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Large Cross-Phase Modulation between Slow Co-propagating Weak Pulses in ^{87}Rb[1]

KARL-PETER MARZLIN, University of Calgary

Cross-phase modulation (XPM) is a nonlinear optical effect in which the index of refraction n of one laser field depends on the intensity I_2 of a second laser field, $n = n_0 + \chi_{\rm XPM} I_2$. Generating a large XPM coefficient $\chi_{\rm XPM}$ for weak laser fields is tremendously important, e.g. for optical quantum information processing and for all-optical switches in classical communication. Several proposals based on electromagnetically induced transparency (EIT) have been brought forward, but so far large XPM remains an experimental challenge. One problem is to achieve equal slow group velocities (double EIT) for two signal light pulses to maximize their interaction time.

We present an optical pumping scheme that combines the best features of previous proposals and adds some new techniques, thereby optimizing $\chi_{\rm XPM}$. A feasible procedure to prepare the atomic initial state is proposed such that double EIT with a single atomic species can be achieved, and a specific implementation of the scheme for ^{87}Rb is presented that only uses a single pump laser and a homogeneous magnetic field of moderate (150 G) strength. The efficiency of the scheme is studied using different theoretical methods, including third-order perturbation theory in the weak signal fields for an atomic five-level model, and a numerical simulation of the master equation that includes the full hyperfine level structure for the spectroscopic D1 line of ^{87}Rb. Furthermore, we study the nonlinear evolution of the two weak signal pulses and present a new upper bound on the maximal XPM phase shift achievable for two Gaussian single-photon pulses.

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