Ultracold Atoms and Molecules in Optical Lattices

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Application Note

The group of Prof. Rempe at the Max-Planck-Institut für Quantenoptik in Garching, Germany is investigating dilute gases at very low temperatures. In our experiment, rubidium atoms are cooled from room temperature down to a few hundred billionths of a degree above absolute zero which is at -273.15 °C. To reach this ultracold regime, we employ cooling techniques that rely on laser light and evaporation of magnetically or optically trapped atoms. A photograph of the experimental setup is shown in Figure 1. Once the temperature is low enough, the atoms in the gas almost come to rest and their behavior is governed by quantum effects. As a result, the atoms form a coherent matter wave, a so called Bose-Einstein condensate (BEC).

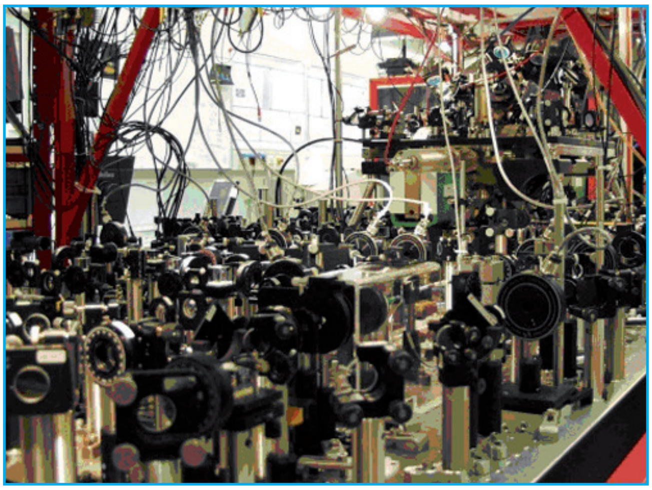

Figure 1: Photograph of the experimental setup. A variety of optical components is used to tailor laser light in such a way that it cools a gas of atoms. By also applying an evaporative cooling technique, the gas is cooled to a few hundred billionths of a degree above absolute zero where it forms a Bose-Einstein condensate.

A BEC is an excellent starting point for further experimental investigations. For instance, new states of matter can be studied in optical lattices.

An optical lattice is a periodic potential landscape created by standing-wave laser beams. In the experiment, we are able to load a BEC into such a structure. When a shallow lattice is switched off rapidly, the atoms are diffracted by the periodic potential. As a result, matter-wave interference patterns are observed as shown in the CCD images in Figure 2.

The images were recorded by a technique called time-of-flight absorption imaging: After the periodic potential was abruptly switched off, the sample was illuminated for 100 µs with a resonant laser beam. The atoms absorb part of the light and cast a shadow in the beam intensity profile. The profile is magnified by a factor of 4 and recorded by an Andor DV887 DCS-FI front-illuminated iXon EMCCD camera. A second image without the atoms is recorded a few milliseconds later. From the two images the atomic density profile is calculated.

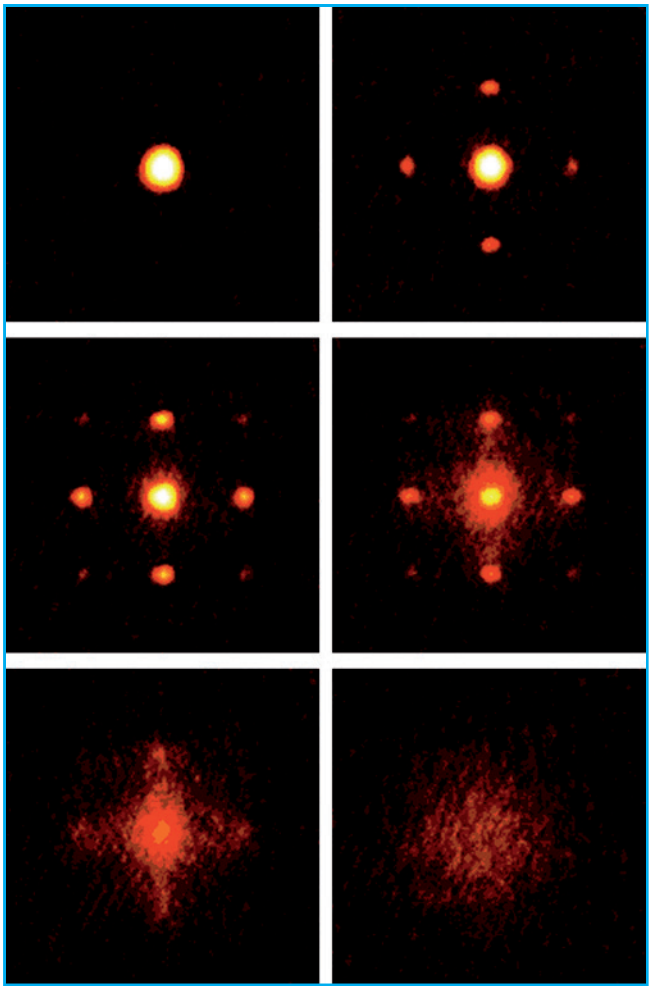

Figure 2: False color absorption images of a cloud of approximately 60000 atoms. The atoms are released from an optical lattice and subsequently imaged onto the EMCCD camera. A matter-wave diffraction pattern is visible for shallow lattice potentials and disappears for large lattice depths. The left topmost image shows a BEC and the lowest image on the right a Mott insulator. The field of view is 0.56 mm x 0.56 mm.

If the BEC is loaded into a deep optical lattice, the atoms rearrange themselves due to their strong repulsive interaction. As a consequence, the same number of atoms is found on each site of the optical lattice in an ideal system. This state is called Mott insulator and was first discussed in the context of solid state physics. As shown in Figure 2, the phase coherence is lost and no diffraction peaks are observed in the absorption image.

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A Mott insulator with exactly two atoms per lattice site is an ideal system to study the association and dissociation of molecules. By applying magnetic field pulses, an atom pair can be associated into a molecule in each potential well. The molecules are as cold as the atoms because no latent heat is released during the association. This allows us to study coherent chemical reactions. The principle is schematically shown in Figure 3. Furthermore, we can even create a coherent superposition state of an atom pair and a molecule at each lattice site.

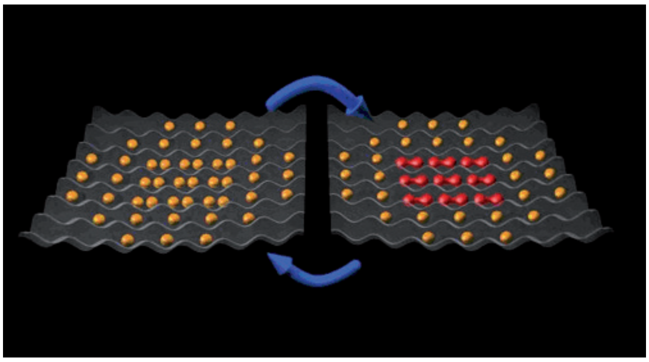

Figure 3: An atomic Mott insulator with a core of exactly two atoms per lattice site is used to study association and dissociation of ultracold molecules from ultracold atoms.

With the Andor DV887 EMCCD camera we are able to record absorption images with low noise using the conventional amplifier mode. By simply changing the software settings, it is also possible to exploit the high amplification provided by the electron-multiplication stage in order to detect very weak signals such as e.g. the fluorescence of molecules.

Due to Andor's good software support for LINUX based systems, it was easy to implement the Andor camera into the existing software system using a standard client-server application.

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