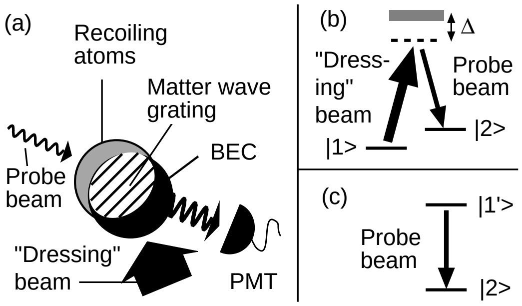
Amplification of light and atoms in a Bose-Einstein condensate

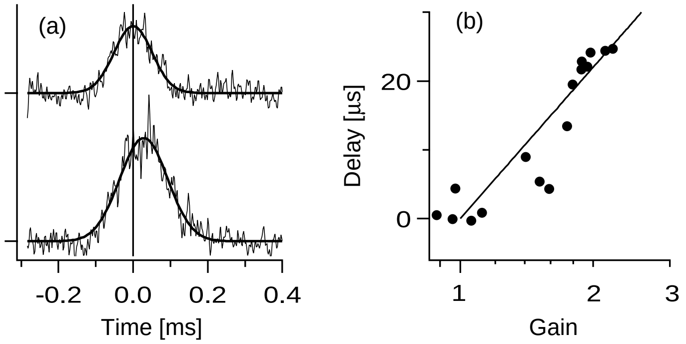
Bose-Einstein condensates illuminated by an off-resonant laser beam ("dressed condensates") were used to realize phase-coherent amplification of matter waves [1, 2]. The amplification process involved the scattering of a condensate atom and a laser photon into an atom in a recoil mode and a scattered photon. This four-wave mixing process between two electromagnetic fields and two Schrödinger fields became a self-amplifying process above a threshold laser intensity, leading to matter wave gain. However, the symmetry between light and atoms indicates that a dressed condensate should not only amplify injected atoms, but also injected light.



Amplification of light and atoms by off-resonant light scattering. (a) The fundamental process is the absorption of a photon from the "dressing" beam by an atom in the condensate (state |1〉), which is transferred to a recoil state (state |2〉) by emitting a photon into the probe field. The intensity in the probe light field was monitored by a photomultiplier. (b) The two-photon Raman-type transition between two motional states (|1〉, |2〉) gives rise to a narrow resonance. (c) The dressed condensate is the upper state (|1'〉) of a two-level system, and decays to the lower state (recoil state of atoms, |2〉) by emitting a photon. Since the system is fully inverted, there is gain for the probe beam.

We have studied the optical properties of a dressed condensate above and below the threshold for the matter wave amplification [3]. The optical gain below the threshold has a narrow bandwidth due to the long coherence time of a condensate. The gain represents the imaginary part of the complex index of refraction. A sharp peak in the gain implies a steep dispersive shape for the real part of the index of refraction n(ω). This resulted in an extremely slow group velocity for the amplified light. The figure shows that light pulses were delayed by about 20 μs across the 20 μm wide condensate corresponding to a group velocity of 1 m/s. This is one order of magnitude slower than any value reported previously [4].

Above the threshold to matter wave amplification, we observed non-linear optical behavior. Thus we could map out the transition from single-atom gain to collective gain.



Pulse delay due to light amplification. (a) Amplification and 20 µs delay were observed when a Gaussian probe pulse of about 140 µs width and 0.11 mW/cm^2 peak intensity was sent through the dressed condensate (bottom trace). The top trace is a reference taken without the dressed condensate. Solid curves are Gaussian fits to guide the eyes. (b) The observed delay time was proportional to ln(g), where g is the observed gain.

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