Laser cooling: Beyond optical molasses

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High-brightness ultracold atom sources have many applications in precision experiments and for the field of Bose-Einstein condensation. Optical molasses has for some time been the best simple technique to create cold atomic samples. However, density-dependent heating mechanisms limit the phase space density $n\lambda_{dB}^3$ attainable in free space to values near 10^{-6} [1]. For atoms confined in a far-detuned optical lattice, light-induced inelastic collisions and the reabsorption of photons emitted during cooling are suppressed, which allows cooling at higher densities [2]. An optical lattice offers the additional advantage that the atoms can be cooled to the vibrational ground states of the periodic trapping potential using a resolved sideband technique, as demonstrated at low densities in 2D [3] and 1D [4] and at high atomic density in 1D [5].

We present a simple, easy-to-implement optical method that cools all atoms collected in a magneto-optical trap (MOT) to a phase space density three orders of magnitude higher than attainable with optical molasses. The method is based on 3D degenerate Raman sideband cooling to the vibrational ground states of an optical lattice in conjunction with adiabatic release [6]. This technique requires only a low-power laser in addition to the MOT lasers, spin polarizes the sample during cooling, and promises to be effective even for atoms where the excited-state hyperfine structure is not resolved and for which sub-Doppler cooling is not possible. Using a single-frequency laser with a power as low as 20mW at a detuning of -16 GHz from the D_2 line for the optical lattice, we have cooled $3\text{x}10^8$ cesium atoms in 10 ms to a temperature of 330 nK at a density of $1.1\text{x}10^{11}$ cm^{-3} [6].

The density dependence of the final temperature is only $8\text{nK}/10^{10}$ cm^{-3}, 75 times lower than observed even for 'dark' optical molasses [7], which demonstrates the advantage of combining a 'dark state' cooling technique such as sideband cooling with a technique that isolates the atoms from each other by confining them tightly at separate lattice sites. For large samples containing up to 10^9 atoms, a phase space density of 1/500 is obtained already at the modest MOT density of 10^{11} cm^{-3}. This value can probably be substantially improved further using a lattice geometry where the density of lattice sites is matched to the atomic density in the MOT.

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