NEAR AND FAR FIELD OPTICAL PATTERNS FORMATION BY ROTATIONAL SYMMETRY MASKS: APPLICATION TO OPTICAL SPATIAL SOLITON GENERATION

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In this report we present the formation of necklace type optical beams from Gaussian beam by rotational symmetry masks. The detailed studies of space evolution of the optical beam formation from the near field to the far field by the use of 7-fold symmetry mask and a single mode laser beam were performed. Different types of necklace beams with different numbers of “pearls” periodically or quasi-periodically situated along the different radii rings were observed during the space evolution of the optical diffraction pattern.

Keywords: Laser; diffraction; pattern formation; necklace type beams; optical soliton.

1. Introduction

The existence and stability of 1D and 2D spatial optical solitons - self trapped optical beams of finite spatial cross-section that travel without the divergence, are the subject of increased interest due to the numerous possible applications, particularly, for controlling of optical beam propagation, in telecommunication systems, for all optical switching etc. Many properties of optical solitons that cannot be observed in bulk uniform nonlinear media have been discovered in nonlinear planar waveguide¹, in nonlinear medium with ring-shaped² and square photonic lattices³. Another way to form the optical solitons in nonlinear medium is the use of necklace ring beams with periodically modulated intensity along the azimuthal direction^{4,5}.

In this work the formation of necklace type optical beams from Gaussian beam by rotational symmetry masks is presented. The detailed studies of space evolution of optical pattern formation from the near field to the far field by the use of 7-fold symmetry mask were performed for the first time.

2. Experiment

2.1. Preparation of Different Symmetry Masks and Testing

From 1 to 10-fold axial symmetry masks were generated by computer graphic technique⁶. The masks consisted of transparent holes periodically disposed along the equidistantly positioned concentric circles, surrounding the central hole. The number of holes on the i th circle was equaled $M_i = ji$, where $i = 1, 2, 3, \dots$ is integer and j is the symmetry order of the mask. The masks of reduced size (0.6 cm in diameter) with $i = 100$ were printed by high resolution printer (3300 dpi) on the transparent film. Both the positive and negative masks were prepared. The prepared negative masks had 10-60 μm distances between 10 μm transparent holes located on the opaque disk. The whole mask consisted from ~35000 holes disposed along the 100 hypothetical concentric circles.

The far field diffraction patterns from these masks were studied by both red 633nm and green 532 nm single mode laser beams. The far field diffraction patterns from 2, 3, 4 and 7-fold symmetry masks obtained by green single mode laser beam were presented in⁶. Here we present the results of the far field diffraction patterns obtained with the use of 5, 6, and 9-fold symmetry masks, as well as the detailed studies of space evolution of diffraction pattern for 7-fold symmetry mask.

2.2. Experimental set-up for observation of space evolution of diffraction pattern by the use of 7-fold symmetry mask

For the observation of space evolution of optical pattern formation from the near field to the far field we used the following experimental set-up (Fig.1). The single mode 633 nm laser beam with 17.7mW power was used to observe space evolution of diffraction

pattern by the use of 7-fold symmetry mask. The laser beam was expanded by confocal lenses and illuminated the mask. CCD camera was placed on the table with the possibility of fine moving.

Fig.1. Experimental set-up: 1 –laser, 2,3 –lenses, 4- mask, 5- CCD camera.

Fig.2 shows the fragment of 7-fold rotational symmetry mask. Fig.3 a-d show examples of optical diffraction patterns obtained by red 633 nm single mode laser beam at different distances from the 7-fold symmetry mask.

Fig.2. Fragment of 7-fold symmetry mask.

Fig.3. (a)-(d) Space evolution of diffraction pattern in the direction Z of beam propagation at different distances from the mask, $Z = 43, 63, 113, 243$ cm, respectively. The radii of the rings along which the “pearls” are disposed increase with the increase of the distance from the mask. The scale of 1 cm in the (a) is two times larger compared with (b), and four times larger compared with (c). The scale on (d) corresponds to 2.5 cm.

