# Resolving and addressing atoms in individual sites of a $CO_2$-laser optical lattice

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Cold atoms can be trapped by dipole forces in the periodic potential created by interfering laser beams thus creating an optical lattice [1]. Such systems have been used as models in studies of quantum dynamical effects and quantum state control. More recently, it has been suggested that such lattices would provide an attractive system for performing quantum logic experiments. Beside the fact that in far detuned optical lattice decoherence rates can be kept small, very efficient quantum error correction schemes can be implemented here due to the inherent possibility of parallel operation [2]. On the other hand, the possibility to selectively address and manipulate single qubits is essential in the operation of quantum logic systems. This is difficult to achieve in conventional optical lattice, where the spatial period is of the order of half the wavelength of an atomic absorption line.

Here, we report on the optical imaging of rubidium atoms trapped in the antinodes of an extremely far detuned optical lattice formed by an infrared standing wave near $\lambda_{trap} = 10.6\mu m$. To our knowledge, this represents the first observation of individual lattice sites with a periodicity of half the trapping wavelength. Besides the unusually large lattice constant of $5.3\mu m$ intriguing properties of this type of lattice also include extremely long coherence times, as the expected photon scattering time is over 5 minutes.

Our experimental setup is similar to that described in our earlier work [3]. In a vacuum chamber, a trapping potential for atoms is generated by the static polarizability in an intense optical standing wave (beam waist of typical 35 $\mu m$) derived from a 50W single mode $CO_2$ laser. The lattice is loaded from a dark magneto-optical trap. We have measured the vibrational frequencies of the lattice by parametric modulation of the potential depth. The Lamb-Dicke limit, corresponding to an oscillation frequency exceeding the recoil frequency, is reached in all three dimensions. We have determined the temperature of the atoms by a TOF method resulting in a temperature of $10\mu$K at a $CO_2$ laser intensity of 5W and a waist of $35\mu m$. For higher trapping laser intensities, the atomic temperature increases to values approaching the Doppler temperature of $140\mu$K. We attribute this to the intensity dependent difference of the ac Stark shifts between upper and lower electronic state which reduces strongly sub-Doppler cooling mechanisms. The atomic phase space density $n\lambda_{dB}^3$ reaches its largest value of about

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1/300 at low trapping laser intensities ($\approx 5W$).
Using an optical microscope, we have imaged the fluorescence emitted by the trapped atoms when illuminating them with resonant light . A typical image of the lattice is shown in Fig.1A. The atoms are localized in pancake shaped microtraps of $5.3\mu m$ spatial period, each lattice site containing roughly 4000 atoms [4]. By sending resonant light through the core of an optical fiber via a beamsplitter through the microscope, we have been able to manipulate atoms trapped in individual lattice sites. The optical setup here corresponds to that of a confocal microscope. In Fig.1B only atoms in an single site have been addressed. The neighbouring lattice sites are still filled, but are not visible here. This is confirmed in Fig.1C, showing an image of the lattice after selectively removing the atoms from a single site, while the neighbouring sites are affected much less. Preparation and reading out individual qubits should thus be possible in the $CO_2$-laser optical lattice.

Besides the prospects for quantum logic experiments, this kind of optical lattice could also allow for the possibility of reaching Bose-Einstein condensation by optical cooling alone.

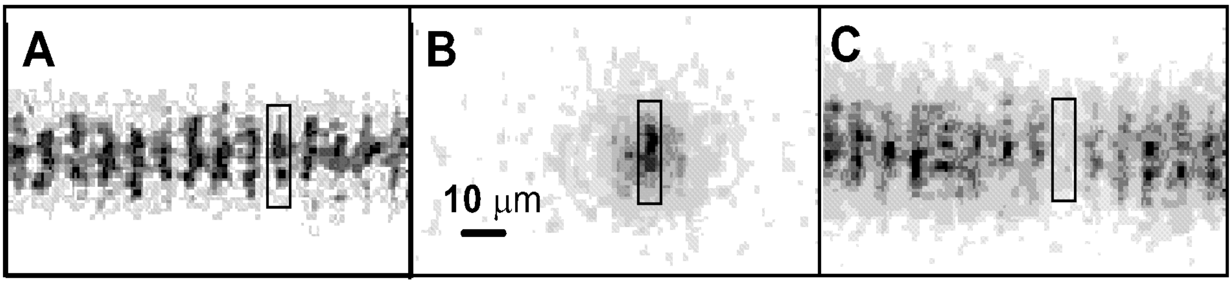

Figure 1: (A)Rubidium atoms trapped in an one-dimensional optical lattice with a period of $5.3\mu m$. The exposure has been recorded with an optical microscope and an intensified CCD camera by imaging the fluorescence emitted by the atoms when irradiating them with resonant light. Each lattice site contains roughly 4000 atoms. (B)Exposure taken while illuminating only atoms in a single site using a focused laser beam. The rest of the lattice is still filled, but is not visible here. (C) An image of the lattice recorded after removing the atoms of one site with a focused intense pulse of light.

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