Investigation the Possibility of Obtaining Spiral Light Beams with Adjustable Parameters

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Abstract— We present a method of generation of beams with the spiral intensity distribution in the direction of propagation. The maximum intensity of the interference pattern of a Gauss beam and a co-propagating beam with a wavefront dislocation forms a spiral curve in the space. The numerical simulations have shown that the spiral pitch decreases with the Bessel beam of the first order divergence increasing, the stable length of the spiral decreases with the Gauss beam divergence decreasing. The proposed method was tested experimentally.

1. INTRODUCTION

Chiral photonic structures are promising material for light parameter controlling. The method of the holographic lithography can be used for chiral structure production, but beams with spiral intensity distribution in the direction of propagation are needed [1, 2]. In addition beams with the desired distribution of intensity, wave front and polarization are useful for microparticle manipulation [3], nondestructive optical testing and investigation, surface treatment and laser welding [4–9]. The spiral beam is known as beam, whose intensity remains the same to within scale and rotation as they propagate [9].

Here we propose another kind of spiral beams whose intensity has got three dimension spiral intensity distribution in the direction of propagation. The interference pattern of two beams one of which has got a phase singularity forms spiral intensity distribution in the direction of propagation. The question arises, is it possible to choose the proper parameters of the beams in order to form the stable spiral intensity distribution in the direction of propagation.

2. BEAM INTENSITY DISTRIBUTION CALCULATION

In order to generate the light beam with the spiral structure along the direction of propagation, we propose the interference scheme shown in Fig. 1. The Bessel Gauss beam with the phase singularity of the first order and the Gauss beam were co-propagating. The interference pattern was calculated at the lens focal waist. To obtain the intensity distribution in the focal waist we solved the wave equation [10]. The obtained intensity distribution is shown in Fig. 2. One can see from Fig. 2 that the bright intensity spot rotates around the propagation direction forming a three dimensional helix. It is turned out that the helix radius and pitch can be changed by the interfering beams parameters change. The calculations were performed for the waist diameter of the Gauss beam equals 0.5 mm. It can be seen from Fig. 3, that the pitch of spiral decreases from 15 mm to 3 μm along with increasing of the Bessel-Gauss beam divergence angle.

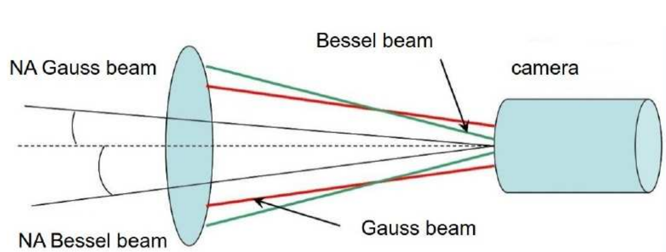

Figure 1: The interference scheme of the co-propagating Gauss beam and Bessel beam of the first order.

The dependence the spiral length on the Gauss beam divergence angle on is shown in Fig. 2. Increasing of the Gauss beam divergence angle leads to decrease of the spiral lenght from 9.5 mm to 3 mm.

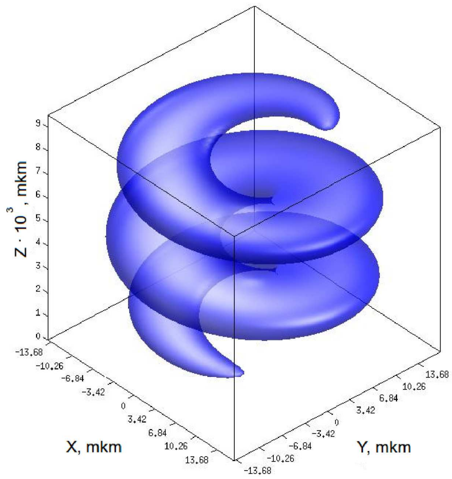

Figure 2: Spiral intensity distribution along direction of propagation of the beam under consideration.

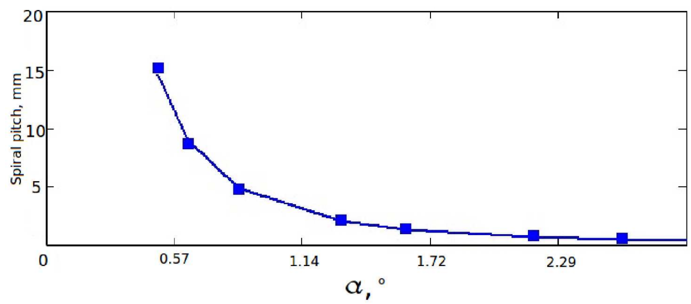

Figure 3: The dependence of the spiral pitch on Bessel-Gauss divergence angle.

