Linear optics of dark beams with mixed phase dislocations

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ABSTRACT

In this work we present extended numerical simulation on the evolution and interaction of one-dimensional dark beams of finite length carrying mixed phase dislocations. In the linear regime of propagation two possible ways to control their transverse velocities are investigated and compared.

Keywords: mixed phase dislocations, diffraction of dark beams, beam steering control

1. INTRODUCTION

Phase singularity generated in an optical field forces both the real and the imaginary part of the field amplitude (i.e. also the field intensity) to be zero at the point(s) of singularity. In the early work of Nye and Berry[1] it is conjectured that mixed edge-screw dislocations cannot exist. An indication for their existence was found[2] however for two interacting optical vortices of opposite topological charges. Odd Dark Beams (ODBs) with mixed phase dislocation are meanwhile identified[3] and generated under controllable initial conditions[4].

In this work we consider two possible types of mixed phase dislocations of finite length – edge-screw (ES) and step-screw (SS). The SS dislocation consists of an one-dimensional phase step of a limited length, which ends, by necessity, with pairs of phase semi-spirals with opposite helicities. The ES dislocation consists of a pair of opposite spirals, which step is equal to π, located at the ends of the phase jump of finite length. The respective phase distributions are shown in Fig. 1.

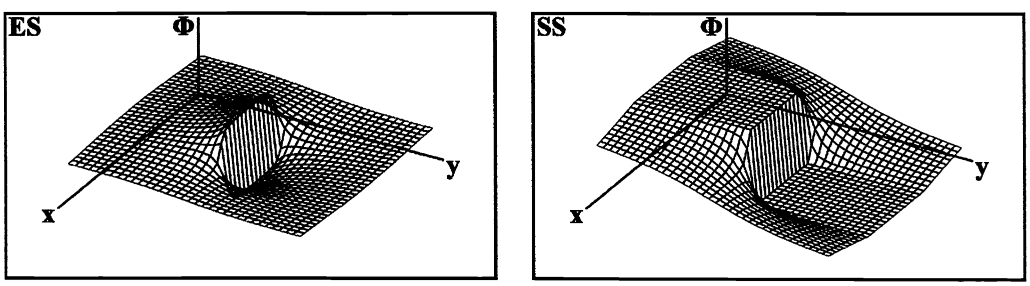

Fig. 1. Phase distribution of ES and SS mixed dislocation.

The transverse steering dynamics of mixed SS and ES phase dislocations under comparable conditions show spectacular difference in favor of the edge-screw (ES) dislocation[5]. Since the background-beam intensity is found to have a weak influence on the ODB steering[3,4], the linear optics of such dark beams is of undoubted interest. Nevertheless, reasonable high intensity is important for keeping the optically-induced gradient waveguides steep, which is crucial for short-range all-optical guiding, deflection and switching of signal beams or pulses. To our best knowledge the only way to produce odd dark beams of finite length is to use computer-generated hologram (CGH).

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13th International School on Quantum Electronics: Laser Physics and Applications,
P. A. Atanasov, S. V. Gateva, L. A. Avramov, A. A. Serafetinides, eds., Proc. of SPIE Vol. 5830
(SPIE, Bellingham, WA, 2005) · 0277-786X/05/$15 · doi: 10.1117/12.618469

2. THEORETICAL ANALYSIS

CGHs producing mixed phase dislocations are shown in Fig. 2. Characteristic for such holograms are interference lines shifted along an imaginary line of finite length and curved lines limiting the dislocations.

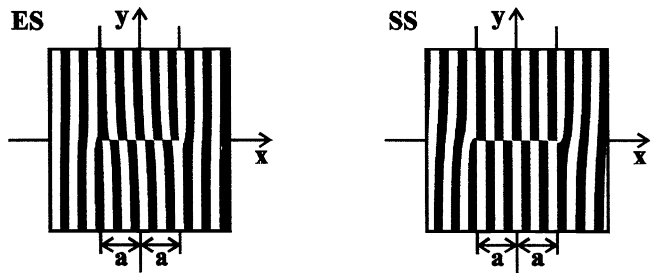


Fig. 2. CGHs generating ES and SS dislocations, respectively.

