SUBWAVELENGTH GRATINGS FOR GENERATING AZIMUTHALLY POLARIZED BEAMS

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Abstract. We have experimentally investigated two binary subwavelength grating-micropolarizers that transform linearly polarized light to the azimuthally polarized beam. The first micropolarizer operates in reflective mode (for wavelength 532 nm) and was manufactured in a gold film. The second micropolarizer operates in transmitting mode (for wavelength 633 nm) and was manufactured in silicon.

Keywords: subwavelength grating, cylindrical vector beam, azimuthal polarization.

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Introduction

A significant amount of scientific papers describes investigation of beams with spatially non-homogeneous states of polarization [1]. In recent years subwavelength grating are used to obtain such beams. A subwavelength grating with properly chosen height of relief could operate as a half- (or quarter-) wave plate; meanwhile, the groove direction defines the spatial orientation of the plate [2].

As the first publications to report on the fabrication of the gratings, we may denote refs. [3,4], where a circularly polarized 10.6 μm light beam was converted into an azimuthally polarized beam. The generation of a radially polarized light beam for a subwavelength grating operating at a 1064 nm wavelength was discussed in ref. [5]. A technique for fabricating a polarization converter in silicon for wavelengths ranging from 1030 to 1060 nm was proposed in ref. [6]. Transmitting micropolarizers for the visible range were also investigated. In ref. [7] aluminum circular subwavelength grating was used to convert circularly polarized light with wavelength 633 nm into radially polarized beam. However the quarter-wave plate was manufactured in [7] and the obtained beam was not strictly radially polarized – at diametrically opposite points of the beam the electric field has the same phase, while in the real radially polarized beam electric field at these points have opposite phase. Earlier, we discussed a 4-zone grating polarizer intended to form a radially polarized beam [8], which was used to form a subwavelength focal spot of area $0.35\lambda \times 0.38\lambda$ by means of a Fresnel zone plate [9].

In our investigation we have experimentally investigated two binary subwavelength grating-micropolarizers that transform linearly polarized light to the azimuthally polarized beam. The first micropolarizer operates in reflective mode and was manufactured in a gold film. The second micropolarizer operates in transmitting mode and was manufactured in silicon.

Fabrication

The proposed reflective micropolarizer consists of four sectors (Fig. 1(a)): in the two sectors on the right, the microrelief features have a 0.46 μm period and make angles 70° and −70° with the y-axis (vertical), whereas in the sectors on the left, the features have a 0.4 μm period and make with the y-axis angles 40° and −40°. The micropolarizer has a size of 100 μm × 100 μm and the microrelief height of 110 nm. The micropolarizer was fabricated by electron beam lithography in a golden layer of thickness 160–180 nm. In the first step of fabrication a golden layer was coated onto a glass substrate, followed by applying a resist layer, on which a four-sector grating polarizer pattern was generated by an electron beam lithography (at 30 kV). Then, the sample was developed by etching with xylene, which dissolved the fragments exposed to the electron beam. Then, using reactive ion etching, the grating-polarizer pattern was transferred into the golden layer, which was etched in places with no resist. Using argon plasma, gold particles were spattered from areas unprotected with the resist. At the final stage, the resist residue was eliminated using oxygen plasma. The reactive ion etching time was optimized so as to achieve an etch depth of about 110 nm.

The transmitting micropolarizer (Fig. 1(b)) also consists of four sectors with angles -60°, 60°, -60°, 60°. The micropolarizer not only transforms linearly polarized light into azimuthally polarized beam but also adds phase shift π at diametrically opposite points of the beam. The micropolarizer was fabricated by electron beam lithography. In the first step of manufacturing a layer of amorphous silicon (130 nm) (a-Si) was coated with a resist (PMMA). The thickness of the resist was chosen optimally (320 nm). The substrate was coated by 15 nm of gold to avoid the formation of the charge on the sample surface. A four-sector grating polarizer pattern was generated by an electron beam lithography (at 30 kV). Then the substrate was developed using solution of water and isopropanol (ratio of 3:7). During this process, the gold layer was completely removed from the surface of the PMMA. Using reactive ion etching the pattern of grating-polarizer was transferred from the resist to amorphous silicon. The manufactured micropolarizer have period 230 nm, step width 138 nm, and groove width 92 nm. The size of the manufactured micropolarizer (Fig. 1b) is 100 × 100 μm.

