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Using Talbot lattices for quantum state manipulation

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One basic feature of optical lattices is that they hardly interact at all with the environment. Therefore, they have recently been suggested as a platform for implementing quantum logic gates. An additional attraction comes from the fact that by modifying the light field, a large ensemble of atoms can be manipulated in parallel.

The basis of these suggestions is that two different states should be trapped in two lattices with the same spatial frequency. By appropriately manipulating the lattices so as to control the interaction between them, one can perform coherent evolutions of the atomic state. In order to build a general purpose quantum computer, one has to have the possibility to manipulate and to detect the state of individual atoms in the lattice. Since the lattice spacing is typically in the order of an optical wavelength this is a non-trivial task. Furthermore, it is desirable with a high filling factor (close to one) and that the atoms are cooled to the quantum mechanical ground state of their respective potential wells. This severely complicates an experimental realization of the suggestions.

A recent report [1] shows that even without ability to address individual atoms, and with relaxed requirements on filling rate and temperature, well controlled overlapping optical lattices still offer interesting applications. In particular condensed matter physics phenomena can be simulated and spin squeezing can be generated.

We suggest a novel approach, based on Talbot lattices, to implement the suggestions. A Talbot lattice can be created by a single laser beam that is transmitted through a periodic mask. According to the Talbot effect, real images of the mask will be produced along the beam in periodically spaced planes. This means that a 3D-lattice can be constructed with a single beam [2]. As a consequence, the spatial frequencies along all directions in the Talbot lattice can be chosen at will, by carefully designing and manufacturing the mask. The spatial period of these lattices will typically be larger than a wavelength. Apart from the fact that this means a higher filling factor, it also carries an extra advantage. It will be easier to image the atomic localization optically. Thereby, the spatial phase of the lattices can be monitored and controlled. Furthermore, it becomes potentially possible to address single atoms.

References

1 : A Sørensen and K. Mølmer, Phys. Rev. Lett 83, 2274 (1999)
2 : C. Menneral-Robilliard et al., Europhys. Lett. 44, 442 (1998)

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