

Spatial Light Modulator with Phase and Amplitude Control for Holographic Displays

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Abstract

A single layer phase and amplitude spatial light modulator for holographic displays is proposed. The device is 0.7 microns thick and can achieve $>1.97 \pi$ phase control for 30-90% intensity, and more than $>1.34 \pi$ phase modulation for 20-30% intensity.

Author Keywords

Spatial light modulator, Phase and amplitude modulation, Pancharatnam phase.

1. Introduction

Light with intensity A and phase α can be represented as,

$$E = A * e^{i*\alpha} \quad (1)$$

A regular photographic hologram is a modulator for both amplitude A and phase α . However, for regular spatial light modulator (SLM), it is either a phase modulator or amplitude modulator. In [1], Makowski shows the image of using phase only SLM, compared to a phase and amplitude SLM by cascading two SLM layers.

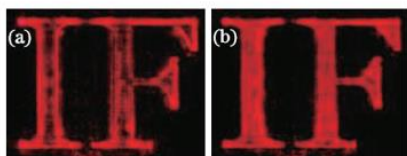


Figure 1. Figure in [1]. The left image shows the obtained projected image using (a) phase only SLM (b) one amplitude SLM and one phase SLM.

To achieve an overall high image quality, independent amplitude (A) and phase (α) modulation are desired for an SLM. Maimone [2] reviewed the current method to get amplitude and phase control SLM. As shown in Fig.1, cascading one amplitude only SLM and one phase only SLM can achieve both amplitude and phase control using two layers. A paper by Hoon Song [3], however, stated the two practical problems when cascading the two SLMs with pixel matching alignment. First, there is serious crosstalk issue due to diffraction during the long-distance propagation of the optical field. Second, the alignment of pixels on the two devices needs to match very closely.

Previous work has been done to seek solutions for a single layer amplitude and phase control SLM. Direct Amplitude Encoding (also called double phase method/double pixel method) [4][5][6] encode the phase and amplitude information of one pixel into two pixels. However, the amplitude control is still through changing the phase α of the two pixels to diffract light, not directly change the amplitude A . Also, the use of two pixels for one SLM pixel reduces the resolution by half.

More recently, Du [7] proposed an amplitude and phase modulation SLM using two different areas in a single pixel. The basic idea is to use half of the pixel to modulate the amplitude (A) and half of the pixel to modulate the phase (α). However, with this approach,

the amplitude and phase are controlled separately in two half pixels, leading to a resultant electric field that is more like the sum of an amplitude term plus a phase term, rather than their product. The result is still not the desired form shown in eqn 1.

So far, a true single layer SLM that modulates both amplitude A and phase α independently has not yet been proposed. This is the motivation of this paper.

In this work, we propose a single layer, phase and amplitude modulating SLM. The amplitude A and phase α are independently controlled by applying different voltage on a single pixel. The proposed device can achieve $>1.97 \pi$ phase control for 30-90% intensity, and more than $>1.34 \pi$ phase modulation from 20-30% intensity.

2. Device Design

2.1 Basic operating principles

Our device design has three objectives: to control the amplitude light transmitted by a pixel; to control the phase of the transmitted light simultaneously with the amplitude control; and to minimize the crosstalk between pixels.

To accomplish these objectives, we use a device based on Pancharatnam phase with the following considerations: the amplitude of transmitted light can be controlled by changing the effective birefringence of a pixel; the phase can be controlled by changing the azimuthal angle of the LC director in a pixel; and inter-pixel crosstalk will be minimized by the factor of two reduction in device thickness when using a Pancharatnam phase device, over a path length based device.

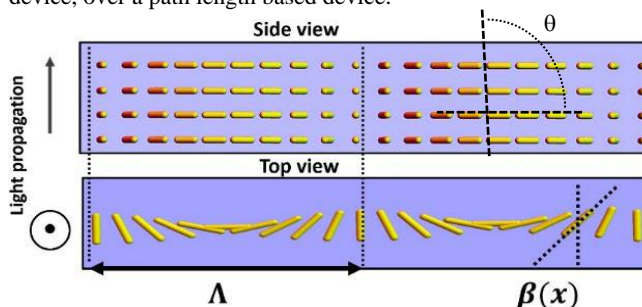


Figure 2. A sketch of a Pancharatnam phase device and defining θ and β as the polar and azimuthal angle of the local director .

