DOCTORAL THESIS

Photonic Metasurfaces for Nonlinear Optical Holography

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Abstract

Photonic metasurface, the quasi-two-dimensional platform, provides flexible control of phase, amplitude, polarization, and other fundamental properties of the light by the elegant design of the constituent artificial structures or so-called meta-atoms. This novel platform makes it more practical to realize optical holography, which has been widely applied in the research fields including three-dimensional image display, bioimaging, optical anti-counterfeiting, and so on. Yet, most applications of photonic metasurface have focused on its linear optical region, while less attention has been paid to its nonlinear counterpart. Recently, the generation of nonlinear optical holography that manipulates light-field with extra degrees of freedom through the frequency conversion processes has been achieved. The development of photonic metasurfaces containing subwavelength meta-atoms is the focus of this thesis to modulate the phase, amplitude, polarization, and frequency of light. In this thesis, we demonstrated photonic metasurfaces with multiple functionalities including real-space and Fourier space images encryption, vortex beam generation, and display of vectorial holographic images. To emphasize, these demonstrations of metasurfaces were generated in the second harmonic generation (SHG) process and utilizing the linear or nonlinear geometric phase.

In this thesis, a review of advances and applications of linear and nonlinear metamaterials and metasurfaces is presented at the beginning. Then a brief introduction to harmonic generations is given. In Chapter 2, the experimental methods of nanofabrication and the optical measurement that are essential in the demonstration of photonic metasurfaces in this thesis were described.

In Chapter 3, we designed and fabricated the nonlinear diatomic

metasurfaces for displaying images in both real and Fourier spaces. The photonic metasurface for nonlinear optical holography is built on the nonlinear geometric phase of plasmonic meta-atoms with three-fold rotational symmetry. We experimentally verified the phase and amplitude control of the diatomic metasurface for holographic images display in the SHG process.

In Chapter 4, we proposed a hybrid platform, dielectric decorated nonlinear optical crystal, to seek a route for nonlinear optical holography with potentially high-frequency conversion efficiency. We simulated and fabricated dielectric metasurfaces on the nonlinear crystals with diffraction efficiency up to ~ 68%. Then we characterize the optical properties of two nonlinear optical crystals. From the design of the dielectric metasurface decorated optical crystal, we experimentally demonstrate the vortex beam generation and holographic image display in the SHG process.

In Chapter 5, we proposed the plasmonic quad-atom metasurface stem from the first work to display holographic images with vectorial polarization distribution. Based on the superposition of two circularly polarized light, the quad-atoms metasurfaces that enable the ability to control the phase and amplitude of second harmonic waves can display holographic images with an arbitrary polarization state. Moreover, we adopted the modified phase retrieve algorithm to design the metasurface hologram which can reconstruct the image with arbitrary polarization and intensity distributions.

The presented approaches in this thesis may attract more interest in the investigation of metasurface for nonlinear optics and would have applications in the fields of optical information storage, nonlinear structured light source, and so on.