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on
Controlled transport of atomic quantum
systems in optical micro-structures

Michał J. Piotrowicz

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In recent years, significant interest has been observed in the field of quantum information processing (QIP). It is mainly because QIP offers the promise of being able to do things that cannot be done with conventional technology.

The aim of this project was to combine state-of-the-art technology in micro- and nano-optics with the quantum optical techniques of laser cooling, laser trapping, and quantum control to open a new gateway for quantum information processing and matter wave optics with atomic systems. The optical configuration for the transport of atomic quantum systems was intended to be set up, implemented into an existing experimental setup, and in the end to demonstrate the transport of atoms with this system experimentally.

Micro-lense systems can be used to create multiple far-detuned dipole traps that serve as a scalable configuration for quantum computation with atoms. Using neutral atoms, like cold ^{85}Rb-atoms, as the carriers of the qubits of quantum information requires efficient means for the preparation, manipulation, and storage of qubits inscribed into atoms as well as schemes for the entanglement of atoms, the implementation of one-, two- and multiple-bit quantum gates, and the read-out of quantum information. A two-dimensional system of atom samples in dipole traps has been already created via a micro-fabricated array of micro-lenses. Due to the large lateral separation of neighboring potential wells, each trap is individually addressable. The internal states can be prepared, manipulated, and retrieved for the atoms in the individual potential wells.

A novel optical system which allows to create two sets of dipole potentials based on optical micro-structures which are dynamically re-configurable was intended to be done. The realization of the setup is presented in Figure 1. The trapping light is derived from a Titanium-Sapphire laser. The beam is

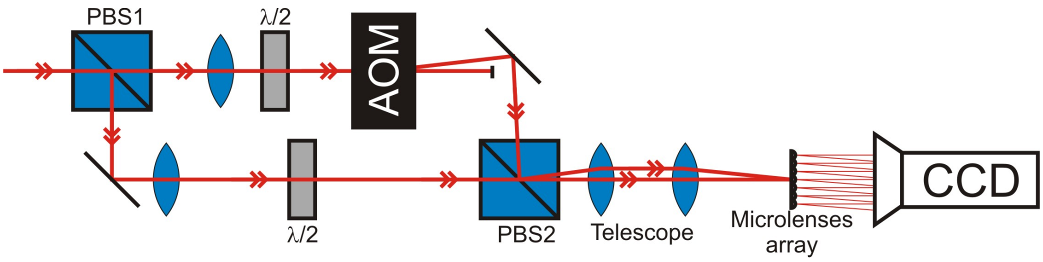

Figure 1: The scheme of movable arrays of dipol traps. The beam going along the upper path from the PBS1 is deflected by the AOM. While imagining the two beams (movable and non-movable) on the micro-lense array we achieve two two-dimensional arrays of laser foci.

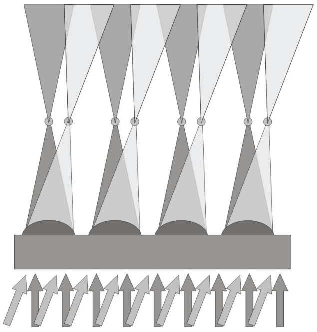

Figure 2: Two separate dipol trap arrays created by illuminating the micro-lense array with two beams at slightly different angle. The distance between two atoms in neighbouring traps changes with the angle between the beams.

first split into two on a polarization beam splitter (PBS1) – one path goes through the AOM (acousto-optic modulator) after which the first order of deflection is taken, while the second path goes directly onto a second beam splitter (PBS2) which again combines the beams. The role of the telescope is to image the beam rotated at the AOM onto the micro-lense array so that there is no movement of the laser spot on the lense array.

Such a setup enables us to create two arrays of dipol traps. In each of the traps single atoms can be caught which then can be used as qubits. The first set of traps created by the beam going through the AOM is moveable. The movement of the traps is done by changing the angle of the beam (see Fig. 2) which is altered by the frequency applied to the AOM. The angle at which the first order beam is deflected at the AOM is given by

$$sin\theta = \frac{\lambda}{2\lambda_s} \tag{1}$$

where λ is the wavelength of light and λ_s the sound wavelength. This allows us to move the array of traps over a distance comparable to a significant fraction of the distance between single traps. Using the re-imaging properties of periodic diffraction structures based on the Talbot effect, movements of the laser foci by more than half of the distance between neighboring traps are achievable. Respective results are presented in Figure 3.