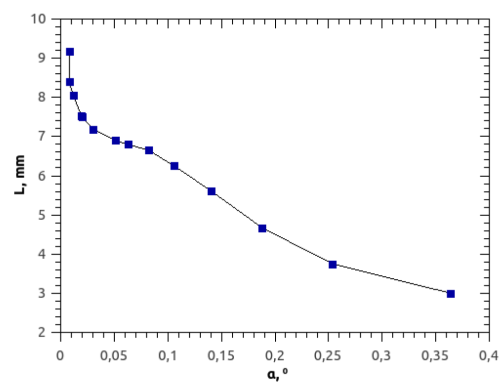

Figure 4: The dependence of the stable spiral length on the Gauss beam divergence angle.

3. EXPERIMENTAL RESULTS

The spiral light beam was obtained experimentally. The experimental setup was the Mach-Zender interferometer with HeCd laser ($\lambda = 441\,\text{nm}$). The Bessel-Gauss beam was obtained in the one of interferometer arm by means of the laser beam diffraction by an amplitude gradient grating. The set of the beams were observed after diffraction. The first order diffraction beam with the phase singularity was selected by a pinhole. The Bessel-Gauss divergence angle, the radius of the Bessel-Gauss and the length of the waist were chosen in such a way to form macroscopic intensity distribution suitable for experimental investigations. The intensity distribution in the beam different transverse crosssection in the direction of propagation was registered by a CCD-camera. An objective with magnification of 8x was used to project the transverse sections at the CCD matrix. Fig. 6 demonstrate the helix intensity distribution, where the stable spiral length $L = 100\,\text{mm}$, spiral pitch $h = 100\,\text{mm}$.

One can see from experimental results that the bright intensity spot rotates around the propagation direction forming three dimensional helix. The experimental results coincide with the calculated ones.

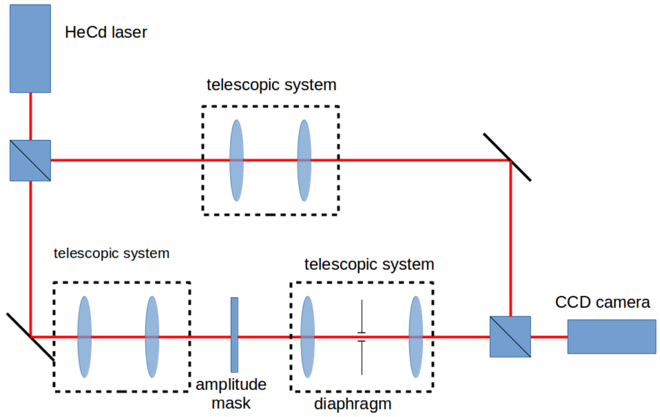

Figure 5: Experimental setup.

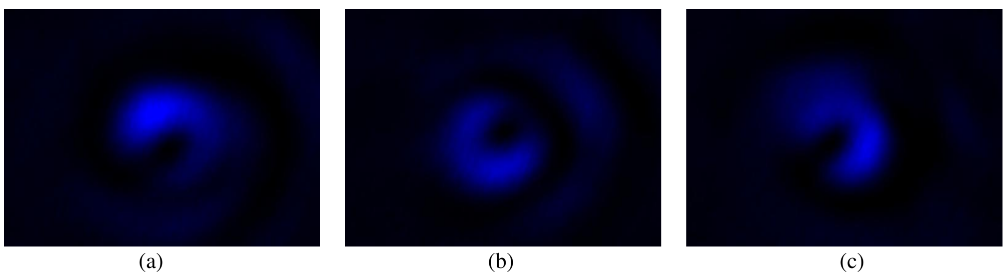

Figure 6: The intensity distribution in the cross section of the spatial spiral at the different length from the focal plane: (a) $L = -50$ mm, (b) $L = 0$ mm, (c) $L = 50$ mm.

4. CONCLUSION

The method for generation of a new kind of beams with 3D spiral intensity distribution in the direction of propagation was presented. It was proven, that the spiral pitch and the spiral length depends on the Bessel and the Gauss beam divergence, correspondingly. The spiral beam was obtained experimentally. The parameters of the beam coincided with theoretically calculated parameters.

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