The transmission function of the both types of CGHs can be written in the form

$$T(x,y) = \sum_{n=-\infty}^{\infty} C_n e^{in\frac{2\pi}{d}x} e^{in\varphi(x,y)}, \tag{1}$$

where *d* is the period of the grating and φ(x,y) depends on the type of the dislocation (ES or SS). For binary holograms the coefficients $C_n = \frac{\sin n(\pi/2)}{n\pi}$. The phase distributions for ES and SS are

$$\varphi^{ES}(x,y) = \frac{\Delta\varphi}{\pi}\left[\arg(x+a+iy) + \arg(x-a-iy)\right] \tag{2}$$

and

$$\varphi^{SS}(x,y) = \begin{cases} -\Delta\varphi/2, & y \geq 0 \quad -a \leq x \leq a \\ \Delta\varphi/2, & y \leq 0 \quad -a \leq x \leq a \\ \frac{\Delta\varphi}{\pi}\arg(-x-a-iy), & x \leq -a \\ \frac{\Delta\varphi}{\pi}\arg(x-a-iy), & x \geq a \end{cases}, \tag{3}$$

respectively. The transmission in first-order diffraction is described by

$$T(x,y) = \frac{1}{\pi} e^{i\frac{2\pi}{d}x} e^{i\varphi(x,y)}. \tag{4}$$

We presume that the transverse profile of the illuminating wave in front of the CGH is Gaussian

$$E(x_0,y_0) = e^{-\frac{x_0^2+y_0^2}{\sigma_0^2}} e^{-i\frac{2\pi}{d}x_0}, \tag{5}$$

where the phase multiplier is added to reflect that the first-order diffracted beam propagates perpendicular to the hologram. The field just behind the CGH is

$$E(x_0, y_0) = e^{-\frac{x_0^2+y_0^2}{\sigma_0^2}} e^{i\varphi(x,y)} . \tag{6}$$

In the last equation φ(x,y) is the phase profile of the mixed dislocations.

We investigate the evolution of the field using the Fresnel diffractions integral

$$E(x, y, s) = \frac{e^{i\frac{2\pi}{\lambda}s}}{i\lambda s} \iint E(x_o, y_o, 0) e^{i\frac{\pi}{\lambda s}[(x-x_o)^2+(y-y_o)^2]} dx_o dy_o . \tag{7}$$

For ES and SS type dislocations we become

$$E^{ES}(x_s, y_s) = \int_0^\infty\int_0^\infty e^{-u^2-v^2} e^{i\frac{1}{s}(u^2+v^2)} \cos(2\sqrt{1+\frac{1}{s}}\, x_s u) \times$$
$$\cos\left\{2\sqrt{1+\frac{1}{s}}\, y_s v + \frac{\Delta\varphi}{2\pi}\left[\arg(u+a-iv)+\arg(u-a+iv)\right]\right\} du dv \tag{8}$$

and

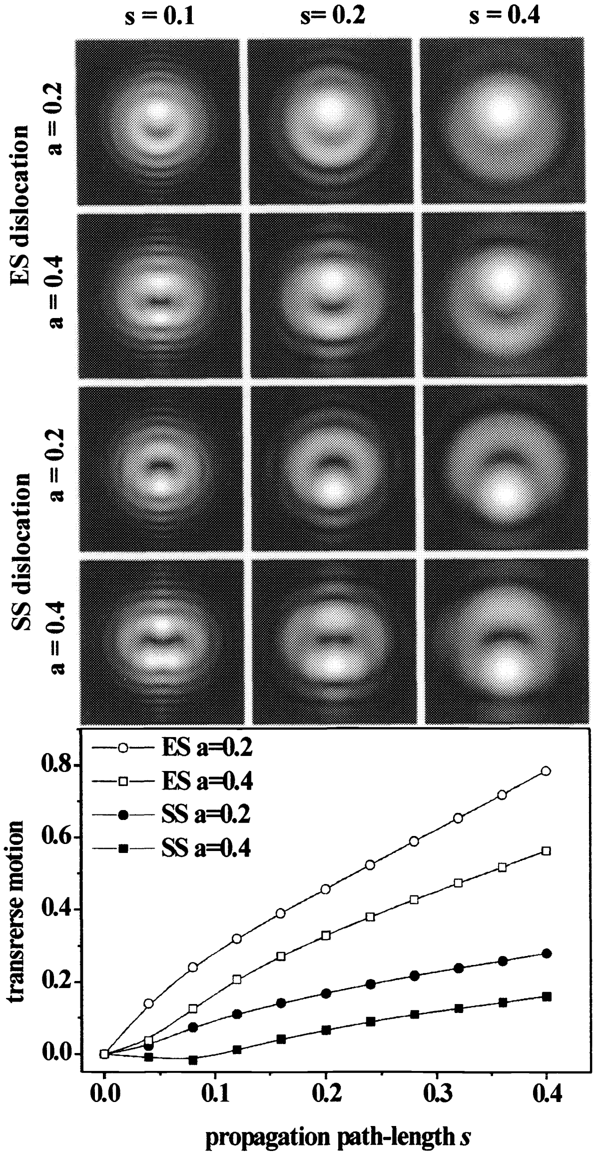
$$E^{SS}(x_s, y_s) = \int_0^a\int_0^\infty e^{-u^2-v^2} e^{i\frac{1}{s}(u^2+v^2)} \cos(2\sqrt{1+\frac{1}{s}}\, x_s u) \cos(2\sqrt{1+\frac{1}{s}}\, y_s v + \frac{\Delta\varphi}{2}) du dv +$$
$$e^{-i\frac{\Delta\varphi}{2}} \int_a^\infty\int_0^\infty e^{-u^2-v^2} e^{i\frac{1}{s}(u^2+v^2)} \cos(2\sqrt{1+\frac{1}{s}}\, x_s u) \cos\left[2\sqrt{1+\frac{1}{s}}\, y_s v + \frac{\Delta\varphi}{\pi} \arg(u-a+iv)\right] du dv , \tag{9}$$