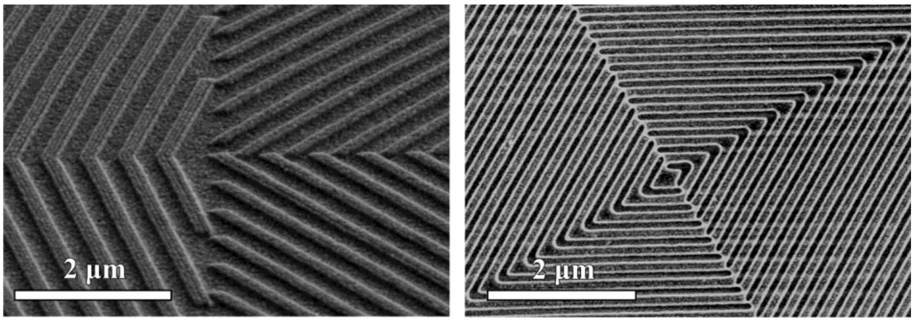

Fig. 1. A scanning electron microscope image of the central fragment of the fabricated (a) reflective and (b) transmitting micropolarizers

Experiment

Reflective polarizer

The performance of the fabricated reflective micropolarizer (fig. 1a) was experimentally tested using a linearly polarized beam of 1 mm width from a 532 nm laser. The beam was focused with a 10 × lens O_1 onto the substrate containing the grating micropolarizer. Experimental setup is shown in fig. 2. The size of the spot focused on the micropolarizer was controlled by varying the distance from the lens O_1 to the micropolarizer surface. Although in this case, the micropolarizer was not found in the beam waist and the incident wave was spherical, the experimental results we discuss below corroborate that the micropolarizer still operated in a proper way.

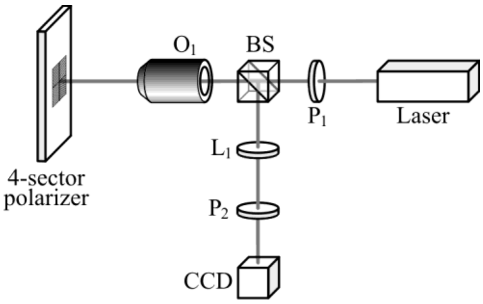

Fig. 2. Experimental setup: P_1, P_2 are linear polarizers, BS is a beam-splitter cube, O_1 is a 10× lens (NA = 0.25), L_1 is a lens ($f \approx 1.5$ cm), and CCD is a camera

Fig. 3 shows intensity of the laser beam reflected from polarizer. A linear polarizer P_2 is located before the camera; an angle between the axis of polarizer and incident light polarization equals to 0° (a), 90° (b), -45° (c) and 45° (d). Fig 3 shows that light reflected from 4-sector micropolarizer is azimuthally polarized.