The details will be shown elsewhere, but it can be shown that the complex output of circularly polarized light for input circularly polarized light (of the opposite handedness) is:

$$Ae^{i*\alpha}$$

$$\text{Where } A = i * \sin\left(\frac{\varphi}{2}\right) = i * \sin\left(\frac{\varphi}{2}\right) = i * \sin\left(\frac{\pi * (n'_e + n_o) d}{2\lambda}\right)$$

$$\text{and } \alpha = 2\pi * (n_{ave}) * \frac{d}{\lambda} + 2\beta = \pi * (n'_e + n_o) * \frac{d}{\lambda} + 2\beta$$

and
$$n'_e = \frac{n_o * n_e}{\sqrt{n_e^2 \cos^2(\theta) + n_o^2 \sin^2(\theta)}}$$

And ϕ is $2\pi(n_e' - n_o)/d$ (where n_e' is the effective extraordinary index of refraction, and d is the LC layer thickness); and β is the azimuthal angle of the projection of the director onto the plane of the device relative to a fixed lab axis.

To change the amplitude A and phase α , the basic idea is:

1. For amplitude control, use the vertical voltage to tilt the director (change the polar angle θ). Recall n'_e is a function of θ , change θ will change n'_e , leading to the change in amplitude.
2. For phase control, use an in-plane voltage to change β , that will change the phase, α .

2.2 Electrode structure and Liquid crystal surface alignment

The LC directors' polar angle at the electrode side of the pixels is θ_e with respect to the z axis (thickness direction) and is homotropic at the ground plane side. The azimuthal angles at the electrode side are $+\beta_e$ degrees for odd pixels, and $-\beta_e$ degrees for even pixels.

Using two driving voltages of V_{common} for common plane and V_{finger} for finger electrodes, we can generate an electric field along the z direction to change the polar angle of the LC director (amplitude of light) and the fringing fields to change the azimuthal angle of the LC director (phase of light).

2.3 Independent phase and amplitude control by applying a two-step pulse width modulation voltage waveform

The vertical voltage V_{vertical} (providing an electric field along the z direction) is set for both common plane and finger electrodes relative to the ground. We can offset the drive waveform of the common plane V_{common} and finger electrodes V_{finger} to set the RMS in-plane voltage V_{inplane} (providing an electric field along the x direction).

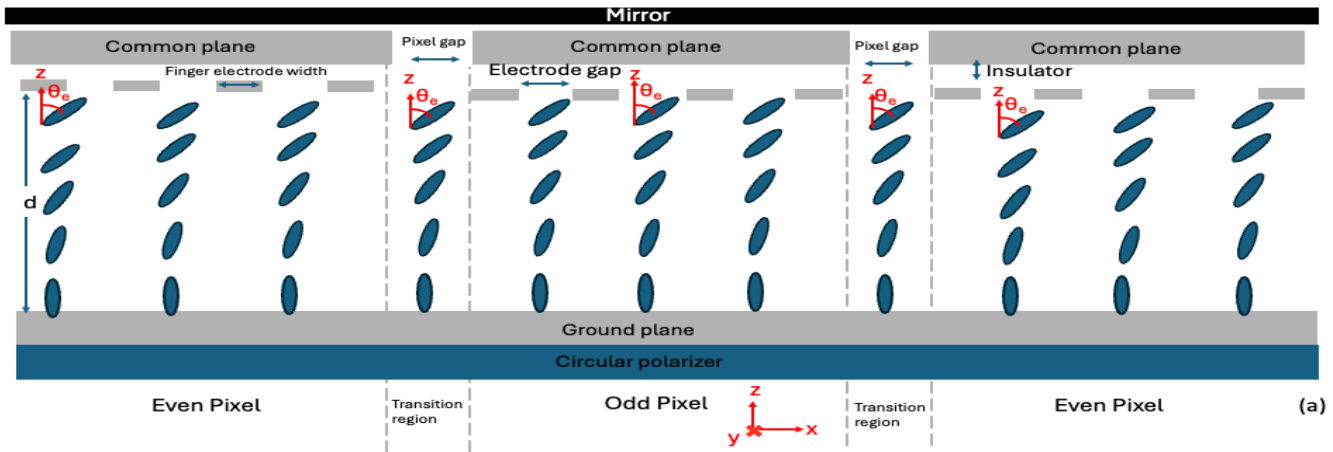
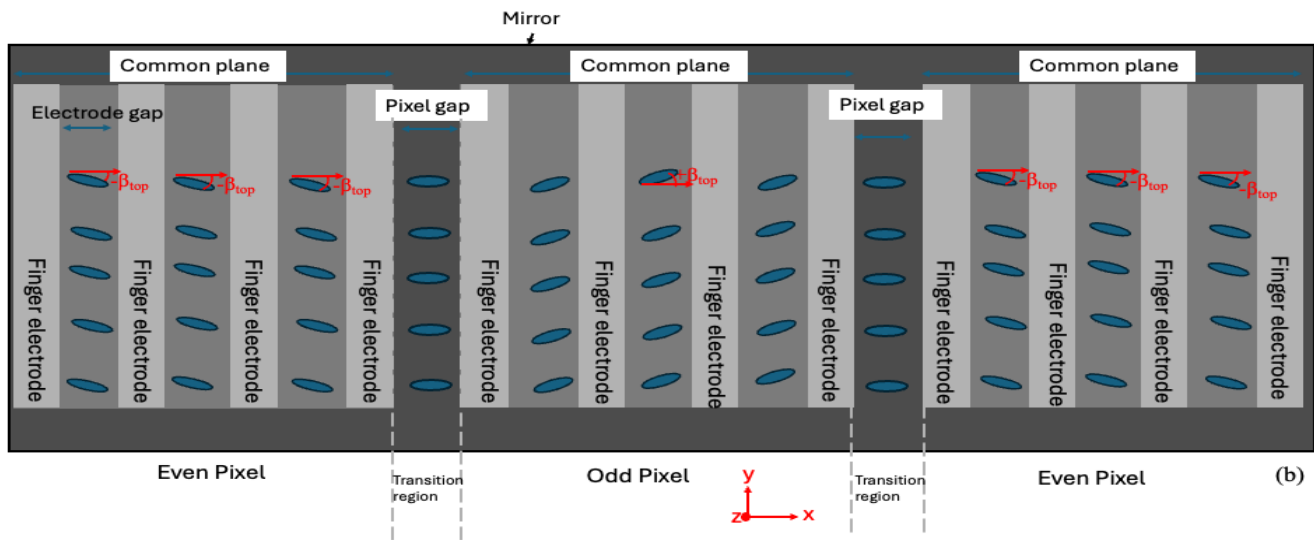


