Bouncing of Vector Solitons

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Abstract: We show how to control the collisions of vector solitons: from solitons going through each other, to solitons bouncing off each other. In bouncing, a weak soliton component switches most of the energy of the strong component.

OCIS codes: 190.0190, 190.3270

When two scalar solitons collide in an ideal Kerr type medium, they experience only a phase shift while conserving their energies, linear momenta, and shapes [1]. Manakov vector solitons however consist of two [2] or more components and their interactions are much richer than those of scalar solitons [3,4,5].

It is useful to think of generating vector solitons in the following manner: starting with two scalar solitons A and B that belong to two independent optical fields (e.g., two orthogonal polarizations) take some energy from each field and inject into the other. More specifically: split A into A_1 and A_2, and B into B_1 and B_2 and then superimpose B_1 on A_1 to form vector soliton 1, VS1, and superimpose A_2 on B_2 to form vector soliton 2, VS2. One would expect that, if the amount of energy split-off is small, then the vector solitons should behave almost as scalar solitons: be unaffected by the collision. Here we show, through numerical simulations and analytical calculations [4, 5], that as little as 10% intensity split-off (i.e., $|B_1/A_1|^2 = 0.1$) can drastically change the collision outcome, making the solitons "bounce" off rather than go through each other.

The setup of the numerical "experiments" is shown in Fig. 1. The input condition is shown in Fig. 1a, and the state transformation (based on the analytic formulation of Ref. [4]) is shown in Fig. 1b. The two amplitude ratios at the input are $\rho_1 = A_1/B_1 = R$ and $\rho_L = A_2/B_2 = \pm 1/R$ where the ± accounts for in or out of phase respectively. The final states are ρ_2 and ρ_R and depend on the collision angle, on R, and on the total intensity in each vector soliton. The final states can be calculated exactly from Ref. [4]. Vector Soliton 1 (so-called VS1) is launched from left to right and VS2 from right to left as shown in Fig. 1b.

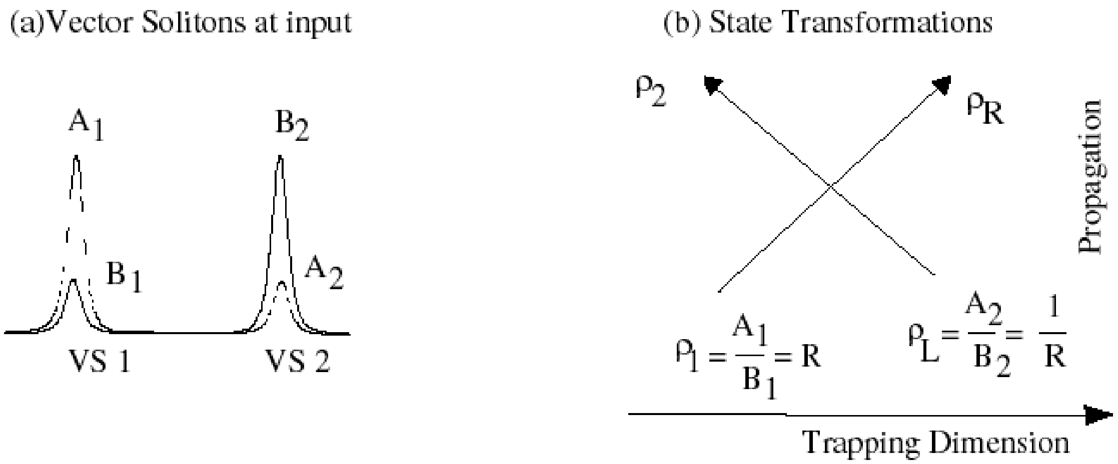

Fig1. (a) The A-field (dotted line) and the B-field (solid line). (b) State transformations and the geometry of the collision, ρ_1 and ρ_L are the initial states and ρ_2 and ρ_R are the final states after the collision.

Bouncing occurs due to large energy exchanged between the components of each field and it occurs for $|\rho_2|^2 > 1$. In that case, the peaks of each field remain on the same side as they begin, giving the impression of bouncing off each other, as shown in Figs. 2a and 2b, where $|\rho_2|^2 = 2.75$. The simulations in Fig. 2 show the intensities for the A and the B fields and corresponds to an angle of 0.6^o, $R = 3$, and to a nonlinear index change of 6.3×10^{-4} in physical units for an intensity of 16. Figs. 2a and 2b show both A and B fields to highlight the symmetry of the bouncing process. Intuitively we can think of this bouncing-interaction being caused by diffraction off two gratings with the same periodicity: the grating written by A_1 and A_2 and the grating written by B_1 and B_2. The ratio R gives the modulation depth of the grating, and together with the total intensity, they determine the strength of the grating. The angle gives the length of interaction.

Building upon the grating intuition we reduce the intensity by a factor of 8 so that the grating is weaker and there is no bouncing as shown in Fig. 2c, where $|\rho_2|^2 = 0.53$. The grating does switch some energy (symmetrically) between the field components of the solitons (as in Ref. [5]) but is not strong enough to switch most of the energy as in Figs. 2a, 2b. Up to now the two gratings were in-phase and they add constructively. But, by making the B_1 out of phase with B_2 the two gratings can cancel each other and therefore the two vector solitons are transparent to each other, as shown in Fig. 2d.

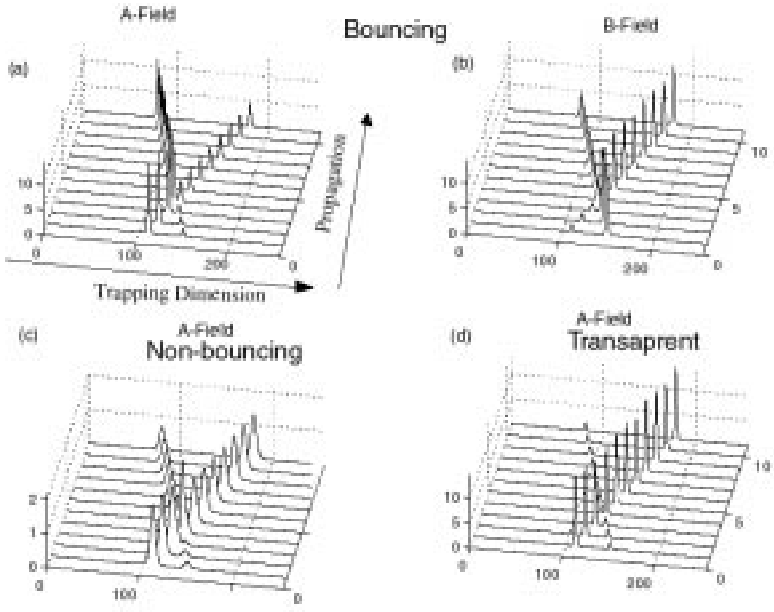

Fig.2. (a) ,(b). The bouncing case showing the A and the B fields respectively. The total intensity in each vector soliton is 16 and $|\rho_2|^2 = 2.75$. (c) The total intensity is reduced to 2, the gratings weaken, $|\rho_2|^2 = 0.53$ and there is no bouncing. (d) Same as (a) but with the two gratings out of phase. This is the transparent case since the collision has no effect on the field components.

In summary, have shown how to control the collisions of vector solitons: from solitons going through, to solitons bouncing and developed a simple physical explanation based on gratings. We are currently investigating experimental implementations in saturable nonlinear media such as photorefractives.

References
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