ISSN 0974 - 9373

Vol. 26 No. 3 (2022) **J. Int. Acad. Phys. Sci.** pp. 275-280

Optical (1+1)D Bright Soliton in Bulk BBO Crystal

Sharbari Deb, Satadru Behera and Ardhendu Saha
Electrical Engineering Department, National Institite of Technology Agartala, Jirania,Tripura(w)
Email: sharbari.deb@gmail.com ; behera.satadru@gmail.com ; arsagtwave@gmail.com

(Received November 3, 2021, Revised May 17, 2022, Accepted June 18, 2022)

Abstract: The evolution of (1+1)D bright soliton has been investigated theoretically in anisotropic bulk media having extraordinary nonlinear responses. To achieve a stable spatial soliton in bulk media transverse instability plays a crucial role which might be abolished. Transverse instability can be fully removed if the soliton is rendered sufficiently incoherent in its transverse dimension. A threshold transverse instability criterion has been evolved that connects nonlinearity to the greatest transverse correlation distance at which the spatial bright soliton is stable. Furthermore, the entire methodology is possible because of the proper balance between nonlinearity and diffraction through the crystal.

Keywords: Bulk media, Bright soliton, Nonlinearity, Transverse instability.

1. Introduction

Over the last decade, research on optical spatial solitons has progressed significantly: new systems that support solitons have been discovered, as have solitons with more than one component. The transverse dimension has been established, as well as the totality of the situation. Self- similar solutions of the nonlinear wave equation are themost frequent theoretical approach to self-trapping which is known as a spatial soliton. Previously, similar solutions have been discovered for coherent beams considering different nonlinear media[1-3].

Chen *et al.*[4] developed beta-barium-borate (BBO, β- BaB2O4) which is very popular because of its extraordinarily advantageous properties[5]. Sheikh-Bahae *et al.*[6] submitted a research article that included all of the nonlinear refraction measurements of the BBO crystal. This negative uniaxial crystal can be a good candidate for spatial soliton generation especially for having a high damage threshold. That is why we consider it for this research work.

Two recent findings, modulation instability (MI) of incoherent light[7] and elliptical incoherent solitons[8-9], provided evidence that TI might be eliminated for stable solitons. In the specific case of (1+1)D spatial soliton that is self-trapped and coherent in one dimension x, is uniform but slightly incoherent in the transverse dimension y, and propagates along z. Solitons are universal phenomena with many common traits[10], one of which is transverse instability (TI). TI is particularly severe for Kerr nonlinearities which prevent (1+1)D spatial soliton considering Bulk media. For this reason, Soliton was launched in a waveguide with a planar structure[11-12]. As of now, experimental arrangements with (1+1)D solitons were carried out in optical fibers, either planar waveguides[11-12] or nonlinearities where TI was considerably suppressed[13] to avoid TI. There has been no previous research in the literature utilizing any anisotropic crystal. In this study, we described how to create a completely stable spatial soliton propagating in a bulk BBO crystal while avoiding TI.

2. Theoretical Approach

The foremost objective of this study is to develop a stable (1+1)D bright spatial soliton in a nonlinear bulk BBO crystal utilizing a continuous wave (CW) optical beam. The specimen dimension of the bulk BBO is 5× 4 × 10 mm^3. Figure 1 depicted a detailed overview of the proposed scheme.

