Complex Spatial Light Modulation for Holographic Displays

Hwi Kim

Department of Electronics and Information Engineering, College of Science and Technology, Korea University, Sejong Campus, 2511 Sejong-ro, Sejong 30019, South Korea
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ABSTRACT

Complex light modulation is a fundamental and crucial issue for holographic displays. We propose three-phase amplitude structure that has three fixed phase and controllable amplitudes to implement a single complex value. In this study, it is also expected to implement an ultra-low noise holographic display with active complex modulation.

1 INTRODUCTION

3D holographic display is a technology to recognize three-dimensional (3D) object by reconstructing phase and amplitude of light. To perfectly reconstruct a hologram, we should simultaneously modulate amplitude and phase. However, conventional holographic display has only amplitude or only phase modulation. Accordingly, it needs inevitably a bulky filter system for eliminating the noise generated by controlling only one component [1]-[2]. For solving these fundamental problems, recently, meta-surface hologram has been presented, and many pixel designs with a high performance have been implemented for complex spatial light modulation [3]-[9]. Most of previous design cannot modulate for all continuous phase range, and noises such as DC and conjugate noise is still generated due to variety problems. In this study, we propose the new pixel design to implement single pixel with complex light modulation, analyzing the modulation characteristic of that structure to overcome these limitations. The computer generated hologram (CGH) designed for the new pixel is able to modulate simultaneously amplitude and phase of the light. Furthermore, it can be applied to holographic display with active complex modulation.

2 THEORY

The proposed principle-proof design is shown in Fig. 1, which is referred to the point-symmetric hexa-petal antenna. A unit-pixel is featured with three fixed phases, $(0, 2\pi/3, 4\pi/3)$ and controllable amplitude (A_1, A_2, A_3) and a cross-polarization component of complex amplitude of a circular polarized light passing through the antenna given by Eq. (1) can be controlled.

$$Ae^{j\phi} = A_1 e^{j(0)} + A_2 e^{j(2\pi/3)} + A_3 e^{j(4\pi/3)} . \quad (1)$$

As shown in Fig. 1, the new pixel design consists of three rods rotated by $2\pi/3$ intervals, and a single complex value is represented by three amplitudes controlled by changing the size of each rod.

3 SIMULATION RESULTS

Three amplitudes on the proposed pixel design can be controlled by changing the width or length of each rod. If we have effective ranges for width or length data of each rod, we can design a new pixel with a capability of complex spatial light modulation. As shown in Fig. 2(a, b), we analyzed effective range for width and length of each rod. For the normalized amplitude from 0 to 1, the ranges of width and length are from 0nm to 60nm and from 60nm to 290nm, respectively. Based on Fig. 2(a, b), the continuous phase change is observed in Fig. 2(c, d). In order to verify the analytical characteristic of complex light modulation, the single pixel with complex value consisted of amplitude (0.8) is assumed and analyzed from 0 to 2π for all continuous phase modulation. These results were analyzed by Fourier Modal Method (FMM) simulation based on Rigorous Coupled Wave Analysis (RCWA). For the previous results of near field, we applied the new design into calculating CGH pattern. As shown in Fig. 3(a), the CGH with the proposed unit-pixel is designed with pixel size of 350nm and resolution of 101 by 101. We can verify that the reconstructed image has ultra-low noise in Fig. 3(b). Additionally, to design a new pixel, we need to verify a hypothesis for a point symmetry of unit pixel. As shown in Fig. 4(a), the diffractive pattern with asymmetric pixel generates the considerable sized DC and conjugate noise. However, we can see that the result of symmetric pixel has a clear reconstructed image, in Fig. 4(b, c).

4 CONCLUSIONS

Most of conventional meta-surface hologram has a pixel design controlling two angle of origin, structurally. However, the proposed design in this study has three fixed phases and controllable amplitudes by changing width or length of each rod. Contrary to conventional design, the noise of a reconstructed image can be significantly reduced. The three-phase amplitude controlling method has a structural simplicity and degree of freedom for continuous phase range.

