Multi-component quantum gases in spin-dependent hexagonal lattices

Application Note

P. Soltan-Panahi, University of Hamburg (October 2010)

In the group of Prof. Klaus Sengstock (Institute of Laser Physics, University of Hamburg), one major area is the research on ultracold atoms. These pure quantum systems exhibit fascinating properties such as constructive and destructive interference, which is classically mostly known for light.

In our experiment, we create an optical lattice – a crystal made of light – where ultracold atoms are arranged in the periodic light field. This allows for the simulation of solids under highly controllable conditions.

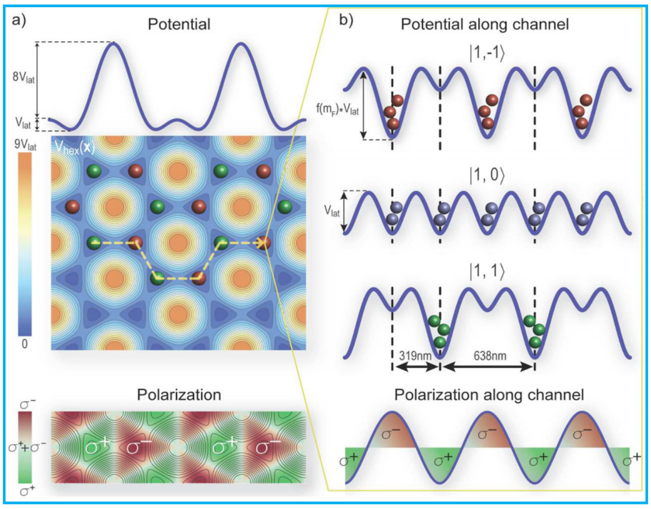

Figure 1 Spin-dependent hexagonal optical lattice with alternating σ+ (green bullets) and σ- (red bullets) polarization. The 1D plots represent the potential along a cut through the 2D potential for different spin-states.

In order to analyze the atomic ensemble, we use different techniques. A very powerful tool is microwave and radiofrequency spectroscopy. By employing this method in a state-dependent optical lattice as it is realized in our experiment (see Fig. 1), we are able to obtain information about the internal structure of the atomic ensemble. In particular, a very small fraction of atoms of one spin-state is transferred to another atomic spin-state. These states can be detected separately. For the detection of the small number of atoms, a detection device with high quantum efficiency and low noise is required. Figure 2 shows a microwave-driven Rabi-oscillation, which follows the same principle as the spectroscopy technique.

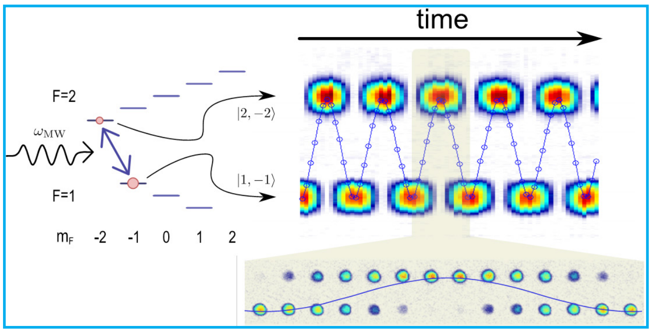

Figure 2 Rabi-oscillation between the hyperfine states F=1 and F=2 of ^{87}Rb (schematically shown on the left side). The two states are coupled via microwave radiation. The lower picture on the right-hand side shows time-of-flight images of both the |2,-2> (top) and the |1,-1> (bottom) state for different evolution times. In the upper image, each column represents a single absorption image integrated over one dimension. The blue line is the relative population between the two hyperfine states. The same experimental method is also used for spectroscopy measurements.

The spatial extension of the atomic cloud is only several 10 µm. In order to detect details in the ensemble, we release the atoms from their confinement in the periodic light field which leads to an expansion of the cloud, which is often referred to as *time-of-flight* measurement (see Fig. 3). We then apply an inhomogeneous magnetic field to spatially separate the different magnetic quantum states. The imaging of the atoms is performed by illuminating the atoms with resonant laser-light and recording the shadow cast by the atoms on a CCD camera.

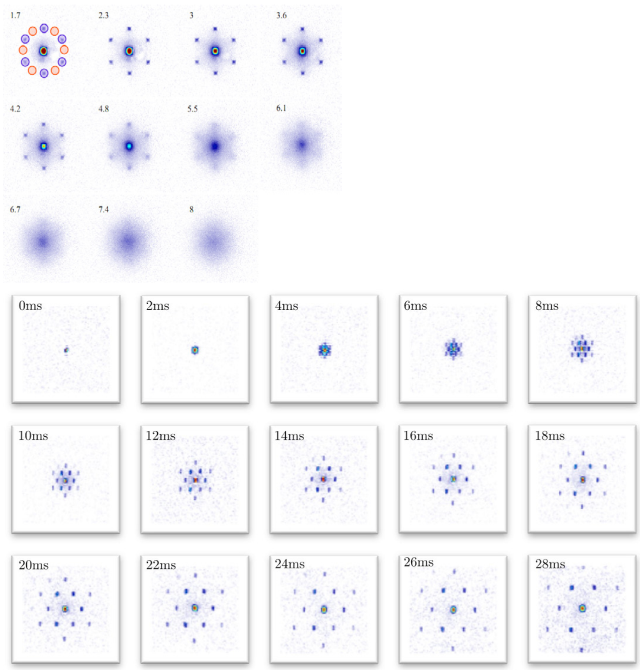

Figure 3 Time-of–flight (TOF) absorption images for different times. The atomic gas is initially confined in a hexagonal optical lattice. In analogy to X-ray or electron spectroscopy, the TOF images represent the momentum distribution of the atomic sample in the lattice.

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In our current setup we use the CCD detector iKon-M DU934N-BR-DD from Andor Technology, which has a quantum efficiency of 90% at our detection wavelength of 780 nm. One half of the CCD is shadowed with a razor blade, which allows using one half of the CCD-chip as storage area and the other half as detection area. For the imaging, we start taking two pictures: one with and the other without atoms. After the CCD is illuminated for the first image, we use the Fast Kinetic Mode of the camera to shift the image into the shadowed area within 2.5 ms and subsequently take the other image. In this way, the two images can be taken in a fast series. This diminishes noise which is caused by interference effects or fluctuation of the laser beam intensity. We finally take two more images without any detection light to eliminate the effect of stray light.

We employ a self-written LabView program to control the camera which incorporates the driver from Andor.

References

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