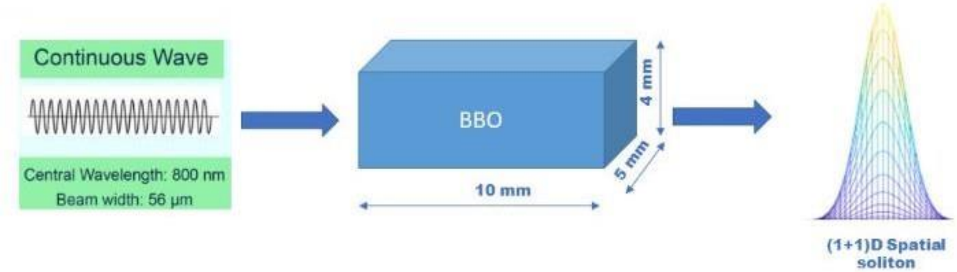

Figure 1: Pictorial view of the proposed scheme

Optical spatial solitons propagate without spreading over a nonlinear medium as a result of a proper balance between nonlinearity and diffraction. The nonlinear Schrödinger equation (NLSE) for most general soliton equations describes wave propagation in nonlinear material[14]. Furthermore, the soliton-type solution is usually the end goal of the theoretical investigation for the nonlinear analysis of the NLSE. This is typically the desirable characteristic of spatial soliton because it can propagate through a quite long distance without diffraction. Other than that when it collides with other solitary waves, its amplitude, shape and speed stay unchanged[15-16].

A series of coherent speckles that vary on average per coherence time can be used to visualize an incoherent beam in our proposed scheme. The spatial correlation function is defined as:

(1.1) $$B(x_1, y_1 x_2, y_2, z) = \langle E * (x_2, y_2, z, t) E(x_1, y_1, z, t) \rangle$$

where $E(x_1, y_1, z, t)$ representing the slowly varying amplitude. This slowly varying amplitude propagates through a nonlinear medium i.e BBO crystal. The final equation derived from the paraxial wave equation is as follows[17-18]:

(1.2) $$\partial \frac{\partial B}{\partial z} - \frac{i}{k}\left\{\frac{\partial^2 B}{\partial x \partial \rho_x} + \frac{\partial^2 B}{\partial y \partial \rho_y}\right\} = \frac{ik}{n_0}\{\delta n(x_1, y_1, z_1) - \delta n(x_2, y_2, z_2)\}B$$

Here, z represents propagation direction, k denotes wave number, n_0 is the bias refractive index, and δn basically describes the change of the nonlinear refractive index. The middle point coordinates are $x = (x_1+x_2)/2$, $y = (y_1+y_2)/2$, while the difference coordinates are $\rho_x = x_1 - x_2$ and $\rho_y = y_1 {}_{-} y_2$. By solving this equation we determine the threshold condition for TI. The process to decide the threshold can be applied to any type of spatial coherence, however, we used a Gaussian angular power spectrum in ourcase. The TI gain decreases as we move closer to the threshold. This methodology is applicable for almost all nonlinear media to achieve (1+1)D bright soliton. These solutions are useful in the sciences and aid in the comprehension of the physical phenomena that this equation produces.

3. Results and discussion

Continuous-wave profile having a central wavelength of 800 nm and beam width of 56 um is described in the form of an incoherent Gaussian beam which has been depicted in Figure 2 for the initial condition.

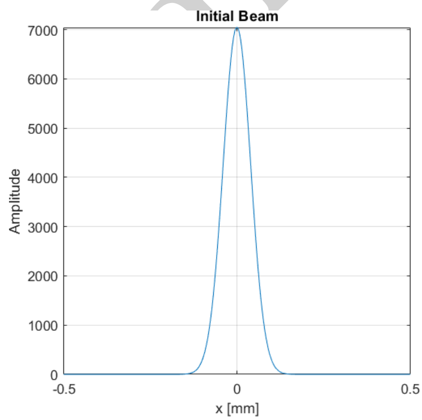

Figure 2: Initial optical beam

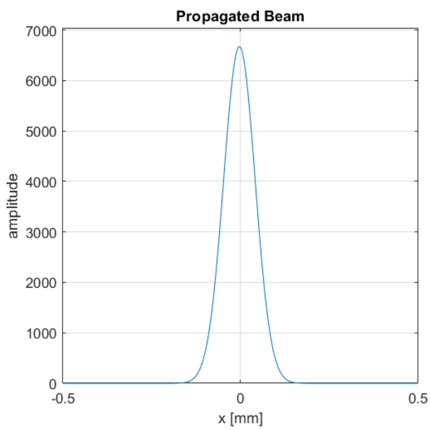

Figure 3: Propagated beam through BBO crystal

However, Figure 3 indicates the final situation of an optical beam after the propagation through a nonlinear medium. The 56 um FWHM input beam linearly diffracts to a 72 um output beam after a successful propagation of 10 mm along the crystal length. In this particular case, some minor changes have occurred in the case of spatial soliton generation due to the diffraction phenomenon of light.

