Perturbation-Damped Optical Interferometer for AR Waveguide Grating Fabrication

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Abstract
A perturbation-resistant interferometer is designed and demonstrated for stable fabrication of sub-micron pitch AR waveguide gratings. Polarization multiplexing allows every component in the interferometer to be shared by two beams which interfere at a high angle. Polarization volume hologram gratings featuring a grating pitch less than 300 nm are fabricated with this approach. The perturbation-resistant short-pitch grating fabrication method offers a reliable and scalable approach to mass-producing holographic gratings with a sub-micron grating pitch.

Author Keywords
Interferometry, holography, augmented reality, AR waveguide

1. Introduction
In this work, a perturbation-damped short-pitch two-beam interference system for fabrication of augmented reality (AR) waveguide gratings is designed and demonstrated. Optical gratings for AR waveguides have proven to be a compact and high-efficiency mechanism for input-coupling and output-coupling an optical image field through an AR waveguide. The use of optical gratings for the input and output coupling of the field has garnered popularity in next-generation demonstrations of AR waveguides for the compactness, efficiency and supported FOV of the approach. Volume holographic gratings, surface relief gratings, and liquid crystal polarization volume holographic gratings have previously been demonstrated as a viable input and output-coupling mechanisms [1]. For a grating to deflect a field into TIR through the AR waveguide, a grating pitch in the range of 300 to 450 nm is necessary, depending on wavelength and the grating's and waveguide's index of refraction. A high-angle two-beam interference is a common method to encode the short-pitch grating pattern onto the grating, either in intensity space or polarization space. However such an interferometer is highly perturbation-sensitive: sag imposed on one beam of the interferometer of the interferometer by a distance of one wavelength will shift the resulting fringe pattern by one period. During the holographic exposure process, this translation of the fringe pattern will re-expose the shifted pattern and consequently destroy the exposure. The common-path Sagnac interferometer involves the interaction of two interfering beams with common optical elements [2], and this reduces perturbations contributed by the shared optical elements. Perturbation-resistant fabrication of liquid crystal holograms has previously been demonstrated with a Sagnac interferometer [3], however the interferometer is limited to small-angle interference. Fabrication of a polarization volume hologram grating for use as a waveguide input and output-coupler requires a high-angle interferometer [4]. In this work, we propose a high-angle interferometer featuring polarization-multiplexed reflectors, to achieve common interaction of all optical elements by both beams in a high-angle interferometer. The common interaction by both beams will cause both beams to inherit perturbation imposed by either mirror in the interferometer. As a result, both beams in the interferometer will effectively "follow" each other when a mirror is shifted. This behavior is similar to that of a common-path interferometer, in which both beams interact with every element in the interferometer, however our design allows two beams to interfere at high angles to generate a grating pitch smaller than 300 nm.

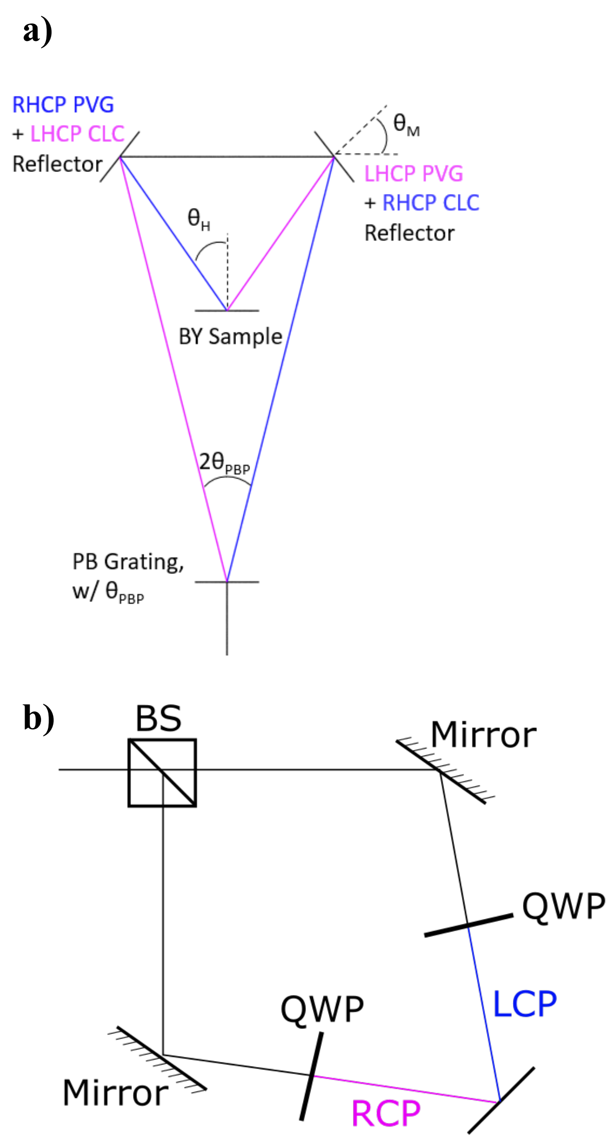

Figure 1. a) Perturbation-resistant high-angle interferometer, b) Traditional high-angle 2-beam interference

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By taking advantage of polarization multiplexing, two beams of orthogonal polarization states may take two unique paths through the optical interferometer. Cholesteric liquid crystal reflectors, and liquid crystal polarization volume holographic gratings, are used to selectively reflect and deflect either of the two polarization states used in the interferometer. Fig. 1a illustrates the design of the polarization-multiplexing perturbation-damped short-pitch high-angle interferometer. In polarization holography, two fields of orthogonal circular polarization states will combine to generate a spatially-varying polarization field. By analyzing this polarization state with a linear polarizer, an interference pattern in intensity and a uniform polarization state will emerge. In this interferometer, interference takes place in polarization-space, and may be analyzed in the rotated polarization basis to realize the fringe pattern in intensity-space. Using the matrix method which transforms a source to imaginary sources in an interferometer [5], we calculate the perturbation dampening achieved by the proposed high-angle interferometer.

