic reduction in light-assisted loss is observed and a trap density of 10^{12} cm^{-3} may be achieved [1]. This technique is known as the dark magneto-optical trap.

In this paper, we discuss the generation of Laguerre-Gaussian (LG) light beams using computer-generated holograms, that are suitable for trapping and cooling atoms. These beams have the form of an annular ring. The higher the azimuthal index l of this beam, the larger the dark spot in the centre of the beam. Thus, high l Laguerre-Gaussian beams are well suited for use in dark MOTs.

We have developed a very compact external-cavity diode laser system operating at 780nm for trapping rubidium atoms. A set of blazed holograms allows us to efficiently (≈40%) generate a range of tunable LG modes (figure 1) with varying index l (1 to 6). This light is then used to study cold atoms trapped in a standard MOT. This method represents a simple way for generating LG beams for studying trapped atoms, in contrast to previous work [2] where an external cavity and cylindrical lens mode converter were employed. Furthermore, our work allows efficient generation of high order LG beams. It paves the way for an extensive study of LG beams and trapped atoms. Further results will be reported at the conference.

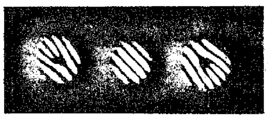

Figure 1: Interference between holographically-generated LG (LG_{01}, LG_{03} and LG_{03}) modes and their mirror images

References

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Coherent channelling of atomic de Broglie waves

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We investigate the coherent motion of atomic de Broglie waves in tailored complex periodic potentials made of light (light crystals) [1,2]. Depending on the potential height one observes diffraction phenomena like Bragg scattering (weak potential, no bound states) or quantum channelling (strong potential, many bound states).

In the channelling regime the transverse energy of the atoms is lower than the maximum height of the periodic potential. The atoms are confined between the planes of the standing light wave and move in these „waveguides" through the crystal. An incident plane wave coherently populates these channels. Behind the crystal the independently propagating waves interfere and the farfield pattern exhibits diffraction peaks quite similar to the diffraction pattern of a thin grating. This demonstrates that wave propagation in these channels is coherent..

Looking more closely we first observe that many diffraction orders are populated and the pattern is relative insensitive to the incidence angle. Furthermore the peaks inside the envelope vary with interaction length (crystal length). We interpret this as a result of beating between the different eigenstates propagating in the channel. In a classical picture this is equivalent to oscillations of the centre of mass motion inside the channel (like balls in a groove). In classical ray optics this would correspond to caustics in ray propagation. The oscillations are dominant for short interaction times and depend critically on interaction time, incidence angle and potential height. For long interaction times these oscillations damp out and the width of the envelope is a constant only determined by the width of a single channel. The centre of mass moves in analogy to the classical picture in direction of the channels independent of the incidence angle.

We have realised with our experiment a system where the transition from a total wavelike behaviour as Bragg diffraction to a classical particle behaviour of balls in corrugated sheet iron can be studied.

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