Interestingly, if the propagated beam was entirely coherent in nature then the soliton will suffer from TI and will break into filaments. To avoid this unwanted situation here we consider an incoherent optical beam. Based on the solution, in figure 4 we observed the evolution behavior of (1+1)D spatial soliton while propagating through a BBO crystal by eliminating TI. This 3D graphical representation proves that the optical beam profile is also affected due to the nonlinear refractive index of that particular crystal.

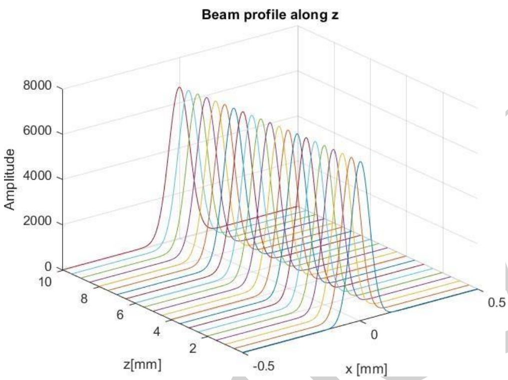

Figure 4: The evolution behavior of the soliton.

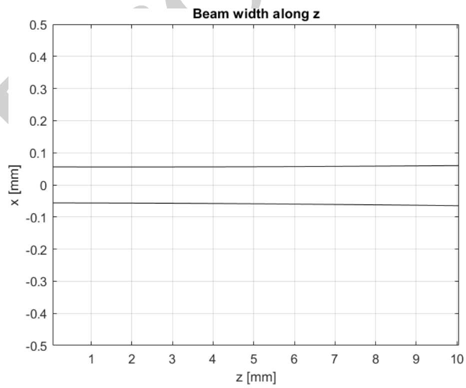

Figure 5: Constant beam width along the spatial crystal length.

The simulation result in Figure 5 shows the constant characteristic of beam width along the crystal length forbright soliton. In our proposed work, MATLAB was utilized to execute the numerical calculations as well as to achieve theappropriate results. To summarize, we have studied the existence and stability of (1+1)D bright soliton.

In conclusion, we demonstrated a novel optical methodology to develop (1+1)D spatial soliton utilizing a birefringent nonlinear medium. This is the sole way for propagating completely stable 1D solitons in a bulk material that we are aware of. Advantageous properties of bulk BBO crystal have been properly exploited to achieve spatial. soliton. In particular, we found that (1+1)D spatial soliton can exist in nonlinear bulk crystal by eliminating transverse instability. We proved our findings theoretically and demonstrated that stable 1D bright soliton can be generated in a bulk material. As per our belief, this study opens up a range of possibilities for removing transverse instabilities in a variety of soliton systems, including the instabilities of 1D dark solitons in various bulk media. These findings can be implemented in various optical applications, which include all-optical switching of the light beam, beam quality control depending on the nonlinearity of the medium, etc. Furthermore, this promising methodology has significant potential application in information processing and communication technology. Even by implementing the electro-optic effect, we may achieve better results in the future.

Acknowledgement:
The authors would like to thank the Department of Electrical Engineering and Department of Mathematics, National Institute of Technology, Agartala, India for the valuable motivation and support.