2. Calculation and Experiment

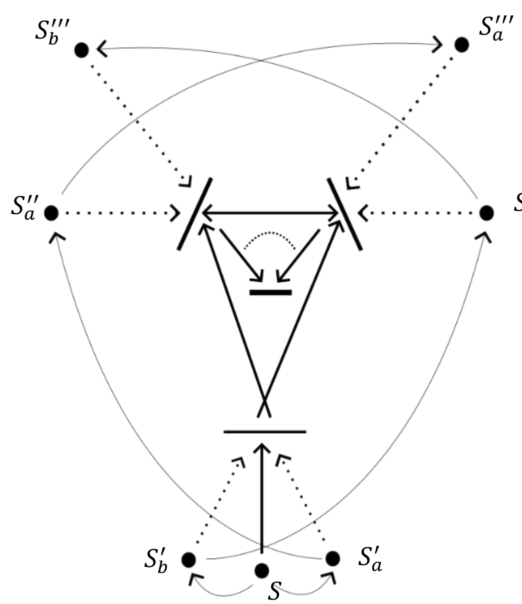

Figure 2. Transformation of source to two imaginary sources

The shift of one of the mirrors in the interferometer will directly translate the location of the imaginary sources. In fig. 1b, is illustrated a standard two-beam interferometer used to generate short-pitch fringe pattern. In the traditional high-angle interferometer, the translation of one mirror corresponds independently to the translation of only one of the two sources' imaginary location. This directly causes one beam to accumulate phase independently of the other, thus causing the fringe pattern to shift during the exposure. Fig. 2 illustrates the transformation of a real source into imaginary sources, which are positioned in imaginary space by the beam-splitter and reflective elements of the perturbation-damped interferometer. A calculation by the matrix method yields the oscillation of the two-beam interference pattern when analyzed in intensity-space, shown in fig. 3a for the traditional interferometer and 3b for the proposed interferometer.

It is shown in Fig. 4 that the passive optical stabilization inherent in the proposed polarization-multiplexed interferometer effectively dampens component-imposed perturbations. The proposed interferometer was built with the polarization-multiplexed reflectors for use at a 457 nm wavelength. Functionality of the polarization-multiplexing interferometer is demonstrated with the fabrication of 400-nm and 295-nm pitch liquid crystal polarization volume holographic gratings, as shown in Fig. 4a and 4b respectively.

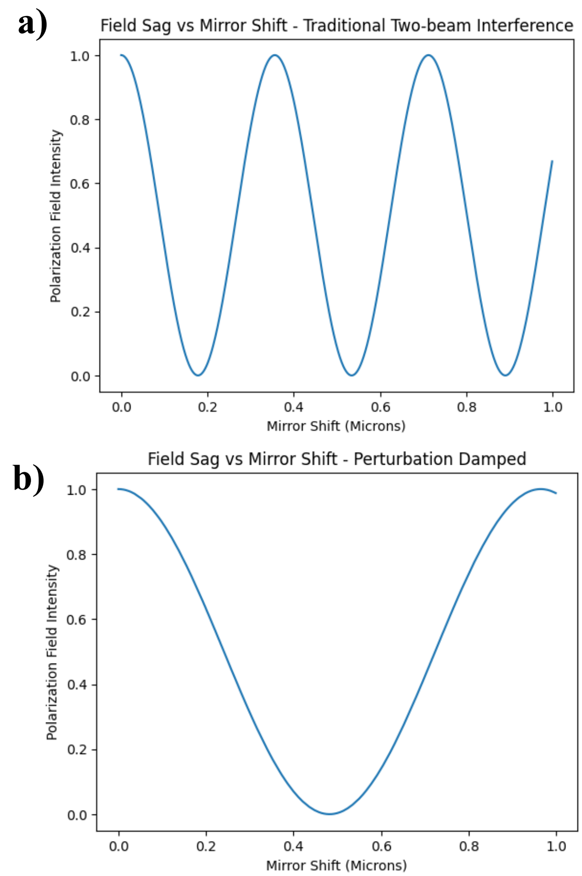

Figure 3. a) Interference perturbation in traditional interferometer, b) Interference perturbation in stable interferometer

3. Conclusion

In conclusion, perturbations imposed by unwanted movement of optical elements in a high-angle interferometric grating exposure system are passively dampened. By sharing interaction with every component in the interferometer, a stable high-angle two-beam interference is realized for reliable fabrication of sub-micron holographic gratings. This enables scalable manufacturing of gratings which are used for augmented reality waveguide input and output couplers.

a)

b)

Figure 4. a) 400 nm polarization volume hologram grating, b) 295 nm polarization volume hologram grating

4. References

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