Asymmetric Induced Cubic Nonlinearities in Homogeneous And Quasi-Phase-Matched Quadratic Materials: Signature and Importance

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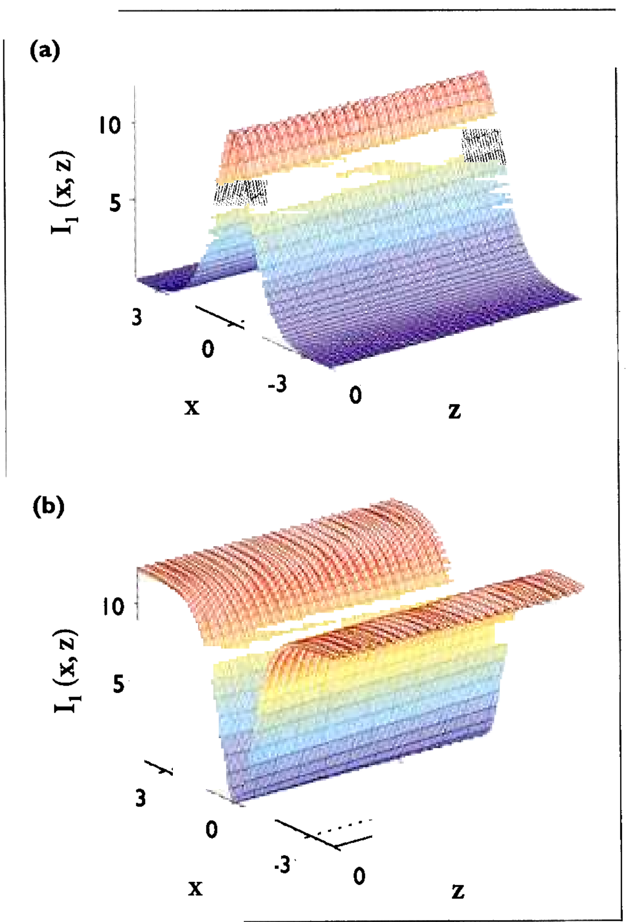

Figure 1. (a) Bright and (b) dark solitons that propagate in a $\chi^{(2)}$ sample in which the linear and nonlinear parts of a QPM grating compete and eliminate the effective $\chi^{(2)}$ nonlinearity. The solitons are supported by ACNs and have the form of sech- and tanh-shaped bright and dark nonlinear Schrödinger solitons, respectively. The intensity of the fundamental at effective phase-matching and positive and negative self-phase modulation coefficient of the ACNs, respectively (see Fig. 6 in Ref. 2), are shown. The second harmonic is zero.

Since the observation of nonlinear phase-shifts larger than π, quadratic nonlinear or $\chi^{(2)}$ materials have been of significant interest in photonics. With the maturing of the quasi-phase-matching (QPM) technique, in particular by electric-field poling of ferroelectrics, such as $LiNbO_3$, the number of applications of $\chi^{(2)}$ materials has increased even more. It is, therefore, more important than ever to have precise models of QPM samples.

In addition to providing effective phase matching, QPM gratings generate asymmetric cubic nonlinearities (ACNs) in equations for the average field.[1,2] This cubic nonlinearity is either focusing or defocusing, depending on the sign of the phase mismatch,[2] and its strength can be increased (e.g., exceeding that of the Kerr nonlinearity) by modulation of the grating.

In continuous-wave operation ACNs induce an intensity-dependent phase mismatch that implies a nonzero so-called separatrix intensity, the crossing of which changes the one-period phase shift of the fundamental by π, with obvious use in switching applications.[3] We derived a formula for this QPM-induced separatrix intensity that corrects earlier estimates by a factor of 5.3, and we found the optimum crystal lengths for a flat phase-versus-intensity response on each side of the separatrix.[3]

Clearly, when one operates close to or on both sides of this separatrix, the ACNs become important: a simple average model with merely an effective mismatch and thus no separatrix, is inadequate.

The most startling example appears when the competition between a linear and a nonlinear QPM grating eliminates the effective quadratic nonlinearity. Without nonlinearity, solitons should not exist but, as shown in Fig.1, both bright and dark solitons do exist and they are stable under propagation.[2] This paradox is elegantly explained by including ACNs in the model, which then correctly support simple bright and dark nonlinear Schrödinger solitons. When describing modulational instability (MI), ACNs become important if the nonlinear QPM grating has a dc value and/or if the QPM grating has both a nonlinear part and a linear part. Examples are quantum-well disordering in semiconductors and alternating linear and nonlinear domains in polymers. We have shown that ACNs are necessary to describe MI gain spectrum correctly in such samples and, in particular, to predict the novel QPM-induced regimes in which long-wave instabilities disappear and plane waves become modulationally stable over hundreds of diffraction lengths.[4]

All these effects are confirmed numerically and thus abundant theoretical evidence supports the presence of ACNs. Furthermore, ACNs are a general effect of nonphase-matched interaction between waves and as such appear also in homogeneous $\chi^{(2)}$ materials (no QPM grating) in a cascading limit.[4] In fact, in this case the asymmetric signature of ACNs could be measured as the difference between the properties in upconversion (second-haromonic generation) and downconversion, since there is no effective quadratic nonlinearity. Such an experiment was reported[5] recently and thus ACNs have now been confirmed experimentally.

Acknowledgments

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