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Fabrication of diffraction gratings for generation of OAM light

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Abstract. In this work we describe fabrication of diffraction gratings for generation of light with orbital angular momentum (OAM). OAM light characterized by topological charge l and modes with different l are orthogonal, which makes OAM light useful in quantum communication and tomography. We demonstrate fabrication route of diffraction gratings with computer generated hologram pattern on sapphire substrate and niobium reflective coat for generation of OAM light of visible spectrum.

Keywords: orbital angular momentum (OAM), vortex light, computer-generated holograms (CGH)

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Материалы конференции
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Изготовление дифракционных решеток для генерации света с орбитальным угловым моментом

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Аннотация. В данной работе рассматривается изготовление дифракционных решеток для генерации света с угловым орбитальным моментом (ОУМ), ОУМ свет характеризуется топологическим зарядом l, моды с различным значением l являются ортогональными, что делает ОУМ свет полезным в применении в квантовой криптографии и томографии. В данной работе мы описываем маршрут производства дифракционных решеток на сапфировой подложке с отражающим покрытием из нитрида ниобия для генерации света с ОУМ в видимом диапазоне.

Ключевые слова: орбитальный угловой момент (ОУМ), закрученный свет, компьютерные голограммы (CGH)

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Introduction

Light has 2 angular momentum characteristics - spin angular momentum and orbital angular momentum. Usually light has only spin angular momentum, because wave vector *k* has no component perpendicular to the direction of propagation. Light with non-zero orbital angular momentum has linear phase dependence on azimuthal angle through constant *l*, which leads to appearance of *k* component tangent to phase plane. Mode with defined *l* can be described in terms of generalized Laguerre polynomial of order l. Those modes are orthogonal which makes modes with different *l* perfectly distinguishable and allows us to use OAM light for high dimensional quantum communication [1-4] and quantum tomography. There are several ways of generating OAM light such as spiral phase plates [5], cylindrical mode converters [6], Q-plates [7], pitch-fork holograms [8]. The last method is using diffraction gratings for generating OAM light. Pattern for this holograms can be obtained by computing interference pattern of OAM light and plane wave. Then we can load those patterns on SLM and use it as diffraction grating, which allows to change patterns very fast [9]. But also we can just make solid diffraction gratings out of some transparent material with reflective coat material. This method has advantages over SLM because of accuracy of pattern of diffraction gratings, which in case of SLM is limited by size of micro mirrors which are used to modulate intensity.

Fabrication route of diffraction grating

Firstly, we need to compute pattern for diffraction grating. For this we need to calculate interference pattern of OAM light and plane wave. Circle mask was applied on initial waves phase distributions and therefore pattern has circular form. OAM and plane wave must be represented just by their phase terms, not taking into account spatial amplitude distribution (1).

$$I(x,y) = \left| e^{i\vec{k}\cdot\vec{r}} + e^{il\theta} \right|^2. \quad (1)$$

The plane wave must be at some angle relative to OAM light to form strip structure. Amplitudes of OAM and plane wave must be equal for high contrast of the pattern. As substrate for gratings double polished sapphire was used and NbN was used as reflective coat. Width of sapphire is 400 μm (±5%) and width of NbN is 60 nm. NbN was deposed by magnetron deposition in nitrogen atmosphere and then was etched in SF6/Ar plasma forming diffraction pattern. The darkest parts of interference picture in Fig. 1 were etched, therefore gratings were designed for transmission diffraction.

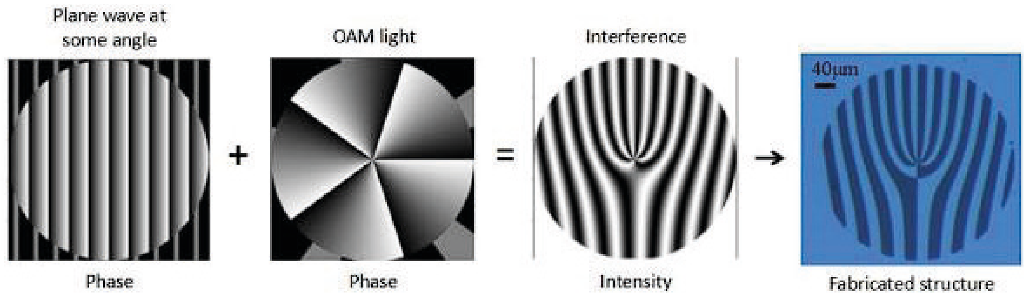

Fig. 1. Computing of hologram pattern and fabricated diffraction grating for $l = 5$

Fabricated structure

We fabricate array of diffraction gratings on sapphire plate. On the structure we arrange 12 fork-diffraction gratings for different number of l and with different grating period. Periods of 20 μm and 30 μm represented. Several periods were made for testing how it will affect generation of OAM. It can be seen from the micrograph in Fig. 1 that the pattern was produced accurately and all irregularities are order of wavelength and can't affect diffraction pattern.