References

1. M. Segev, M. F. Shih and G. C. Valley; Photorefractive screening solitons of high and low intensity, *JOSA B,* 13-4 (1996), 706-718.
2. M. D. I. Castillo, P. A. M. Aguilar, J. J. Sanchez Mondragon, S. Stepanov and V. Vysloukh; Spatial solitons in photorefractive Bi12TiO20 with drift mechanism of nonlinearity, *Appl. Phys. Lett.*, 64-4 (1994), 408-410.
3. A. V Mamaev and M. Saffman; Propagation of Dark Stripe Beams in Nonlinear Media: Snake Instability and Creation of Optical Vortices, *Phys. Rev. Lett.*, 76 (1996), 2-5.
4. D. Eimerl, L. Davis, S. Velsko, E. K. Graham and A. Zalkin; Optical, mechanical, and thermal properties of barium borate, *J. Appl. Phys.*, 62-5 (1987), 1968– 1983.
5. D. N. Nikogosyan; Beta barium borate (BBO) - A review of its properties and applications, *Appl. Phys. A Solids Surfaces*, 52-6 (1991), 359-368.
6. M. Sheik-Bahae and M. Ebrahimzadeh, Measurements of nonlinear refraction in the second-order χ(2) materials KTiOPO4, KNbO3, β-BaB2O4, and LiB3O5, *Opt. Commun.*, 142(4-6) (1997), 294-298.
7. M. Soljacic, M. Segev, T. Coskun, D. N. Christodoulides and A. Vishwanath; Modulation instability of incoherent beams in noninstantaneous nonlinear media, *Phys. Rev. Lett.*, 84-3 (2000), 467–470.
8. Z. Chen, M. Mitchell, M. Segev, T. H. Coskun and D. N. Christodoulides; Self-trapping of dark incoherent light beams, *Science,* 280-5365 (1998), 889-891.
9. E. D. Eugenieva, D. N. Christodoulides and M. Segev; Elliptic incoherent solitons in saturable nonlinear media, *Opt. Lett*., 25-13 (2000), 972.
10. G. I. Stegeman and M. Segev; Optical spatial solitons and their interactions: Universality and diversity, *Science*, 286-5444 (1999), 1518-1523.

11. A. Shabat and V. Zakharov; Exact theory of two- dimensional self-focusing and one-dimensional self- modulation of waves in nonlinear media, *Sov. Phys. JETP*, 34-1 (1972), 62-69.
12. J. S. Aitchison A. M. Weiner, Y. Silberberg, M. K. Oliver, J. L. Jackel, D. E. Leaird, E. M. Vogel, and P. W. E. Smith; Observation of spatial optical solitons in a nonlinear glass waveguide, *Opt. Lett.*, 15-9 (1990), 471-473.
13. K. Kos, H. Meng, G. Salamo, M. feng Shih, M. Segev and G. C. Valley; One-dimensional steady-state photorefractive screening solitons, *Phys. Rev. E Stat. Physics, Plasmas, Fluids, Relat. Interdiscip.* Top., 53-5 (1996), 4330-4333.
14. Trillo, Stefano and William E. Torruellas, *Spatial solitons*, Springer Science & Business Media, 2001.
15. Y. Zhao, Y. Chen, J. Dai, Y. Wang and W. Wang; Bright Soliton Solution of (1+1)-Dimensional Quantum System with Power-Law Dependent Nonlinearity, *Adv. Math. Phys.*, 2019 (2019).
16. M. Arshad, A. R. Seadawy, D. Lu and F. U. Khan; Optical solitons of the paraxial wave dynamical model in kerr media and its applications in nonlinear optics, *Int. J. Mod. Phys. B*, 34-9 (2020), 1-17.
17. V. V. Shkunov and D. Z. Anderson; Radiation transfer model of self-trapping spatially incoherent radiation by nonlinear media, *Phys. Rev. Lett.*, 81-13 (1998), 2683-2686.
18. Charalambos Anastassiou, Marin Soljačić, MordechaiSegev, Eugenia D. Eugenieva, Demetrios N. Christodoulides, Detlef Kip, Ziad H. Musslimani, and Juan P. Torres; Eliminating the transverse instabilities of Kerr solitons, *Tech. Dig. - Summ. Pap. Present. Quantum Electron. Laser Sci. Conf. QELS* (2001), 227-228.