Simulation model for visualization of diffraction property of volume holographic optical elements

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Holography is a widely recognized technique for generating a new wavefront from an existing one through a diffraction medium[1]. In the case of a thin hologram, the phase-match condition permits the occurrence of multi-order diffraction lights, resulting in relatively low diffraction efficiency. However, a notable advantage lies in the absence of significant Bragg selectivity in both spatial and wavelength domains. In contrast, a volume hologram adheres to stringent Bragg conditions, reflecting energy and momentum conservation in k-space[2]. This characteristic renders a volume hologram highly sensitive to the reading conditions[2]. Deviation from the Bragg condition, either in incident angle or reading wavelength, leads to ineffective diffraction. Volume holograms can be categorized into two types: transmission and reflection. Both types can achieve 100% diffraction efficiency, albeit with distinct behaviors. For a transmission volume hologram, the diffraction efficiency oscillates as the coupling strength increases. Conversely, the diffraction efficiency of a reflection volume hologram exhibits a different behavior, approaching 100% as the coupling strength reaches a sufficiently large value. In the case of a transmission volume hologram, it attains the status of a strong volume hologram upon reaching the first 100% diffraction efficiency. Consequently, when designing a volume holographic optical element (VHOE), it is imperative to meticulously consider the Bragg condition and other incident conditions.

One of the notable advantages of VHOE is their ability to efficiently transform one wavefront into a desired form with 100% efficiency. However, a significant challenge arises when designing VHOEs for arbitrary wavefronts, as an effective method for calculating diffraction efficiency was lacking.

Existing calculation models, such as the couple mode equation for holograms with two plane waves, and methods like Born's approximation and VOHIL, are suitable for scenarios with small coupling strength, i.e., when diffraction efficiency is limited [3-4]. When dealing with intricate diffraction efficiency calculations and determining the Bragg condition for a local field, VOHIL proves to be a particularly effective and clever approach. Its utilization of a phase mismatch factor facilitates the handling of the Bragg condition in real space rather than in k-space.

In our proposed approach, we introduce a novel method to calculate the phase mismatch factor throughout the entire volume of a VHOE. As illustrated in Figure 1, varying phase mismatch factors exist across the VHOE when the reading light deviates slightly from the direction of the reference light. When the difference in the phase mismatch factor along a specific diffraction direction exceeds 2π, effective diffraction along that direction is impeded. This approach proves valuable in determining the Bragg condition for designing a VHOE, especially when the reading light must deviate from the reference light.

Figure 2 presents a more complex scenario where two spherical writing lights counter-propagate. The spherical reading light deviates slightly from the reference light, inducing a Bragg mismatch in the VHOE. Each cube in the figure corresponds to a certain diffraction light with a spherical wavefront propagating along a direction linked to the deviation between the reading light and the reference light. By examining the phase deviation map, a designer can ascertain the existence of effective diffraction. This scheme proves instrumental in the development of intricate VHOEs, particularly those intended for use in Augmented Reality/Mixed Reality near-eye glasses [5-6].

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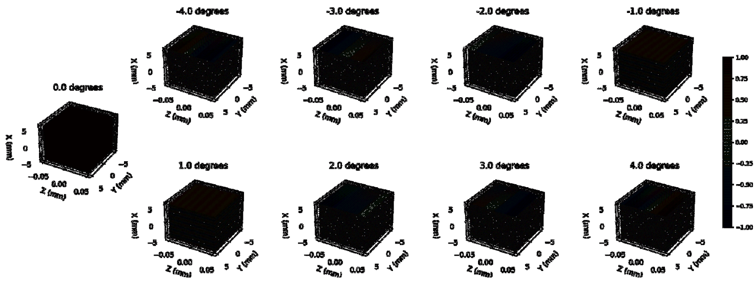

Fig. 1 The Diffraction behaviors for a 2K reflection volume hologram. The phase deviation map comes from the reading light deviating from the reference light.

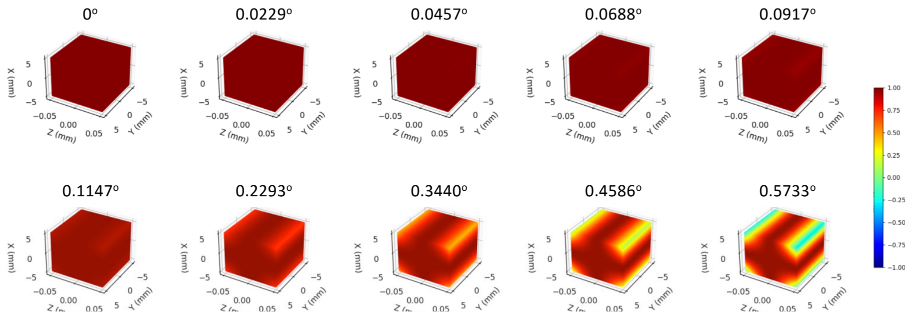

Fig. 2 The Diffraction behaviors for a 2K reflection volume hologram. The phase deviation map comes from the reading light deviating from the reference light and diffracted light has the same deviation from the other writing light. All lights in the simulation are spherical waves.

References

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