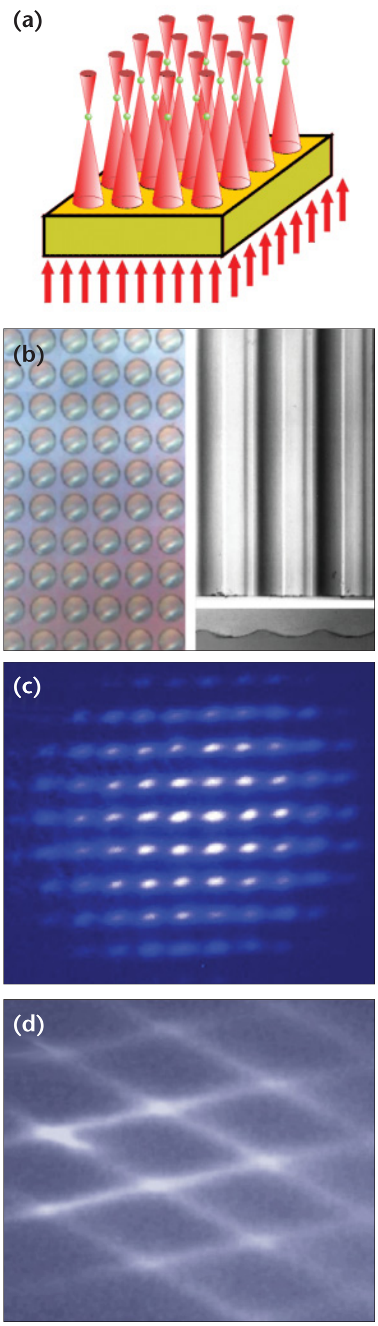

Figure 1. Application of micro-optic systems for quantum information processing and matter wave optics with atoms. Arrays of focused laser beams (a) created by micro-fabricated and nanofabricated arrays of lenses (b) allow the trapping and guiding of neutral atoms. Applications result, for example, in two-dimensional arrays of trapped atoms that can serve as a scalable configuration for quantum computation with atomic qubits (c) or integrated structures for Mach-Zehnder (d) or Michelson-type interferometers for matter wave optics.

QUANTUM INFORMATION

Micro-Optics Advances Quantum Computing and Integrated Atom Optics

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State-of-the-art technology in micro- and nano-optics has been combined 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. Within the past year, two significant results have been reported. Microfabricated optical systems have been used to create light fields that trap and guide neutral atoms as a result of the optical dipole force experienced by the atoms. The realization of arrays of laser traps that can serve as registers for atomic quantum bits and as integrated waveguide structures for atom optics and atom interferometry has been achieved. This approach creates an opportunity for scaling, parallelizing and miniaturizing systems for quantum information processing and atom optics in fundamental research and application.

In one set of experiments, micro-optic elements have been used to create multiple far-detuned dipole traps [Fig. 1 (a)] that can serve as a scalable configuration for quantum computation with atomic systems.[1] Using neutral atoms as the carriers of 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-qubit quantum gates, and the read-out of quantum information.

For this purpose a microfabricated array of microlenses [Fig. 1 (b), left] has been used to create a system of as many as 80 atom samples in dipole traps with a mutual separation of 125 μm [Fig. 1 (c)]. Because of 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 individual potential wells. By changing the optical configuration, one can create two sets of trap arrays with a variable separation. The two sets can be brought close to each other or even made to overlap, opening the path to implementation of various schemes for quantum entanglement and two-qubit gates (see, e.g., Ref. 2).

In a second set of experiments, micro-optic elements have been used to generate waveguides, beam splitters and interferometer-type geometries for guided atoms. These systems constitute the atom-optic equivalents of their namesake structures in the field of integrated light optics. As central elements, arrays of cylindrical microlenses [Fig. 1 (b), right] create arrays of atomic waveguides by focusing a laser beam into a set of focal lines. Atoms can be guided along the focal lines. Combining two of these arrays allows atoms to be sent through *X*-shaped beam splitters and more complex systems such as the geometries for Mach-Zehnder [see Fig. 1 (d)] and Michelson-type interferometers.[3]

In the future, the application of micro-and nano-optics for optical manipulation of atomic systems is expected to have a significant effect on quantum optics, quantum information processing and matter wave optics. Moreover, the use of microfabricated and nanofabricated optical, magnetic and electric systems will firmly establish the newly emerging field of integrated atom optics.[4,5]

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