PHASE OPTICS

Formation of Pancharatnam-Berry Phase Optical Elements With Space-Variant Subwavelength Gratings

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The Pancharatnam-Berry phase is a geometric phase associated with the polarization of light. When the polarization of a beam traverses a closed loop on the Poincaré sphere, the final state differs from the initial state by a phase factor equal to half of the area encompassed by the loop upon the sphere. In a typical experiment, the polarization of a uniformly polarized beam is altered by a series of space-invariant (transversely homogeneous) wave plates and polarizers. The phase that evolves in the time domain is measured by means of interference.

Recently, we developed novel optical phase elements based on the space-domain Pancharatnam-Berry phase.[1] Unlike diffractive and refractive elements, the phase is not introduced through optical path differences, but results from the geometric phase that accompanies space-variant (transversely inhomogeneous) polarization manipulation. We show that such elements can be realized using computer-generated space-variant subwavelength gratings. The elements are polarization dependent, thereby enabling multipurpose optical elements that are suitable for applications such as optical switching, optical interconnects and polarization beam splitting. Optical elements that use this effect to form a desired phase front are called Pancharatnam-Berry phase optical elements (PBOEs).

We introduced and experimentally demonstrated continuous PBOEs based on subwavelength gratings such as polarization beam splitters, optical switches[2] and spiral phase elements bearing various topological charges.[3] By continuously controlling the local orientation and period of the grating, we can achieve any desired phase element. Figure 1(a) illustrates the geometry of the continuous blazed PBOE, as well as the geometrical phases for incident right-hand and left-hand circularly polarized lights. Moreover, we exploited our PBOEs to demonstrate polarization Talbot self-imaging,[4] as well as nondiffracting periodically space-variant polarization beams.[5]

We also discuss a theoretical analysis and experimental demonstration of multilevel discrete Pancharatnam-Berry phase diffractive optics (multilevel PBOE).[6] The multilevel geometrical phase is formed by discrete orientation of a local subwavelength grating with uniform periodicity. By use of advanced photolithographic and etching techniques, we realized a quantized geometrical blazed polarization diffraction grating, as well as a polarization-dependent focusing lens for CO_2 laser radiation at a wavelength of 10.6 μm on GaAs substrates. The magnified geometry of the multilevel blazed polarization grating for a number of discrete levels, N=4, is presented in Fig. 1(b), as is the predicted geometrical quantized phase distribution for incident left-hand circularly polarized light. Figure 1(b) also shows the measured and predicted diffraction efficiency for first diffracted order for the different multilevel PBOEs. The excellent agreement between the experimental results and the predicted efficiency confirms the expected multilevel discrete binary phase. In addition, we formed a multilevel Pancharatnam-Berry diffractive focusing lens which had a multilevel discrete spherical phase function with number of discrete levels N=8 [see Fig. 1(c)]. As predicted, the measured diffraction efficiency was 94.5% ± 1%, which indicated that high diffraction efficiency can be attained by use of a single binary computer-generated mask. The PBOEs will advance a variety of applications in modern optics, especially in the area of nano-optics.

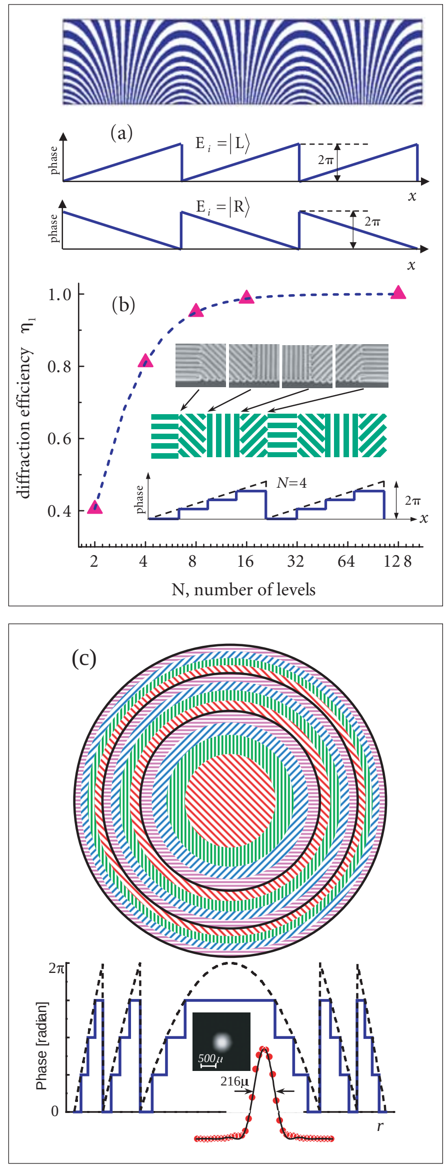

Figure 1. (a) Magnified geometric representation of continuous blazed polarization diffraction grating and geometrical phases for incident right-hand $|R\rangle$ and left-hand $|L\rangle$ circularly polarized light. (b) Magnified geometry of multilevel blazed polarization diffraction grating for number of discrete levels, N=4, as well as predicted geometrical quantized phase distribution for incident left-hand circularly polarized light, and scanning electron microscopy images of some regions of the grating. Measured (*triangles*) and predicted (*dashed curve*) diffraction efficiency as a function of the number of discrete levels, N. (c) Magnified geometry of a multilevel-PBOE focusing lens with N=4, as well as predicted multilevel geometrical phase. Image of diffraction-limited focused spot size as well as the measured (*dots*) and theoretically calculated (*solid curve*) cross section.

References

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