Holographic fabrication of graded photonic super-crystals using spatial light modulator

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Abstract: Using the pixel-by-pixel phase engineering in a spatial light modulator together with reflective optical element, we have studied holographic fabrication of graded photonic super-crystals with a square lattice in square and hexagonal symmetries.

OCIS codes: (230.6120) Spatial light modulator; (220.4000) Microstructure fabrication

Very recently, we have studied holographic fabrication of a new type of photonic crystals: titled graded photonic super-crystals (GPSC) [1,2]. The GPSC has a graded basis in the unit super-cell. To fabricate GPSCs, the spatial light modulator (SLM) phase pattern was designed to produce outer beams with high diffraction efficiency and inner beams with low diffraction efficiency. A supercell of 24-pixel by 24-pixel area as indicated by the solid blue square in Fig. 1(a) was tiled across a 1920×1080 image. The basis units of the phase pattern consist of SLM pixels (8×8 μm^2) with gray levels 158, 192, or 254. The gray level of 158 or 192 was combined with 254 in a checkerboard fashion, as shown in Fig. 1(b), to form 12-pixel by 12-pixel "supercell subunits" with size indicated by the solid red square in Fig. 1(a). These supercell subunits were then also tiled in a checkboard fashion to produce the overall image displayed on the SLM. When a 532 nm laser was incident to the phase pattern, two sets of diffraction spots were produced from the SLM. These eight beams form the interference pattern as simulated in Fig. 1(c).

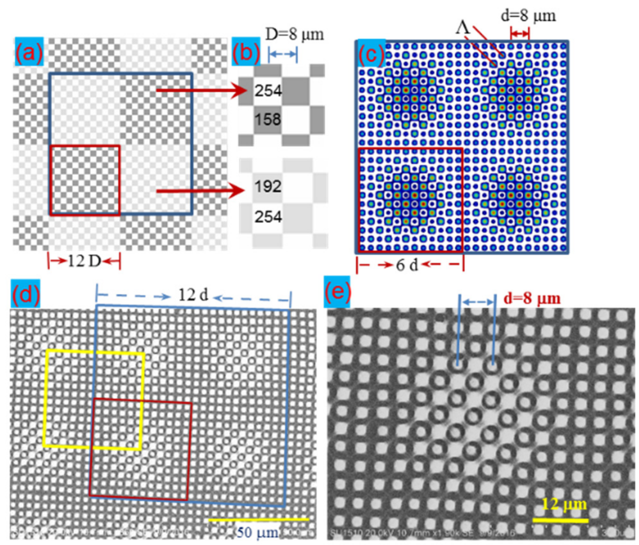

Fig. 1. (a) Supercell phase tiles assembled from 12×12 tiles of checkerboard phase patterns. (b) Enlarged view of phase patterns. (c) Simulated iso-intensity surface of the interference pattern. (d) SEM of a fabricated sample showing large periodicity and square symmetry. (e) Enlarged view of a fabricated GPS.

The SEM image in Fig. 1(d) shows the fabricated structures with graded, superlattice configuration, in agreement with the simulation in Fig. 1(c). The solid red square indicates the unit of graded superlattice corresponding to the interference pattern inside the red square in Fig. 1(c). The solid blue square with a size of 12d×12d indicates the unit of graded superlattice corresponding to the interference pattern in Fig. 1(c). The dual periodicity, as indicated by the solid yellow square in Fig. 1(d) connecting the centers of supercell subunits of a graded lattice of the small periodicity inside the red square, is clearly observed. Fig. 1(e) shows an enlarged view of the fabricated GPSC. The length scale d was measured to be 8 μm, thus the lattice period, Λ, is 8 μm/$\sqrt{2}$, in agreement with theory.