Diffraction patterns show the evolution from 7 to 14 “pearl” necklace beams at the distances of 43, 63 and 113 cm Fig.3 (a-c), respectively. Fig.3a shows the formation of seven “pearl” necklace beam. Fig.3b shows the periodically disposed double “pearls” and Fig. 3c shows 14 “pearl” necklace beam. The radii of the rings along which the “pearls” are disposed increase with the increase of the distance from the mask. The diffraction pattern does not change further after distance of 243 cm from the mask in the far field Fig.3d.

2.3. Formation of necklace-type beams by far-field diffraction from 5,6 and 9-fold symmetry masks

Here we present the far field diffraction patterns obtained with the use of 5, 6 and 9-fold rotational symmetry masks shown in Fig.4 (a-c). Fig.4d shows the far field diffraction

pattern obtained from 5-fold symmetry negative masks by red 633 nm 17 mW single mode laser beam. Fig.4 e,f show the diffraction patterns obtained from 6 and 9-fold symmetry positive masks by a single mode green 532 nm 50 mW laser beam.

When the masks were illuminated by Gaussian beam the observations showed that for even symmetry masks the rotational symmetries of mask and far field diffraction pattern from the mask were the same (see Fig.4b,e). However, for odd symmetry masks the symmetry of diffraction pattern is twice as high compared with the the symmetry of the mask (Fig.2 and Fig.3 c,d, and Fig.4 a,d). The same results were obtained for 2,3 and 4-fold rotational symmetry masks ⁶.

Fig.4d shows 10 “pearl” double ring necklace beam from 5-fold symmetry mask and Fig. 4f shows 18 “pearl” single ring necklace beam from 9-fold symmetry mask, whereas the Fig. 4 e shows 6-fold symmetry diffraction pattern from 6-fold rotational symmetry mask.

Fig. 4. Fragments of 5, 6 and 9-fold rotational symmetry masks (a,b,c) , and far field diffraction patterns (d,e,f) obtained from 5, 6 and 9 fold symmetry masks, respectively, by red 633nm (d) and green 532 nm (e,f) laser beams. The symbol J on the bottom of masks notes the rotational symmetry order of the masks.

3. Numerical simulations of diffraction patterns from rotational symmetry masks

Numerical simulations of diffraction patterns from different symmetry masks were performed. Fig.5a shows the result of simulations of diffraction pattern from 6-fold symmetry mask (Fig.4b). The simulations were performed taking into account the mutual interference between beams diffracted from each hole. For comparison the experimentally obtained diffraction pattern from 6-fold symmetry mask by red 17 mW laser beam also is shown in Fig. 5b. The comparison between experimental results and simulations shows the perfect coincidence.

Fig. 5. (a) Results of numerical simulations of far field diffraction pattern from 6- fold rotational symmetry mask, the fragment of which is shown in Fig. 4(b). (b) Experimentally obtained far field diffraction pattern from 6-fold symmetry mask by red laser beam.

The simulations of space evolution of diffraction patterns from different rotational symmetry masks are under way and will be published elsewhere.

4. Conclusions

The formation of necklace type optical beams from Gaussian beam by rotational symmetry masks was observed. The detailed studies of space evolution of optical patterns formation from the near field to the far field by the use of 7-fold symmetry mask were performed and showed the formation of different types of necklace beams with different

numbers of “pearls” periodically or quasi-periodically situated along the different radii rings.

The far field necklace type beam patterns from 5, 6 and 9-fold rotational symmetry masks were also observed. The numerical simulation of the far field diffraction pattern from 6-fold rotational symmetry mask was performed and showed perfect coincidence with experimental results.

The necklace beams can be used for the formation of spatial optical solitons in nonlinear solid crystals, such as lithium niobate, lithium tantalate, strontium barium niobate, in liquid crystals and in resonant atomic media.

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