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Topological charge influence on self-action of femtosecond optical vortices in the range of anomalous group velocity dispersion

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Abstract. The self-action of femtosecond optical vortices in LiF crystal at wavelength 1800 nm in the range of anomalous group velocity dispersion is considered. The influence of the topological charge on the spatio-temporal dynamics of the pulse and peak intensity values in the formation of ring light bullets is analyzed.

The propagation of femtocesond pulses in a nonlinear medium can be accompanied by a phenomenon of filamentation, when a long thin filament of a laser field with a high localization of light energy is formed [1]. Femtosecond filamentation is influenced by the group velocity dispersion (GVD) of the pulse. In the conditions of anomalous GVD the formation of so-called "light bullets", which are relatively stable in space and time, is possible [2]. Filamentation in presence of light bullets has been widely studied for Gaussian beams [3]. Self-action of ring beams with a phase dislocation - optical vortices, where a helical wavefront prevents the localization of the field on the optical axis, was analyzed significantly less [4]. Potential applications of such beams are associated with obtaining micromodification of the refractive index of the ring shape [5]. The self-action of femtosecond vortices in condensed media was studied both under conditions of normal [6] and anomalous [7, 8] GVD. Spatiotemporal dynamics, multifocus spatial structure, quantitative characteristics of light bullets, arising during propagation, and spectral transformation of pulse energy were studied. The purpose of this work is to analyze the influence of the vortex topological charge on the spatiotemporal pulse dynamics in LiF crystal at wavelength lying in the region of the anomalous GVD.

Numerical simulation of the self-action of femtosecond optical vortices was carried out by solving a nonlinear system of equations for complex amplitude of the light field $A\ (r,t,z)$, written in slowly varying wave approximation [9], and plasma concentration $N_e\ (r,t)$. On the input surface of the LiF crystal the optical vortex takes the form:

$$A^{(m)}(r,t,0) = A(r,t,0)\exp\{im\varphi\} = A_0\left(\frac{r}{r_0}\right)^m \exp\left\{-\frac{r^2}{2r_0^2}\right\}\exp\left\{-\frac{t^2}{2t_0^2}\right\}\exp\{im\varphi\},$$

where r_0 and t_0 are the characteristic spatial and temporal scales of the vortex. We considered vortex beams with topological charges $m = 1$ and $m = 2$ at two central wavelengths $\lambda_0 =$

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1800 nm and $\lambda_0 = 3000$ nm, corresponding to moderate ($k_2 \simeq -39$ fs^2/mm) and strong ($k_2 \simeq -239$ fs^2/mm) anomalous GVD. The pulse peak power P_0 exceeded the critical power $P_V^{(m)}$ for a given topological charge m by five times.

At the beginning of the pulse propagation in nonlinear medium, a five-fold excess of the peak power over the critical power leads to spatial self-focusing of the vortex in the ring, which is accompanied by simultaneous self-compression in time leading to the formation of an annular bullet. For a fixed topological charge, the distances to the first focus at different wavelengths approximately coincide (Fig. 1).

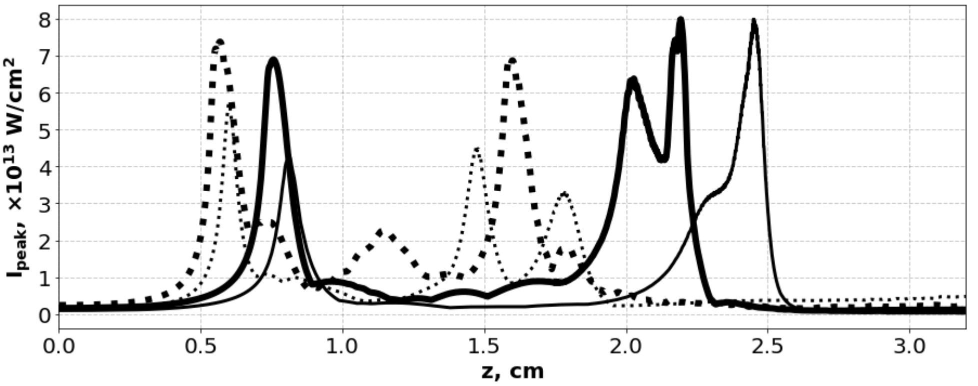

Fig. 1. Optical vortices with topological charges $m = 1$ (solid lines) and $m = 2$ (dotted lines) peak intensity dependence on the propagation distance z under self-action in the LiF crystal at central wavelengths $\lambda_0 = 1800$ nm (thin lines) and $\lambda_0 = 3000$ nm (thick lines).

The first nonlinear focus of vortices with $m = 1$ is located at a distance of about 0.75 cm, while for vortices with $m = 2$ the nonlinear focus is located in the vicinity of $z = 0.6$ cm. Topological charge promotes self-focusing of radiation in the ring providing a faster increase in intensity. The radius of the last (third) annular bullet increases with the topological charge. For an optical vortex with $m = 2$, it is three times larger than for $m = 1$. Fig. 1 shows that the global maximum of intensity in vortices with $m = 1$ is reached in the last nonlinear focus, while for vortices with $m = 2$ - in the first focus. Thus, an increase in the topological charge complicates the appearance of near-axial light bullets and prevents peak intensity increase in the nonlinear focus as the pulse propagates.

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