where $u=x_0/\sigma_0$ and $v= y_0/\sigma_0$ are dimensionless transverse coordinates, x_s and y_s are measured in units of $\sigma_s = \sigma_0\sqrt{1+\frac{1}{s}}$ and the propagation length s is normalized to the Rayleigh diffraction lengths $\pi\sigma_0^2/\lambda s$.

3. NUMERICAL SIMULATIONS

It is shown[4] that one can effectively control the inherent steering dynamics of odd dark beams of finite length by varying both the magnitude and the relative length of the mixed phase dislocations. In Fig. 3 we show grayscale images of ODBs with ES and SS mixed dislocations after propagation path-lengths s=0.1, 0.2, and 0.3 for different values of the dislocation length $2a$. As seen in the comparative 2D plot, after the initial evolution stage the ODB deflection appears to be of a well-expressed linearity vs. s. The transverse dynamics of the ES dark beams was found to be much faster as compared to the dynamics of the ODBs with SS dislocations.

In Fig. 4 we present results on the phase control of the steering of ODBs. The evolution of both types of mixed phase dislocations is modeled under comparable initial conditions. In qualitative agreement with the experimental observation in nonlinear regime[4], the ODB steering increases with decreasing the magnitude of the phase jump and the dependence is linear. The difference in the steering dynamics of ODBs with different phase profiles it is due to the presence (in the ES case) or absence (in the SS case) of phase gradients across the one-dimensional portion of the dislocation.



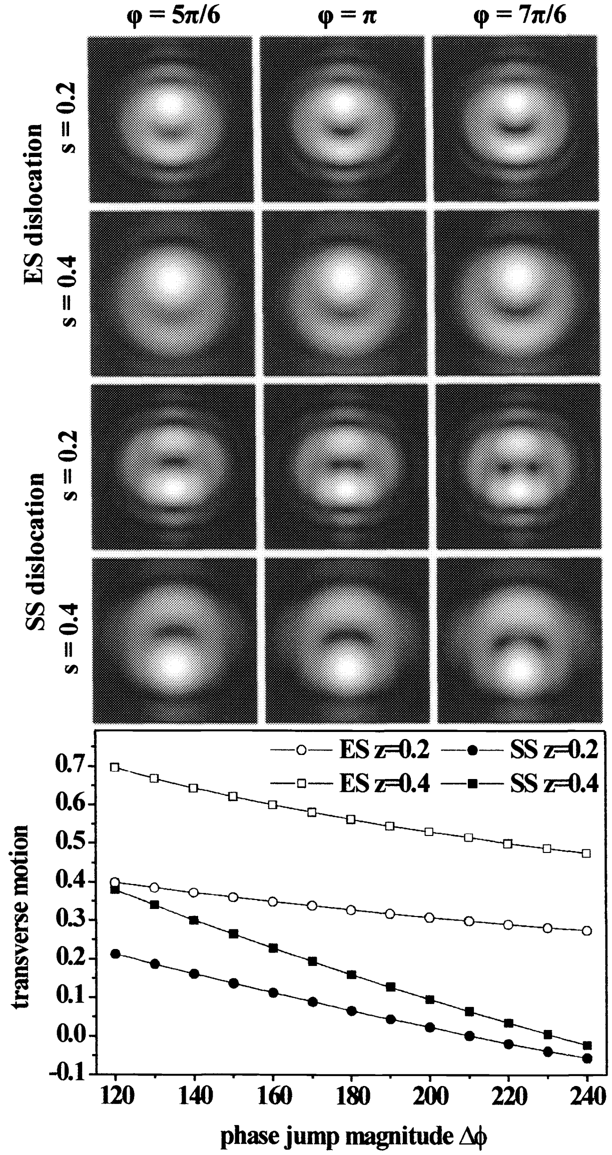


Fig. 3. Grayscale frames presenting the evolution of ES (upper two rows) and SS dislocations (lower rows) for different values of the dislocation length *2a*. The dependencies of the beam steering on the length and the type of dislocations are shown in a 2D plot