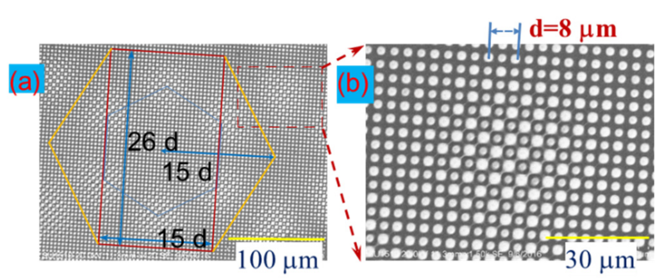

Fig. 2: (a) A large-area SEM of simultaneous square and hexagonal symmetry structures. The red rectangle indicates a supercell in the structure. The yellow hexagon is drawn for eye guidance of the hexagonal symmetry. (b) Enlarged view of structures in dashed red rectangle in (a).

The 158/254 and 192/254 pixels were similarly arranged to form triangular supercell subunits that were tiled across the SLM pattern. Such an SLM pattern produced four-fold diffraction due to the alternating square pixels and six-fold diffraction from the supercell subunits arranged in a triangular pattern. The sets of first-order diffraction beams were allowed to interfere to fabricate the structures in Fig. 2(a) with large, hexagonal symmetry and small, square symmetry. The hexagon in Fig. 2(a) is for the eye guidance of the large period structures. Fig. 2(b) shows an enlarged view of structures in the dashed red rectangle in (a).

We have also studied holographic fabrications by integrating reflective optical element (ROE) with SLM. The motivation for integrating the ROE with the SLM is to achieve a large-area fabrication of GPSCs with small and desired feature period. A desired ROE can be designed and easily printed by a 3D printer for the control of the number of overlapping beam and their wave-vectors. 3D laser projection system in Fig. 3(a) has been demonstrated for large-area fabrication of GPSCs with small feature size. Figure 3(a) shows the experimental setup of the integrated ROE+SLM laser projection system for holographic fabrication. A diffraction pattern is shown in Fig. 3(c) after the laser is diffracted by the phase pattern in (b), passed through the first lens, and filtered by a Fourier filter. These eight beams form an interference pattern after the inner spots are imaged through the second lens and the outer spots are reflected by the ROE without passing the second lens as shown in Fig. 3(a). An enlarged view of interference angles for inner and outer beams (one for each) is shown in Fig. 3(d). The interference angle β is related to the reflective surface tilt angle, γ=83 degrees, of the reflective surface in Fig. 3(d) by β=180-2γ. Fig. 3(e) shows an SEM image of the fabricated GPSCs in negative photoresist DPHPA. A large area sample with a size of ~16 mm^2 has been obtained due to the use of an ROE instead of an objective-lens. The sample shows a graded structure with an unit super-cell size of 26a×26a.

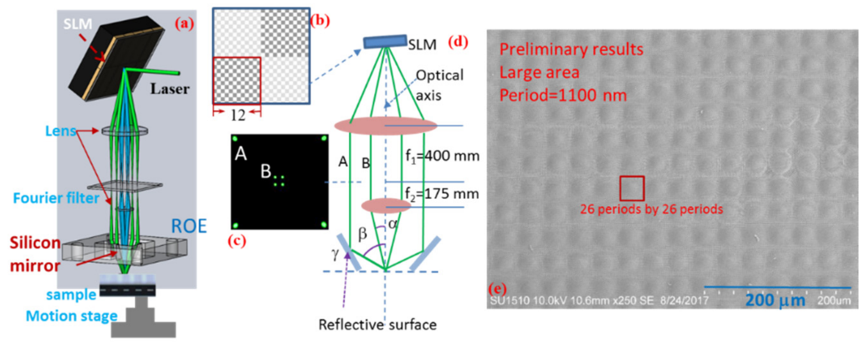

Fig. 3: (a) Schematic diagram of the experimental setup where an ROE is integrated with an SLM-based laser projection system. (b) A phase pattern with a super-unit; (c) The inner diffraction spots are imaged through a second lens while an ROE interferes the outer diffraction spots. (d) An enlarged view of the optical setup showing the interference angles of the two diffraction beams A and B as shown in (c). (e) SEM images of fabricated GPSCs in large area.

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