Guiding Light by Light Using Dark Spatial Solitons

By Barry Luther-Davies,, Xiaoping Yang,** Laser Physics Centre,* Optical Sciences Centre,** Research School of Physical Sciences and Engineering, The Australian National University, Canberra, Australia*

The guiding of light by light is one long term aim of nonlinear photonics since it offers the possibility of developing all-optical circuitry where a controlling light beam can rapidly switch or modulate a second information-carrying beam. In this context, there has been considerable recent interest in spatial solitons and their interaction.

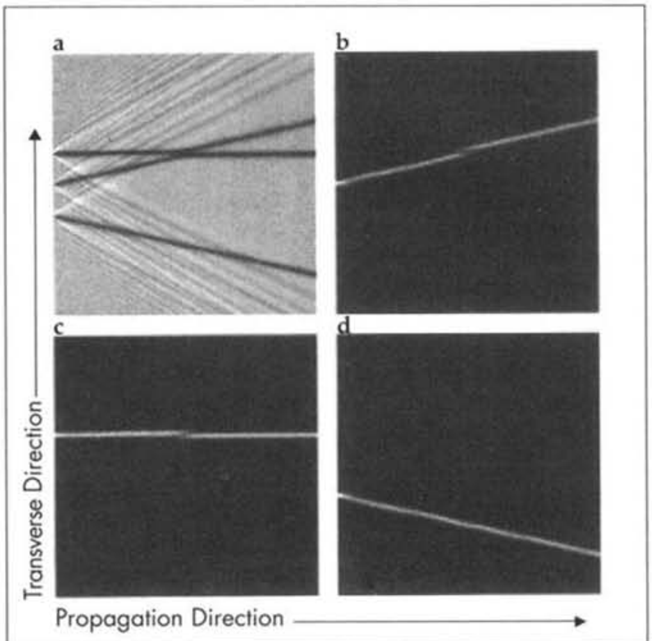
Spatial solitons are optical structures that propagate without diffracting through a medium with nonlinear optical properties. To date, most interest has focused on so-called bright spatial solitons that are two-dimensional structures rather like a laser beam confined in one dimension in a slab waveguide. Bright spatial solitons are self-guided beams that form in media whose refractive index increases with increasing light intensity. The center of the beam, where the light intensity is highest, thus sees a higher refractive index than the edge of the beam where the intensity is low. The beam, therefore, "writes" a waveguide into the medium through which it propogates and stable "soliton" propagation occurs, provided the field of the light wave is also the fundamental mode of the waveguide created.

Because the soliton writes a waveguide into the nonlinear medium, a secondary information carrying beam can be launched into that waveguide and can propagate as one of its bound modes. This secondary beam can then be manipulated by switching the soliton forming beam on or off.

In recent work[1] we have extended these ideas to another type of spatial soliton, so-called dark spatial solitons.[2] Dark solitons are regions of low light intensity embedded in a quasi-plane wave. They form in media whose refractive index is reduced by increasing light intensity and are essentially zones of total or partial destructive interference between phase shifted waves lying on either side of the soliton. They are also self-guided beams since they write a waveguide into the nonlinear medium, but in contrast with bright solitons, a dark soliton is a radiation mode of the waveguide it induces.

We have shown that dark soliton induced waveguides form quite different structures from their bright soliton counterparts. For example, they can be used to write a range of technically important structured waveguides such as adiabatic tapers, Y-junctions, X-junctions, and optical switchyards.

The most interesting prospect is the possibility of developing fast reconfigurable devices of which the switchyard is one example. A computer simulation of a sample device is shown in the figure. Here a single soliton-forming beam containing three phase shifts at boundaries within the beam forms a structure containing three soliton induced waveguides. The propagation direction of the individual guides is controlled by the magnitude of the phase shifts and can be adjusted to connect the individual input ports to an array of output ports. The figure shows the operation in a sample configuration where the phase shifts were (0.65π) - π - $(-0.65\ \pi)$, respectively. Notice that the solitons cross without interacting and that the guided beam also crosses the resulting junctions without loss. Devices such as this have obvious potential for signal routing in advanced photonics systems.



(a) A computer simulation shows three dark spatial solitons forming from a single input beam containing three phase jumps $(0.65\ \pi)$ - π - $(-0.65\ \pi)$. The intensity of the light beam is represented using a grey scale plot. (b), (c) and (d) plot the profiles of guided beams launched into the three soliton induced waveguides. In this simulation, the maximum refractive index change induced by the soliton forming beam was 0.008, the propagation distance was 1000λ, and the width of the window in the transverse direction 83λ.

REFERENCES

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