Investigation of bichromatic optical superlattices

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We report on the first demonstration of a bichromatic superlattice of ^{85}Rb atoms, a new type of optical lattice. The trapping light field potential is produced by optical standing waves oscillating at two different frequencies. The optical potential thus consists of wavelength-sized micropotentials, with a depth modulated with a larger period given by the beat wavelength. Two dipole force components act on the atoms; one is the usual rapidly alternating dipole force term responsible for the micropotentials, while the other has a unidirectional average value over a macroscopic distance. As a result, the atoms are preferentially cooled and trapped into the micropotentials at particular locations, which gives rise to a macroscopic density modulation; a superlattice structure [1].

The principle of bichromatic superlattices is easily explained in a 1D *lin* $\perp$ *lin* polarization geometry. Assume a precooled atomic sample of ^{85}Rb prepared in the $F_g = 3$ ground state hyperfine level subjected to a superposition of two 1D *lin* $\perp$ *lin* standing waves operating near to the D_1 and D_2 line, respectively (the resulting beat wavelength, λ_b, is 21 μm). More specifically, assume that the weak D_1 light field is slightly blue-detuned by some linewidths from the $F_g = 3 \rightarrow F_e = 2$ hyperfine transition and the D_2 field is far red-detuned by several hundred linewidths with respect to the $F_g = 3 \rightarrow F_e = 2, 3, 4$ transitions. The optical potential provided by the D_2 field alone merely contributes to a spatially varying light shift but no optical pumping. The D_1 field, which also contributes to the total optical potential, provides the efficient cooling together with pumping into non-coupling magnetic substates. Polarization dependent optical pumping by the D_1 field acts to populate the potential minima of the common light shift potentials, where both light fields exhibit the same circular polarization and the coupling of the atoms to the light fields is negligible (i.e. the bichromatic lattice is a dark lattice). The superlattice with its locally enhanced filling factor and inherent cooling mechanism might have intriguing opportunities for novel experiments.

About 10^9 ^{85}Rb atoms are first collected in a standard MOT configuration. Immediately after turning off the light beams and the magnetic field for the MOT, the atoms are exposed for about 20 msec to the superimposed bichromatic standing waves operating near the D_1 and D_2 lines, respectively. For 3D superlattices we superimpose three pairs of counterpropagating bichromatic light beams with polarizations and phases adjusted as in our previous experiments with monochromatic bright lattices [2]. Absorption imaging is employed as a probing tool. The shadow cast in the probe beam is projected onto a plane parallel to one side of the superlattice unit cell and imaged on a CCD camera, which allows us directly to observe the superlattices period. We observed the density maxima periodically arranged in a face-centered square structure with an edge length of $2\lambda_b = 42$ μm, clearly manifesting that the atomic density distribution in the 3D superlattice exhibits a macroscopic bcc structure. This is in accordance with the fact that the locations of coinciding polarizations of the D_1 and D_2 fields form a bcc structure with a $2\lambda_b$ periodicity. The best density contrast is achieved when the absolute values of the light shift produced by either of the fields are of comparable size (typical lattice beam parameters per beam in the horizontal plane are : $+3\Gamma$, 1.0 mW/cm^2 for the D_1 field and -300Γ, 30 mW/cm^2 for the D_2 field). In our current experiments, the observed maximum density is only about 2.5 - 3 times larger than the average density. This observation, however, is limited by the resolution of our imaging system. A significantly larger density contrast is expected. By observing the images at different times, we can monitor the formation and decay of the superlattices. The build-up time of the density modulation is not sensitive to the potential depth itself. Rather, it strongly depends on the intensity of the near-resonant D_1 field. The formation becomes faster at increasing intensity, while the steady-state density contrast decreases probably due to increased heating. For a typical choice of the detunings and intensities, the density modulation is found to be built up within 1 msec ($\tau \approx 800$ μsec). The contrast decays within approximately 200 μsec after releasing the atoms from the bichromatic fields. A simple theoretical model lets us roughly deduce a temperature of $\sim$10 μK for this case.

We can transfer the atoms trapped in the bichromatic superlattice into a far-detuned monochromatic lattice by adiabatically turning off the near-resonant D_1 field. The transfer process can be directly monitored as well via Bragg diffraction. In the bichromatic superlattice the periodicity of the potential is distorted by the existence of the D_1 field, which reduces the intensity of the light diffracted from the (1 0 0) planes of the D_2 monochromatic lattice. When we shut off the D_1 field a sudden increase in the diffracted power is observed. This indicates that the trapped atoms are actually transferred into the monochromatic lattice. The local density enhancement originally produced in the bichromatic superlattice is still preserved for about 1 msec after the transfer, showing that the atoms remain at their microscopic lattice sites during the transfer.

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