Nonlinear Effects and Patterns in a Cold Atomic Cloud

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The nonlinear interaction between an optical medium and an electromagnetic field can induce gradients in the index of refraction distribution, leading to patterns or filamentation in the most diverse nonlinear materials: solids, anisotropic soft matter (liquid crystals), cells containing thermal vapors, etc. One common difficulty in interpreting the results of these experiments and in comparing them to models is that the details of the interaction in these media are very complex. Cold atomic systems have well known linear and nonlinear optical properties, as illustrated in experiments on four wave mixing, electromagnetic induced transparency or slow light propagation. Such samples are thus an excellent candidate for improving the comparison between theory and experiments, but so far to our knowledge no investigations on patterns have been performed in such systems.

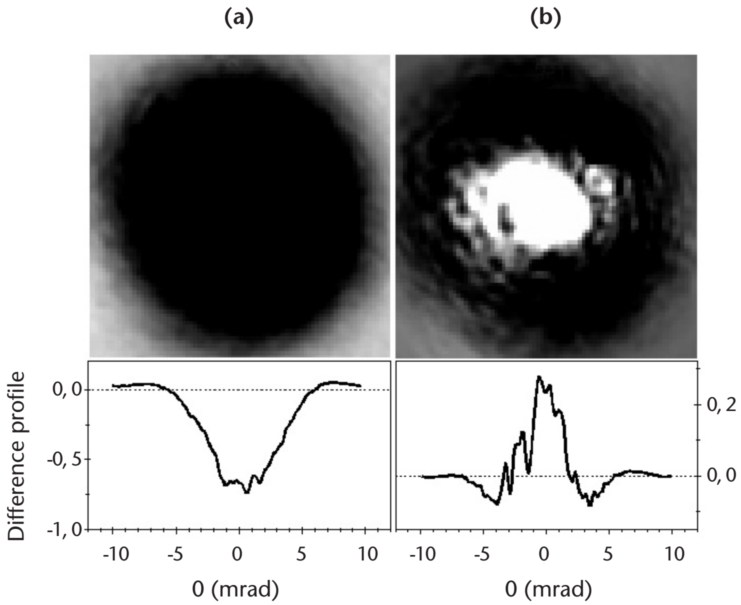

Figure 1. Transmitted intensity profile for small (a) and large (b) saturation of the atomic transition with corresponding radial cuts below.

Our experiment[1] demonstrates, for the first time to our knowledge, the appearance of transverse optical structures in the field distribution of a high intensity laser beam transmitted through a cold atomic cloud. The measurements are taken in the far field of the transmitted probe for varying probe power.

The cold cloud, a magneto-optical trap (MOT), is turned off during probing, and measurements are taken with a gated camera which integrates the transmitted light over time windows varying between 0.25 seconds and 20 seconds—depending on the amount of transmitted light—thus averaging the field intensity distribution of several probing cycles. (The probe is turned off when the MOT is periodically switched on). For these measurements, the shape of the MOT has a nearly Gaussian profile with diameter ~4 mm (FWHM) and reaches a spatial density $n_{\mathrm{at}} \sim 4\times10^{10}$ cm^{-3} at the center of the cloud. The corresponding optical thickness, measured with a weak collimated probe, is $b_{\mathrm{res}} \sim 18$. The atomic velocity distribution, measured with time-of-flight techniques, provides an estimate for $v_{\mathrm{rms}} \sim 10$ cm s^{-1}. The probe laser is tuned close to the 3<->4' transition of the ^{85}Rb atom.

By subtraction of the incident beam from the one transmitted by the cold atomic sample, one observes the appearance of radial, rotationally symmetric, structures (Fig. 1), which increase by up to 25 percent the amount of power on the optical axis (provided the probe is sufficiently strong). The reshaping holds up to the largest values of saturation we used ($s_0 > 10^4$) and is also detectable in the near field, thus hinting at residual propagation effects.

Simple modeling of the atoms as two-level systems interacting with a resonant beam shows that the main factor determining the beam reshaping in our experiment is related to the position of the incident beam waist relative to a (geometrically) *thin* sample, just as it occurs in *z-scans*. The introduction of the presence of the other (detuned) transitions (3<->2', 3<->3') and of propagation through the length of the cloud introduce minor corrections to the main result, thus confirming the correctness of the simple physical picture. Our measurements also indicate that the sample has not been strongly perturbed by the laser beam.

This experimental observation of spatial beam reshaping by a cold sample—the first to our knowledge—opens the door to investigations on more complex structuring in media which offer excellent experimental control and modeling possibilities.

References

1. G. Labeyrie, T. Ackemann, B. Klappauf, M. Pesch, G. L. Lippi and R. Kaiser, Eur. Phys. J. D **22**, 473-83 (2003).

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