By adding another AOM at the second beam path we can achieve the movement of both arrays and in this way bridge the whole distance between the traps. In this case the movement of trapped atoms between neighbour traps will allow us to implement two qubits quantum gates or quantum state registers [1].

After achieving the moveable laser foci it is possible to transfer the foci

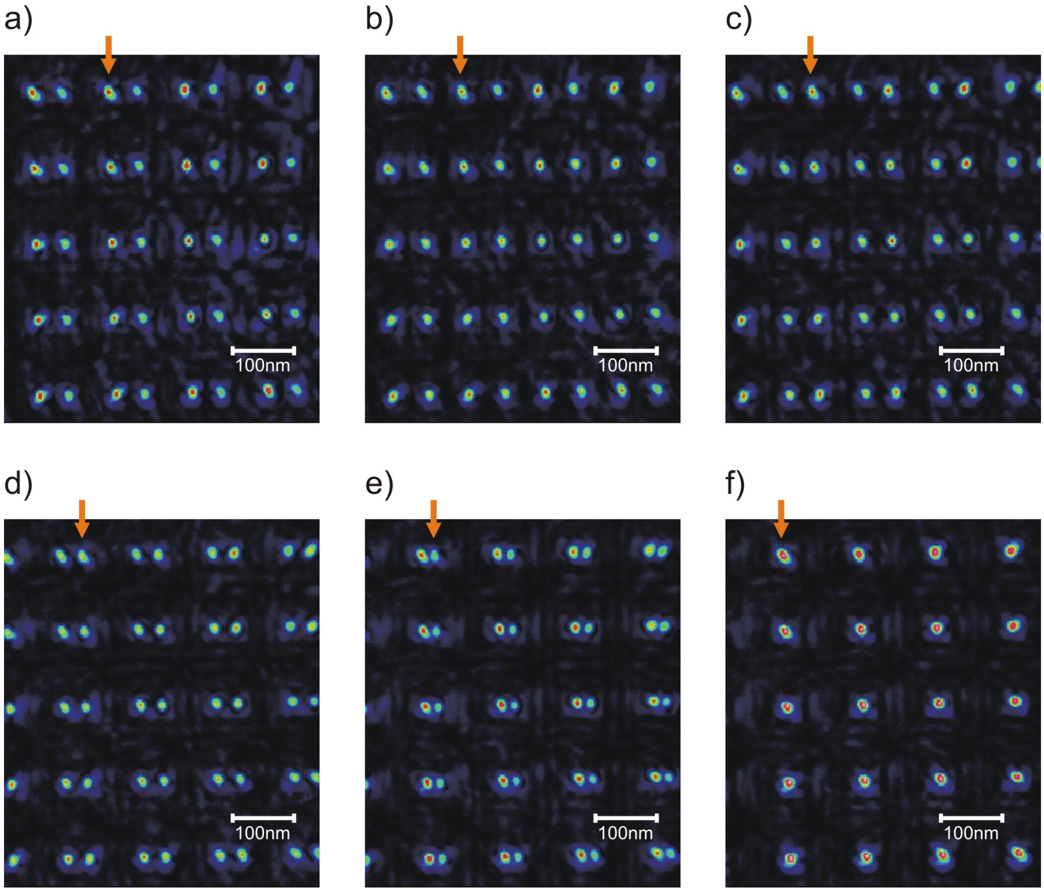

Figure 3: Pictures of foci at different frequencies applied to the AOM. The array marked with an arrow moves from 2/3 of the way between foci of the non-movable array to the position where foci from both arrays overlap.

into the vacuum chamber by the use of a telescope. This allows also to change the period of the trap array and the focal size.

During my visit at the Institut für Quantenoptik in Hannover, I carried out additional work on efficient MOT operation and dipol traps towards evaporate cooling. This part of my stay manifested in creating a tapered amplifier for laser cooling and the realization of TiSa laser stabilization to rubidium lines.

A continuation of the collaboration with the host is intended by both sides. As the exchange of knowledge and ideas is very important we are looking forward to continuing visits.

The results of the work done within the visit were presented on the NIST conference in Gaithersburg at the talk “Atoms in Arrays of Dipole Traps:

Coherent Manipulation & Atom Transport" [2].

References

[1] G. Birkl, F.B.J. Buchkremer, R. Dumke, and W. Ertmer, *Atom Optics with Microfabricated Optical Elements*, Opt. Commun. **191**, 67–81, 2001.

[2] A. Lengwenus, M. Volk, M. Piotrowicz, G. Birkl, *Atoms in Arrays of Dipole Traps: Coherent Manipulation & Atom Transport*, NIST, Gaithersburg 2005.