Dynamic instability of self-induced bidirectional waveguides in photorefractive media

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We report on the experimental observation of a dynamic instability in the interaction of counterpropagating self-trapped beams in a photorefractive strontium barium niobate crystal. While the interaction of copropagating spatial optical solitons exhibits only transient dynamics, resulting in a final steady state, the counterpropagating geometry supports a dynamic instability mediated by intrinsic feedback. Experimental observations are compared with and found to be in qualitative agreement with numerical simulations.  © 2005 Optical Society of America

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The formation of stable self-trapped beams (commonly called optical spatial solitons) in photorefractive (PR) media has been the topic of intensive research in the past decade, primarily owing to potential applications in all-optical switching. Prior investigations have largely been confined to copropagating solitons, which exhibit characteristic interaction behavior: Individual solitons can attract or repel as well as exchange energy and fuse or mutually excite a new soliton. However, given one-sided boundary conditions, such nonlinear optical beams generally exhibit no dynamic behavior beyond initial transient dynamics.

A recent series of reports on spatial solitons consisting of counterpropagating (CP) waves indicates growing interest in the interaction of CP self-trapped beams. CP geometry adds intrinsic feedback to the soliton interaction. In general, CP waves coupled with feedback are often found to exhibit soliton interaction. In this Letter we present for the first time to our knowledge experimental confirmation of the numerically predicted instability, using mutually incoherent CP self-trapped beams in a PR cerium-doped strontium barium niobate crystal (Ce:SBN:60) crystal (Fig. 1). The crystal is biased by an external dc field along the transverse x direction, coinciding with the crystallographic c axis. Both beams are obtained from a single laser source and rendered mutually incoherent by a mirror oscillating with a period significantly shorter than the relaxation time constant of the PR material. The beams’ polarizations are also selected along the x axis, taking advantage of the high electro-optic r33 coefficient of SBN. Propagating in the +z and −z directions, both beams individually self-focus, as a result of the PR screening of the external field, which has a value of 1.3 kV/cm. The diameter of each beam (x axis) is 25 μm FWHM, and the power of each is 1 μW. To help the formation of PR screening solitons, the interaction region is illuminated by white light. The beams’ power and the level of nonlinearity are adjusted such that each of the beams individually forms a spatial soliton. To demonstrate both above-
and below-threshold behavior with a single crystal sample, we utilize two medium lengths by rotating the crystal about its $c$ axis, thus yielding $L_1 = 5 \text{ mm}$ and $L_2 = 23 \text{ mm}$.

Because the actual evolution of CP beams within the PR medium is not accessible in this experiment, images of beam outputs at the crystal faces are recorded (Fig. 2). Besides each beam leaving the medium, a reflection of the CP input is recorded as a lateral reference. Initially, both beams are adjusted such that their inputs and outputs overlap on both ends of the crystal, if propagating independently and in a steady state, including the shift through beam bending. This configuration was chosen to minimize the possible effects of beam bending on the stability of a fully overlapping state [Fig. 3(a)].

For comparison with numerical simulations, experimental data are reduced to one transverse dimension: The images obtained on the exit faces of the crystal are projected onto the $x$ axis. As these data are plotted over time, one gets a representation of the dynamics of the beam exiting a crystal face [Figs. 3(a)–3(c)]. Although changes parallel to the $y$ axis are not represented, most of the observable dynamics is confined to the $x$ axis, owing to the significance of the $c$ axis for the PR effect.

Considering a medium of short length ($L_1 = 5 \text{ mm}$), the output beams on both crystal surfaces initially shift their position in the experiment [Fig. 3(a), $t < 20 \text{ s}$], as well as in corresponding simulations (not shown), converging to an overlapping steady state ($t > 20 \text{ s}$). Because the solution is stable and stationary, the considered medium length is below the predicted dynamic instability threshold.

In the case of a significantly longer medium ($L_2 = 23 \text{ mm}$) the beams initially self-focus separately [Fig. 3(b), $t < 30 \text{ s}$] and attract and overlap ($30 \text{ s} < t < 60 \text{ s}$). However, this state is unstable and yields to irregular repetitions of repulsion and attraction. This process does not feature any visible periodicity and is observed for time spans that are orders of magnitude longer than the time constant of the system. The reported dynamic state [Fig. 3(c)] can be seen to directly correspond to numerical simulations of the
tor soliton or any other stationary waveguide structure. Instead, a dynamic instability enforces spatial separation of the localized beams while rendering such separated states unstable. A threshold interaction length was found beyond which the interaction leads to nontransient dynamics that is experimentally observable on the exit faces of the crystal. Qualitatively, experimental observations were found to be in good agreement with numerical simulations. Above- and below-threshold states were clearly distinguishable. Quantitative investigation of the threshold, the inclusion of beam bending and repulsive forces observed between PR solitons into the analysis, and a determination whether the observed aperiodic dynamics is chaotic, are challenging experimental tasks and are the subjects of ongoing research.

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References
14. It should be noted that the threshold parameter is actually the coupling strength, which is the interaction length times the PR coupling constant. Holding the latter at a fixed value, we restricted the investigation to the interaction length threshold.