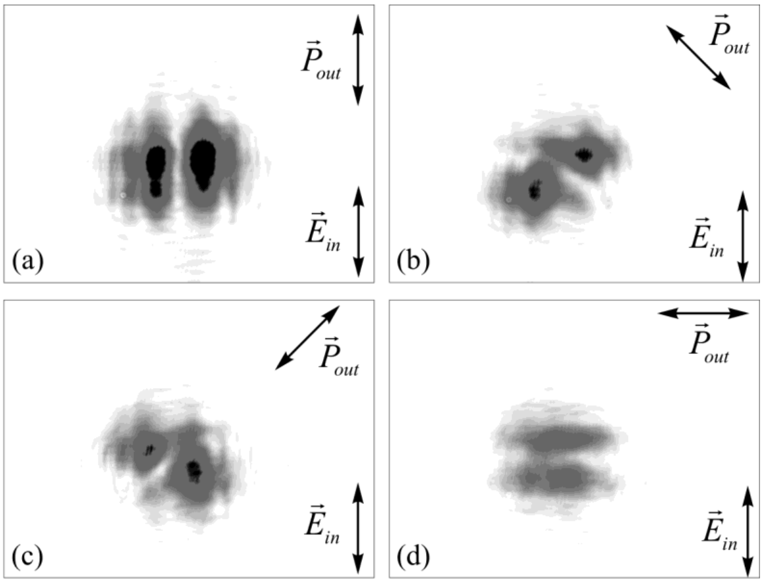

Fig. 3. Image of the laser beam reflected from polarizer (Fig. 1a) in far field. A linear polarizer is located before the camera; an angle between the axis of polarizer and incident light polarization equals to 0° (a), 90° (b), -45° (c) and 45° (d). Image size is 6.2 mm × 4.2 mm

Transmitting polarizer

The performance of the transmitting micropolarizer (Fig. 1b) was experimentally tested using a linearly polarized beam from a 633 nm laser. The beam was focused with a 40× lens O_1 onto the substrate containing the grating micropolarizer (Fig. 4). The size of the spot focused on the micropolarizer was controlled by varying the distance from the lens O_1 to the micropolarizer surface. The substrate was mounted on a movable stage, and the position of the light spot on the micropolarizer was controlled by shifts of the stage. The CCD camera image was obtained using a 20 × lens O_2. As previously, linear polarizer P_2 is located before the camera to check a polarization state of the reflected beam.

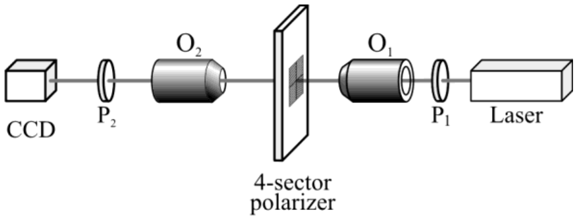

Fig. 4. Experimental setup: Laser is a He-Ne laser, P_1, P_2 are linear polarizers, O_1 is a 40× lens, and O_2 is a 10 × lens

Fig. 5 shows image of the transmitting micropolarizer in Fig. 1b in the laser light. An angle between the axis of output polarizer P_2 and incident light polarization equals to

0° (a), 90° (b), -45° (c) and 45° (d). Based on fig. 5, we can infer that the four-sector micropolarizer in fig. 1(b) converts an incident linearly polarized beam into an azimuthally polarized light beam.

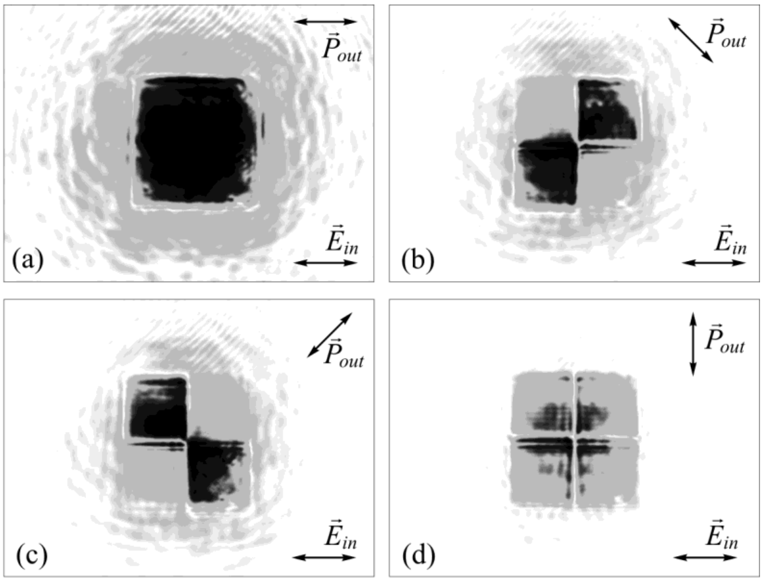

Fig. 5. Image of the micropolarizer in Fig. 1b in the laser light. In front of the camera was an output polarizer/analyzer P_2, making an angle of (a) 0°, (b) 90°, (c) −45°, and (d) 45° with the incident beam

