Spotlight on Optics

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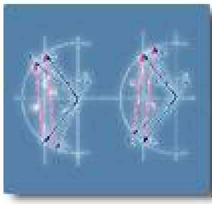

Absolute instability in backward wave four-wave mixing: spatial effects

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Spotlight summary: The spontaneous formation of patterns in nonlinear optical systems, starting from smooth input beams, is known in many different situations and for many different nonlinear optical media. For example, beams with an initial Gaussian profile can, after propagation through an atomic vapor or a liquid-crystal cell, give rise to honeycomb patterns. Patterns can develop without the help of feedback (there is just one beam that is propagating through the nonlinear material) or, more commonly, either with the help of feedback that can be provided by mirrors reflecting the input beam or by the distributed interaction of two counterpropagating beams.

A class of optical materials that is well suited for the observation of pattern formation is photorefractive media. These media, which can be crystals or polymers, do in fact possess extremely large optical nonlinearities, so that experiments can be performed with low-power cw lasers. In addition, the high value of the nonlinearities does not depend on sharp quantum resonances, making fine-tuning of the laser wavelength unnecessary.

The calculations and experiments of Mathey et al. deal with an instability in photorefractive media (they use crystals in their work). This instability is linked to the fascinating phenomenon of optical phase conjugation—the generation of a beam whose electric field is the phase conjugate of an input beam and that by consequence propagates inversely with respect to the input, that is, the generated beam returns to the same foci or undoes the effects of perturbations after traveling back through any perturbing media the input beam traveled through before being phase conjugated.

A picture of phase conjugation in photorefractive crystals and the resulting instabilities is best appreciated when considered in a few separate steps. Phase conjugation is a consequence of a four wave mixing interaction. Two counterpropagating pump beams interact with an input beam in the crystal. The interference pattern between one of the two pump beams and the input beam leads, through the optical nonlinearity of the crystal, to a refractive-index grating (the fact that only some terms of the interference pattern are important for grating formation results from the details of the nonlinear response of the material). The other pump beam scatters off this grating, reading it like a hologram. With a suitable arrangement of the pump beams, the only phase contained in the hologram, which is then imprinted onto the scattered beam, is the opposite of that of the incident beam, thus leading to phase conjugation.

Amnon Yariv and David Pepper showed in the 1970s [Opt. Lett. 1(16) 1977] that if two counterpropagating pump beams are present in a photorefractive crystal and the nonlinearity is sufficiently strong, a couple of mutually phase-conjugated beams can appear without any input, growing spontaneously from noise. The direction of the beams and the pump intensity threshold can be controlled by placement of mirrors around the crystals to provide feedback, but the beams can also form without external mirrors. In this case, the phenomenon is called “mirrorless oscillations,” and the orientation of the beams depends only on the nonlinear interactions inside the crystal. The result is often the production of a variety of patterns that are typically arcs, since beams can be generated simultaneously in more than one direction. (As an aside, it is interesting to note that under the right conditions—given a beam incident on a photorefractive crystal and two mirrors placed around the crystal to form a cavity oriented in a transverse direction with respect to the input beam—two “pump” beams can appear in the cavity, generated by the input itself and thereafter a beam conjugate to the input. The system is then a self-pumped phase conjugator, one of the many that can be realized.)

The work of Mathey et al. is concerned with the fine details of the mirrorless oscillations. In particular they study the effect on the patterns of slight pump misalignment, which has already been shown to decrease the threshold for mirrorless oscillations. They provide a careful theoretical explanation, computer simulations from which they derive the threshold conditions and several characteristics of the oscillations, and precise experiments with which the calculations (that do not contain free parameters) agree quite well.

A detailed understanding of the development of patterns is satisfying because it shows that the theory is complete and mature. In addition, this precise understanding opens the possibility to control the patterns themselves (for example, to select which patterns are generated).

In conclusion, the present work can be considered as a model for the investigation of optical instabilities and a helpful contribution to the problem of their control.

--Giovanni Piredda

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