An ultra-low light detector for single atom experiments in optical lattices

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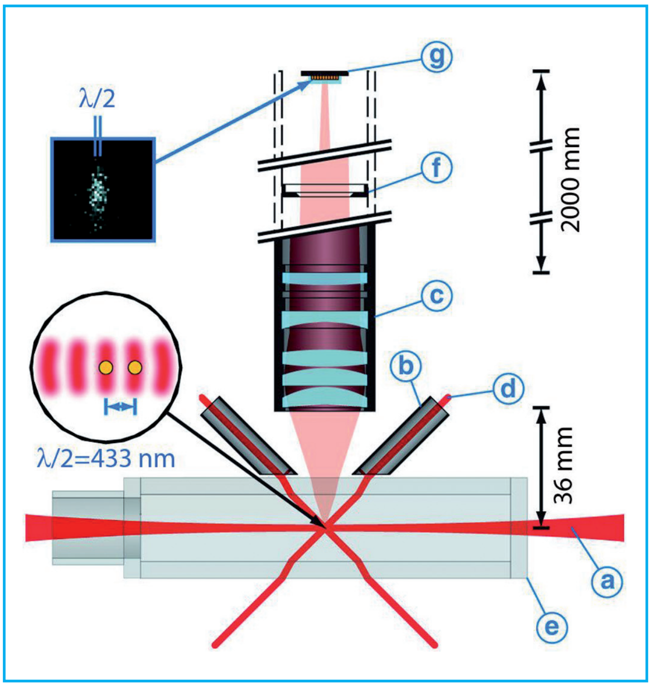
Application Note

Introduction

Our experiments investigate quantum systems composed of few atoms, where we aim at the highest control of individual Cesium-133 atoms trapped in an optical lattice. Controlling both – the internal (spin) and external (motional) – degrees of freedom we perform measurements of quantum phenomena like quantum walks [1], atom interferometers [2] or atom-atom entanglement. For all these experiments we need to determine the exact lattice site the atom occupies. In order to measure the position of the atoms in a short time (few hundred ms) with the required resolution of half the lattice laser wavelength ($\lambda/2 \sim 0.5$ µm) we need a detector with high quantum efficiency and ultra-low noise properties, resolving single photon clicks.

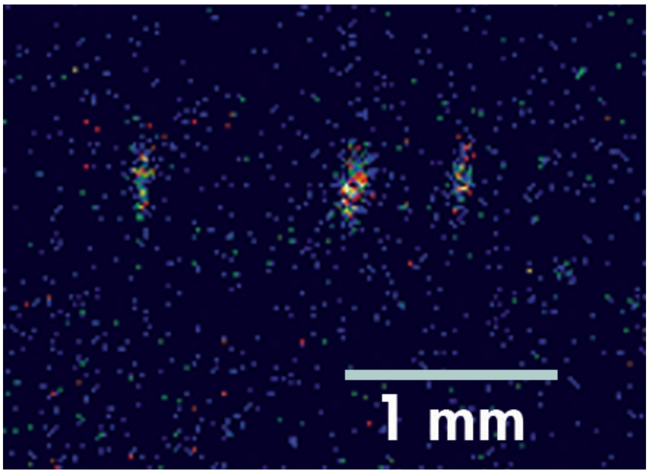
Setup

One of our typical experimental setups is shown in Fig. 1 (from Ref. 3).



Typical experimental setup (from Ref. 3). Two counter-propagating laser beams (a) form an optical lattice. Beam tubes (b) shield the objective (c) from stray light of imaging beams (d) off the glass cell (e). Apertures (f) strongly suppress the remaining stray light. An optical filter in front of the EMCCD camera (g) filters stray light from the optical lattice.

Trapped atoms are illuminated with near-resonant laser beams at 852 nm. Their fluorescence is imaged via an objective (f=36 mm, NA=0.29) [4] onto an EMCCD detector (iXon3 DU897 DCS-BV from Andor Technology). Given restricted optical access the objective was designed with a moderate NA resulting in a Rayleigh resolution of ca. $4 \bullet \lambda/2$. Therefore, on first sight, it seems to be impossible to resolve single lattice sites on the scale of $\lambda/2$. However, a high signal-to-noise ratio – possible through the EMCCD technology of Andor cameras – and a fitting algorithm based on a deconvolution of the measured broad atomic distribution allow us to determine the position of the atoms on the scale of $\lambda/2$, beating the diffraction limit [3]. Fig. 2 shows a typical picture of trapped atoms in an optical lattice.



3 cooled Cesium atoms (temperature about 50 µK) are trapped in an optical lattice and imaged – in a similar way as shown in Fig. 1 – onto the chip of an iXon3 DU897DCS-BV EMCCD detector. The exposure time is 1 s.

Experiment

In one of our experiments we utilize state-dependent lattice potentials to transfer quantum mechanical superposition states from the spin space to real space. This means that we can split a single atom coherently into a quantum superposition of being at the same time in two different places. In our laboratories these two places can be 10 µm apart from each other [2] and are easily resolved using the system described above.

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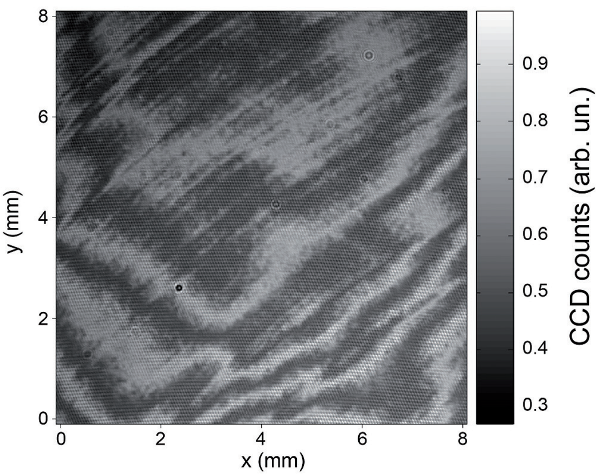
Technical Performance

We recently purchased two back illuminated iXon3 EMCCD detectors DU897-DCS-BV from Andor Technology. The advantage of a back illuminated system over a front illuminated one is the higher quantum efficiency which is approximately doubled for our detection wavelength of 852 nm. This means that the repetition rate of our experiments – which is limited by the exposure time – can essentially be doubled by halving the exposure time for one picture while maintaining the same signal-to-noise ratio. However, there is a downside of the back illuminated sensors, called etaloning effect, manifesting itself in interference fringes on the CCD chip which become visible under coherent illumination (see Fig. 3).



Interference fringes on the back illuminated EMCCD chip under coherent illumination at 852 nm [5]. The average peak-to-valley variation is about 40% of the signal. The axes show the spatial extension of the EMCCD chip.

The interference fringes lead to an unwanted spatial inhomogeneity of the camera's sensitivity. Nevertheless, we have measured that the fringe pattern is quasi stationary, shifting by half a fringe for a temperature change of the chip by 20 °C. Therefore – keeping the temperature of the chip stable below a 0.5 °C variation which is specified for the Andor EMCCD cameras – we can correct for the etaloning by dividing each measured image by a fixed calibration image. Furthermore, positioning our region of interest on a bright interference fringe, we profit from the locally enhanced quantum efficiency.

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