Simulation

We perform computer simulations in order to calculate how the gratings generate OAM. To simulate the process of light propagation, we use a plane wave with constant intensity as the initial wave. Then the intensity of the plane wave is multiplied by spatial grating pattern. Afterwards, we use fast Fourier transform to calculate far-field intensity. Calculation results are provided in Fig. 2. Then intensity plane was multiplied by grating pattern to simulate propagation through plane. Then we use fast Fourier transform to calculate far field intensity. Results of simulations provided in Fig. 2. Topological charge $l = 5$ is chosen for simulation. It can be seen that in the center of intensity plane picture we have gauss beam with $l = 0$. Also we have two OAM beams with $l = 5$ and $l = -5$ at the first orders. The fact that charges are opposite can be proven by phase diagram in Fig. 2,*a*. We can see two helical phase fronts, which are twisted in opposite directions, which means that charges are opposite, because charge defines direction of rotation of phase front. Phase diagram also shows us that $l = 5$ (by absolute value) because of shape of

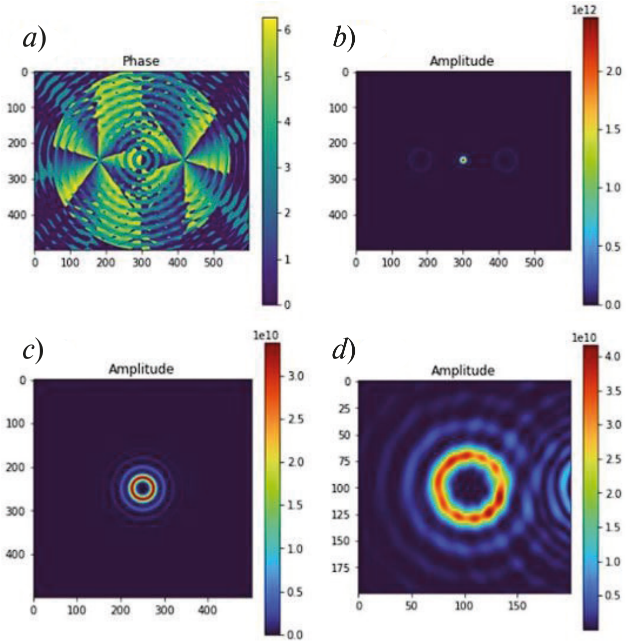

Fig. 2. Phase profile of the OAM light generated by grating (*a*), intensity profile of the OAM light generated by grating (*b*), ideal OAM light generated by simulation without grating (*c*), enlarged picture of OAM mode with $l = 5$ generated by grating (*d*)

phase front of OAM beams, it has exactly 5 periodically changing regions, which is evidence of helical shape of phase front. Fig. 2,*c* shows the intensity profile of beam with $l = 5$ is provided. Fig. 3,*d* shows enlarged intensity profile of beam with $l = 5$ generated by gratings. It can be seen that profiles look the same which also proves that needed charge was obtained. Also we need to comment that circle mask was used during simulation and therefore in Fig. 2,*a* we can see circle and region with zero phase.

Simulation of generation of OAM light with $l = 5$ was also provided for larger field of screen to see other orders of diffraction and check if they appear. In this case we did not use circular mask to see all orders and not nullify them. Results of simulation can be seen in Fig. 3. It can be seen from Fig. 3,*a* that phase still periodically changes with azimuthal angle, corresponding to $l = 5$, but phase profile for higher orders has more difficult structure which can be explained by overlapping of different orders. As l grows the radius of the beam also grows while distance between orders stays the same, therefore overlapping occurs which leads to interference of different orders. The overlapping can be also seen from Fig. 3,*b* where second order interfering with first order leading to appearance to interference strips between orders. The possible overlap is not good for generation because we may need to use different orders of OAM light from one grating. To prevent this situation, we may just use more strips in grating which can be done by increasing angle between plane wave and helical phase front during computation of diffraction pattern.

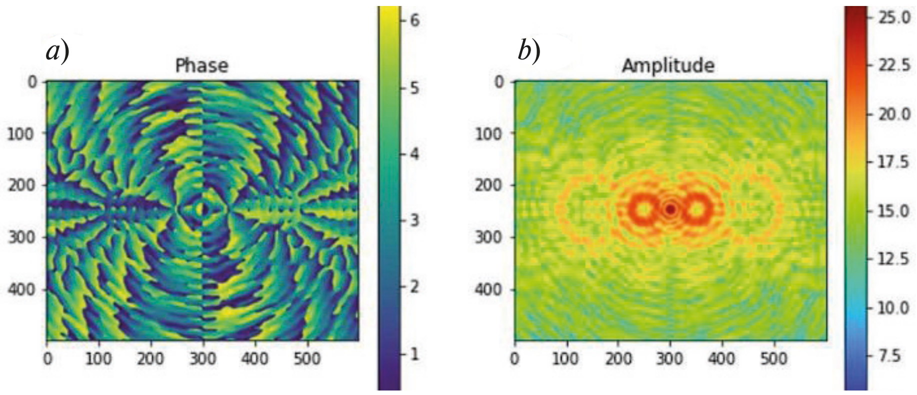

Fig 3. Phase profile of OAM light after grating (*a*),
intensity profile of OAM light after grating in logarithmic scale (*b*)

Conclusion

We have designed and fabricated a set of holographic diffraction gratings for generation of light with orbital angular momentum. We confirmed both in computer simulations and experiment that gratings with different periods and patterns produce the desired topological charges. Our work has great potential for developing compact structures for generating of light with orbital angular momentum which is particularly suitable for high-dimensional quantum communications.

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