It is inferred that the point-symmetric hexa-petal topology can be generally applied to spatial light modulator for dynamic control of holographic light field. Accordingly, we can apply this method to both CGH patterns with static complex modulation and holographic display with active complex modulation. If it is modulated for complex light modulation, we will be able to implement ultra-noise holographic display and construct compact optical system. Accordingly, the three-phase amplitude technique can be applied to research and industrial field like augmented reality (AR) system

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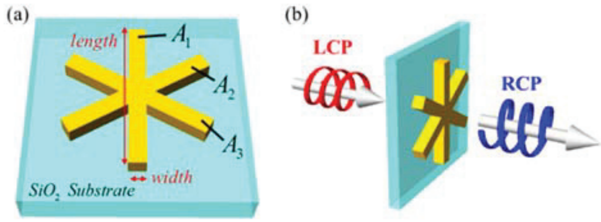

Fig. 1 (a) the scheme of hexa-petal antenna, (b) complex spatial light modulation by cross-polarization component of circular polarized light

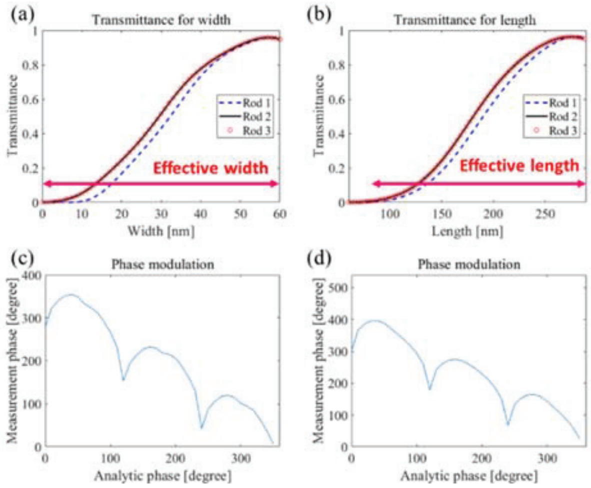

Fig. 2 Effective ranges for (a) width and (b) length of each rod, near field simulation results modulating continuous phase from 0 to 2π and fixed amplitude (0.8) for (c) width and (d) length

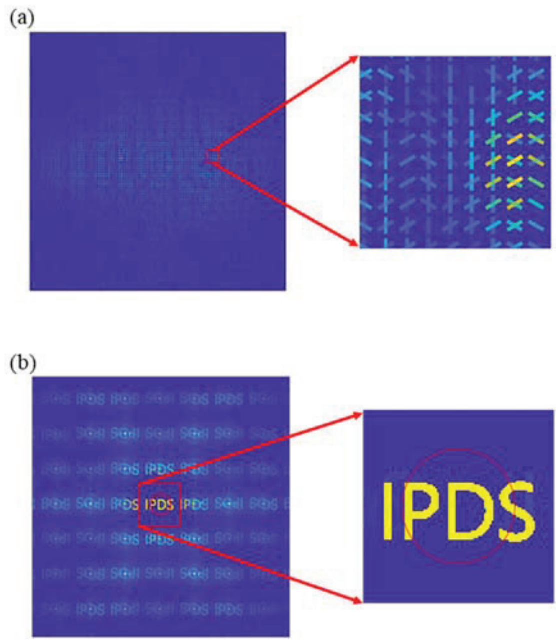

Fig. 3 (a) CGH pattern designed with hexa-petal

antenna array and (b) far-field diffraction pattern to prove the complex light modulation capability of the proposed principle

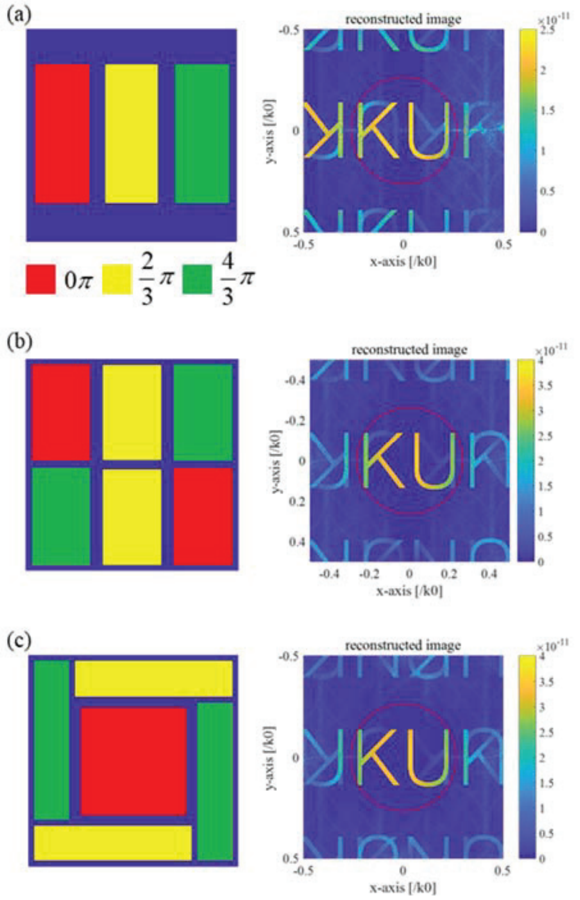

Fig. 4 (a) the scheme of unit macro pixel and far-field distribution for each pixel with (a) asymmetry, (b) and (c) point symmetry