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Rapid Research Note

Observation of Two-Dimensional Spatial Solitons in Iron-Doped Barium–Calcium Titanate Crystals

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Since the discovery of photorefractive spatial solitons [1, 2], these non-diffracting waves have been the subject of an intense research effort, because they are particularly interesting for building all-optical diodes, transistors, switches, and all-optical computers. Until now steady-state bright spatial solitons have been observed in BTO [3], SBN [4], InP:Fe [5], $KNbO_3$ [6], KLTN [7], and $BaTiO_3$ [8] crystals. Barium–calcium titanate (BCT) [9, 10] is a promising photorefractive material and an alternative to $BaTiO_3$, which is much easier to grow and does not have any phase transition within the temperature range from $-120\,^\circ$C to $100\,^\circ$C. This crystal also possesses slightly larger electro-optic coefficients r_{13} (20 pm/V) and r_{33} (130 pm/V) compared to $BaTiO_3$. However, no studies of photorefractive spatial soliton formation have been reported so far in BCT crystals. In this contribution, we investigate photorefractive spatial soliton formation in iron-doped BCT crystals and observe, for the first time to our knowledge, the formation of steady-state two-dimensional (2D) screening solitons in this material.

Samples of the congruently melting composition $Ba_{0.23}Ca_{0.77}TiO_3$ are grown in the crystal-growth laboratory of the Department of Physics at the University of Osnabrück [9, 10]. The dimension of our sample that is doped with 290 ppm Fe is $5 \times 5 \times 5$ mm^3. All surfaces are polished to optical quality. On both faces normal to the *c*-axis of the crystal, electrodes are prepared with silver paste. The light propagates along the *a*-axis in our experiment. Our experiments are conducted in a standard setup for soliton formation, in which an external electric field E_0 is applied along the ferroelectric *c*-axis. A frequency-doubled Nd:YAG laser ($\lambda = 532$ nm) is used as the light source. Because of the low dark conductivity of our sample $\sigma_d \approx 6 \times 10^{-14}\,\Omega^{-1}\,\text{cm}^{-1}$ [9], a background illumination is necessary to tune the degree of saturation of the nonlinearity. This ordinarily polarized background light of the same wavelength 532 nm is made spatially incoherent by passing it through a rotating diffuser. The ratio *r* between the soliton light intensity (extraordinary polarization) and the background irradiance is $r \approx 5$. The soliton intensity is always kept below 50 mW/cm^2 to minimize photovoltaic self-defocusing.

Figure 1 shows a characteristic result of 2D soliton formation. In this experiment, the beam intensity is $I \approx 30$ mW/cm^2. The beam diameter at the crystal's input face is $d_{in} \approx 14\,\mu$m. Without an external electric field E_0 applied, the beam width *d* increases during propagation due to both,

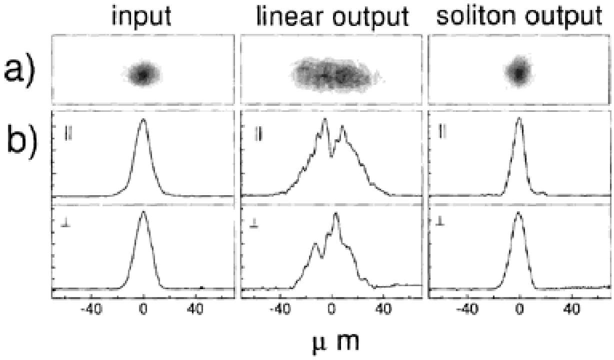

Fig. 1. Formation of 2D solitons in BCT crystals. a) Images of the input beam (left hand), the diffracted output beam (center) and the self-trapped soliton beam (right hand). b) Horizontal (parallel to *c*-axis, ||) and vertical (perpendicular to *c*-axis, $\perp$) beam intensity profiles of the input beam, the diffracted output beam for $E_0 = 0$, and the 2D soliton output beam, respectively

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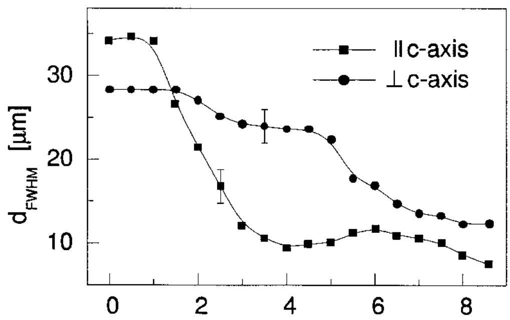

Fig. 2. Horizontal (parallel to c-axis, ||) and vertical (perpendicular to c-axis, $\perp$) beam diameter d (FWHM) at the crystal's exit face as a function of the electric field E_0

linear diffraction and photovoltaic self-defocusing. At the exit face, the beam width perpendicular to the c-axis is increased to about 29 µm, whereas for the parallel direction an increase to about 41 µm is measured. By application of an appropriate field to the sample, a 2D screening soliton can be induced. In Fig. 1, an electric field of about 7 kV/cm is necessary for soliton formation. This soliton is stable and reshapes itself with a diameter (FWHM) of 11.0 µm parallel to the c-axis and a diameter of 12.8 µm perpendicular to it. The beam is slightly elliptical, but this effect is much less pronounced than it is observed for 2D solitons in $BaTiO_3$ [8]. Very similar results are obtained when light of a helium neon laser ($\lambda = 632.8$ nm) is used for the soliton beam, while still using the green background light. In this case, for about the same value of the external field the red light beam forms a 2D soliton of slightly larger size.

In Fig. 2, we illustrate the soliton formation as a function of the applied field E_0, for the same experimental conditions as in Fig. 1. The dependence of the output beam diameter on the applied field shows a threshold-like behavior. Both beam profiles change distinctly for electric fields larger than about 2 kV/cm. Within the range from 4 kV/cm to 6 kV/cm, the beam width parallel to the c-axis increases slightly with increasing field, while the beam width perpendicular to it decreases. For even larger fields, both diameters decrease up to saturation. The different threshold-like behaviors for the vertical and horizontal beam profiles are quite different from those observed in other crystals.

In most investigations on bright photorefractive solitons, especially in those performed in SBN, photovoltaic effects can be neglected. However, in BCT the photovoltaic field influences the soliton formation in addition to the external drift field. This can affect the beam profiles in a quite complicated manner. For instance, oscillation and pulsation of the output beams in time and space are often observed and always deteriorate the formation of solitons. On the other hand, the competition between photovoltaic and drift effects also produces new and interesting phenomena which are worth further investigation.

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