Figure 3. (a) LC director side view (xz axis) for three neighboring



pixels (b) top view (xy axis, from the mirror side) for three neighboring pixels.

In this work, we will set the phase to be 0 when azimuthal angle is 0 degrees for 90% intensity. The phase zero point is calculated when $V_{\text{vertical}}=3V$, $V_{\text{inplane}}=0V$. All output phase is relative to this 0 phase point for consistency.

By activating the even pixels first(as demonstrated in section 2.3, applying in-plane voltage on even pixels but not on odd pixels) for the two step voltage method, we can reduce the output phase. On the other hand, we can increase the output phase by applying in-plane voltage for the odd pixels first.

Using the different V_{vertical} and V_{inplane} , we can vary the phase for intensities between 20% to 90%. As an example, we have varied the phase for 20%,30%,50% and 90% intensity.

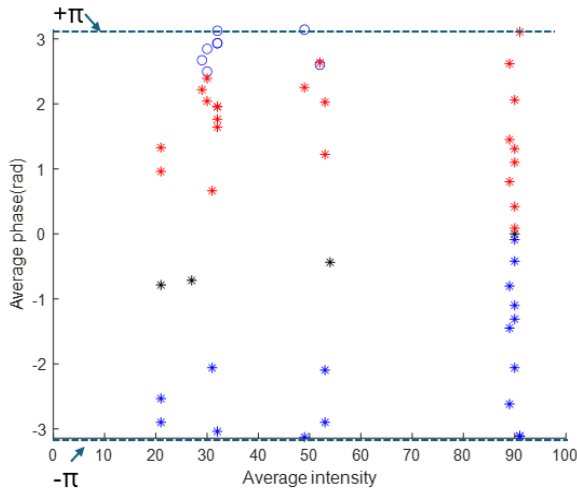


Figure 6. Average intensity and phase achieved with the proposed device. The black points are when $V_{\text{inplane}}=0V$. The blue points are activating the even pixels first while the red points are activating the odd pixels first.

Some of the phase points obtained directly from our calculations have values below $-\pi$. Considering the equivalence of a phase angle and when the angle has 2π added to it, for those points where the phase is less than $-\pi$, we add 2π to bring the phase back to the phase range of $[-\pi, +\pi]$. Those special points after adding 2π are indicated by blue circle marks. The significance is that there will be a 2π phase change between the blue circle points and the red points.

4. Summary and discussion

In this work, we proposed a SLM that can achieve $>1.97\pi$ phase control for intensity from 30%-90%, and $>1.34\pi$ phase control for intensity between 20%-30%.

Many parameters can be changed for further optimization, depending on the goal of the device, but also with trade off. As discussed, the polar angle on the electrode side can be changed for a lower minimum intensity, but the response speed will be slower. In this paper, we chose a relatively small dielectric anisotropy $\Delta\epsilon$ of -4.2 and limit the highest driving AC voltage to 5V(peak to ground). With higher dielectric anisotropy materials, the device is expected to have higher maximum intensity and lower required maximum driving voltage.

5. Acknowledgements

This work was funded by Meta Reality Labs.

6. References

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