A lens with a focal length of 24 mm was placed in front of the polarizer P_2 (in Fig. 4) to investigate the intensity distributions in the far field. Fig. 6 shows intensity of the laser beam in far field. The micropolarizer forms a peak of intensity on the optical axis. A central lobe has a circular shape, and a side lobe has a form of non-uniform ring due to the square shape of the micropolarizer. Based on fig. 6 we can infer that the micropolarizer not only convert linearly polarized light into azimuthally polarized beam but also add the phase shift π to diametrically opposite points of the beam [10-14].

Conclusions

In this work we have investigated two subwavelength gratings that transform linearly polarized light into azimuthally polarized beam. The first micropolarizer operates in reflective mode and was manufactured in a gold film. The second micropolarizer operates in transmitting mode and was manufactured in silica. It was shown experimentally the following:

1) Manufactured 4-sector reflective micropolarizer illuminated by linearly polarized light with wavelength of 532 nm forms azimuthally polarized beam in near and far field

2) Manufactured 4-sector transmitting micropolarizer illuminated by linearly polarized light with wavelength of 633 nm forms in near field azimuthally polarized beam with phase shift π at diametrically opposite points of the beam. In far field of diffraction the micropolarizer forms a central circular focal spot surrounded by a light ring.

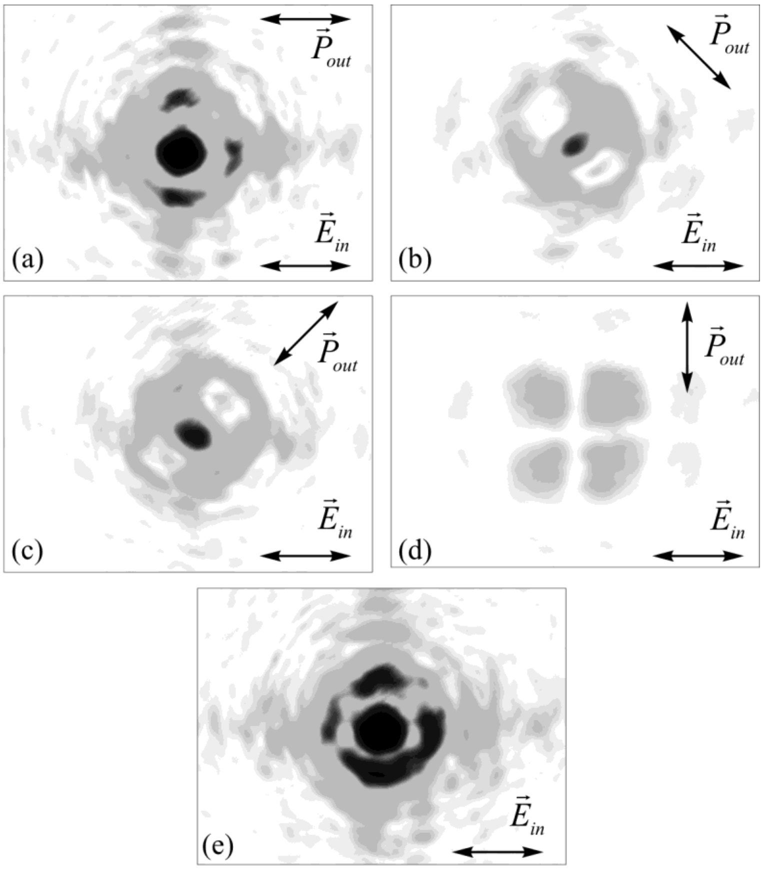

Fig. 6. Image of the laser beam transmitted through the polarizer (Fig. 1b) in far field. A linear polarizer is located before the camera; an angle between the axis of polarizer and incident light polarization equals to 0° (a), 90° (b), -45° (c) and 45° (d). Image size is 2.7 mm × 2.0 mm

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