Fig. 4. Grayscale frames showing the dependence of the dislocation position on the magnitude of the phase jump for different distances *s* behind the CGH. The dislocation length *2a* = 0.8. 2D plot - comparison between the dependencies

The presence of phase gradients is even stronger pronounced when two dislocations of finite length are simultaneously nested on the background beam. In Fig. 5 we show results obtained for counterpropagating pairs of ES and SS dark beams after comparable propagation path lengths. It is interesting to note, that instead of annihilation of semi-vortices the dislocations decay into ordered structure of vortices with integer topological charge (at s=0.4 and 0.8 for ES and SS beams, respectively). In the far field, however, the mixed phase dislocations recover, but rotated at 90^0. It is natural to expect that the rotation is due to the influence of the Guoy phase but this point will be further clarified.

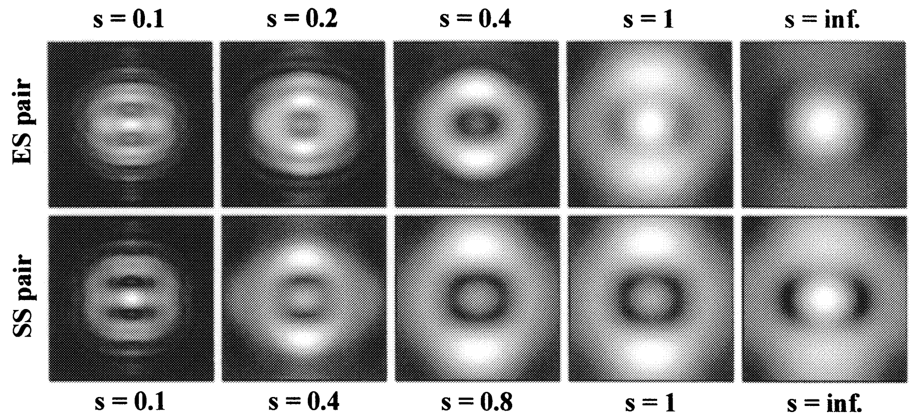


Fig. 5. Evolution scenario of two ES (uper row) and two SS dislocations (lower row). The initial distances between the dislocations are equal to their length 2a = 0.8.

CONCLUSION

The results of extended numerical simulations in purely linear regime can be summarized as follows: The transverse velocities $V_\perp$ of odd dark beams with mixed phase dislocations depend on both the dislocation type and length and are constant after certain initial evolution stage. Under comparable initial conditions $V_\perp^{ES} > V_\perp^{SS}$ and in both cases $V_\perp$ decreases with increasing the dislocation length *2a*. The transverse velocities $V_\perp$ are linear and decreasing functions of the magnitude of the phase jump $\Delta\Phi$. In the interaction of counterpropagating ODBs with mixed phased dislocations we observed decay into four optical vortices with alternatig topological charges and recovering and rotation (at 90^0) of the structure in the far field.

ACKNOWLEDGMENT

This work was supported by the National Science Fund (Bulgaria), under contract F-1303/2003.

REFERENCES

1. J. F. Nye, M. V. Berry, "Dislocations in wve trains," Proc. R. Soc. London **A 336**, pp. 165-190 (1974).
2. V. Bazhenov, M. Soskin, M. Vasnetsov, " Screw dislocations in light wavefronts," J. Mod. Opt. **39**, pp. 985-990 (1992); I. Basistiy, V. Bazhenov, M. Soskin, M. Vasnetsov, " Optics of light beams with screw dislocations," Opt. Commun. **103**, pp. 422-428 (1993).
3. A. Dreischuh, G. G. Paulus, F. Zacher, "Steering one-dimensional odd dark beams of finite length," Appl. Phys. **B 69**, pp. 113-117 (1999); A. Dreischuh, G. G. Paulus, F. Zacher, I. Velchev, "Quasi-two-dimensional dark spatial solitons and generation of mixed phase dislocations," Appl. Phys. **B 69**, pp. 107-111 (1999).
4. A. Dreischuh, D. Neshev, G. G. Paulus, H. Walther, "Experimental generation of steering odd dark beams of finite length," J. Opt. Soc. Am. **B17**, pp. 2011-2017 (2000).