Ultracold Regime of the Collective Atomic-Recoil Laser

M. G. Moore and P. Meystre
Optical Sciences Center and Department of Physics
University of Arizona, Tucson, Arizona 85721

We present a wave atom optics theory of the Collective Atomic Recoil Laser, where the atomic center-of mass motion is treated quantum mechanically. This theory is similiar to the analysis of atomic diffraction by standing waves, but with the electromagnetic field now treated as a dynamical variable. It is also closely related to the study of collective atomic motion in optical lattices, except that the depth of the optical potential is now driven by this collective motion.
Two main aspects of this system will be discussed:
First, by comparing the predictions of our theory with those of ray atom optics, which treats the center-of-mass atomic motion classically, we show that for the case of a far off-resonant pump laser the ray optics model fails to predict the linear response of the CARL when the temperature is of the order of the recoil temperature or less. In this temperature regime, one can no longer ignore the effects of matter-wave diffraction on the atomic center-of-mass motion.
We then discuss how the CARL provides an ideal testing ground to study the coherence properties of dynamically coupled Maxwell and Schrödinger field. This is illustrated by analyzing the interplay between the number statistics of the bunched atoms and the intensity fluctuations of the optical field.