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Computer-generated diffraction gratings in optical region*

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1. Introduction

The conventional computer-generated holograms (CGH) presented in papers [1]–[3] are calculated by use of the discrete Fourier transform. In optical reconstruction of the CGH, the spatial components diffracted from a photographically reduced holograms are collected by a lens to produce a reconstructed picture. The angles between the diffracted spatial components and the optical axis are typical in the range of milliradians.

On the other hand, computer-generated diffraction gratings can be calculated without any Fourier transformation by using discrete wavefront theories [4], [5]. The reduction of the holograms to the right scale can be made, e.g., by using focused electron beam, focused laser beam or photographic process.

In our applications, some diffraction gratings are calculated with the aid of the Stardent 3040 system with four MIPS R3000 parallel processors (64 MB) and reduced by using photographic processes to complete the diffraction gratings into optical range applied by the conventional holography.

2. Computational procedure

The wavefront aberrations of object and reference point sources from the reference sphere are given by the law of hologram imagery presented by Latta [6], [7]. The aberrations are calculated in the hologram plane from the reference sphere with the coefficients of spherical aberration, coma and astigmatism. To avoid an increase in the number of data points, the areal weighting average aberration [8] is used for the variation of spherical, coma and astigmatism aberrations over the hologram aperture. The optimization of aberration was calculated by using refractive index matching. In these applications, zero-chromatism caused by the refractive index was less than 1 μm.

The diffraction efficiency of the phase grating was calculated with the aid of the coupled wave theories [9]–[12]. The computer-generated holograms in accordance with the optimization of aberrations were calculated by using Stardent 3040 system.

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3. Applications

Matching of the Bragg condition was accomplished for the transmission phase gratings working in three different on-axis hololens forms. The diameter of the hololens apertures planned for multi-/demultiplexing or external cavity operation was 8 mm. The focal length of the hololens 1 (Fig. 1**a**) was 10 mm with grating spacing from infinity to 1.24 μm. The numerical aperture of hololens 1 in recording condition was 0.2. The focal length of the hololens 2 (Fig. 1**b**) was 20 mm with the grating spacing from infinity to 2.49 μm. The numerical aperture of hololens 2 in recording condition was 0.2. The focal length of the hololens 3 (Fig. 1**c**) was 16 mm with the grating spacing from infinity to 1.98 μm. The numerical apertures of hololens 3 in recording condition were 0.2 and 0.05 in reference and object spaces, respectively.

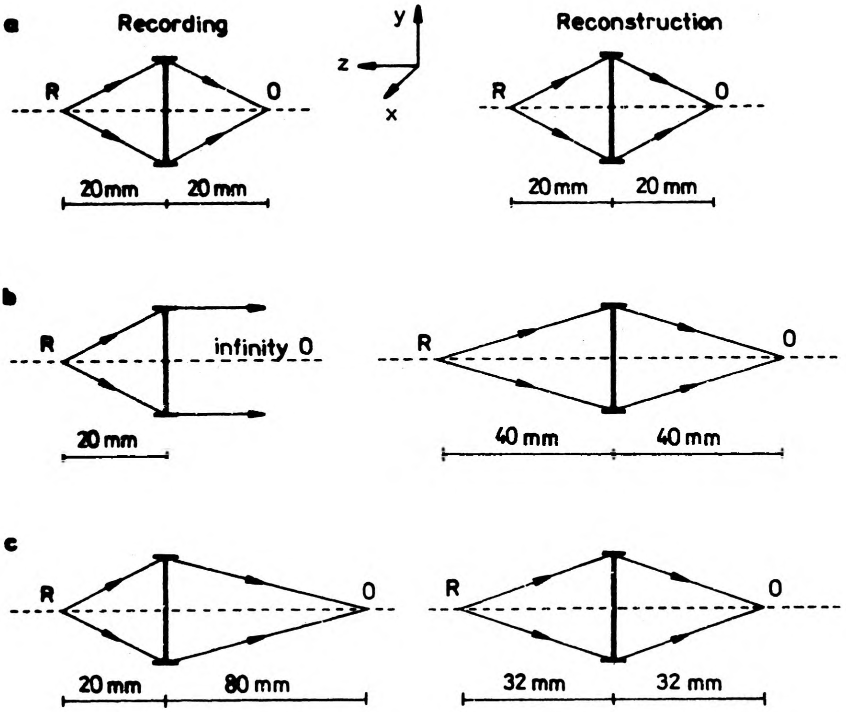

Fig. 1. Hololens with the focal length of 10 mm and numerical aperture NA = 0.2 (**a**), 20 mm and NA = 0.2 (**b**), 16 mm and NA = 0.2 (**c**). The reference (R) and the object (O) sources are in *xy*-plane

4. Results

The calculated areal weighted values of geometrical aberrations of lens 1 (Fig. 1**a**), lens 2 (Fig. 1**b**), and lens 3 (Fig. 1**c**), recorded with 0.488 μm wavelength and reconstructed with 1.5 μm wavelength, were 117.7 μm, 9.5 μm and 25.1 μm (Fig.2) before the Bragg condition. The calculated areal weighted values of geometrical aberrations of the respective lenses were less than 1.6×10^{-3} μm after the refractive index matching made for three reconstructing wavelengths (see the Table).

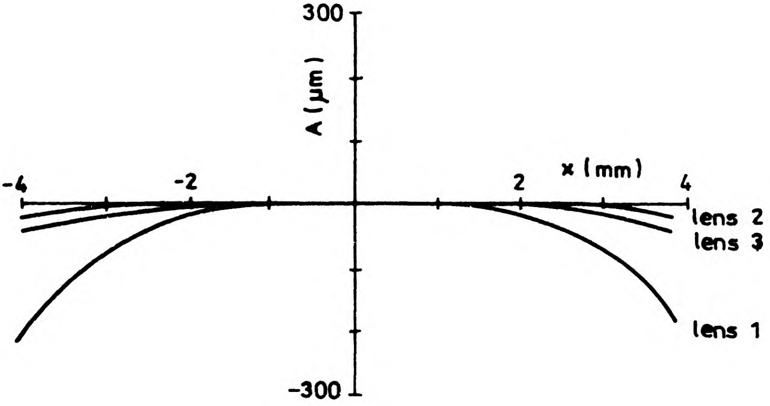

Fig. 2. Effects of aberrations (A) of sperical aberration, coma and astigmatism as a function of hololens (see Fig. 1) recorded at 0.488 μm and reconstructed at 1.5 μm wavelengths in x-direction

Refractive index values used to realize the Bragg condition of the hololens 1, 2 and 3 at three reconstructing wavelengths (λ_c)

λ_c / Lens	1.3	1.4	1.5
1	1.923	2.020	2.114
2	1.212	1.272	1.323
3	1.505	1.582	1.656

The calculated spectral bandwidths of the lens (Fig. 3**a**), lens 2 (Fig. 3**b**), and lens 3 (Fig. 3**c**) recorded with the 0.488 μm wavelength were 0.1 μm, 0.2 μm, and 0.2 μm, when the respective matching of the Bragg condition in the wavelength regions of 1.3 μm, 14 μm, and 1.5 μm were made.

The calculated diffraction efficiencies of lens 1, lens 2 and lens 3 (Fig. 4) in symmetric working condition after the refractive index matching were 92. 0%, 92.7% and 90.8%, respectively.

The attenuation losses of lens 1, lens 2 and lens 3 were −0.61 dB, −0.38 dB and −0.42 dB, respectively, when the refractive index of the phase grating ($n = 1.54$) and the matching glass in accordance with the diffraction efficiency of the lenses are taken into consideration.

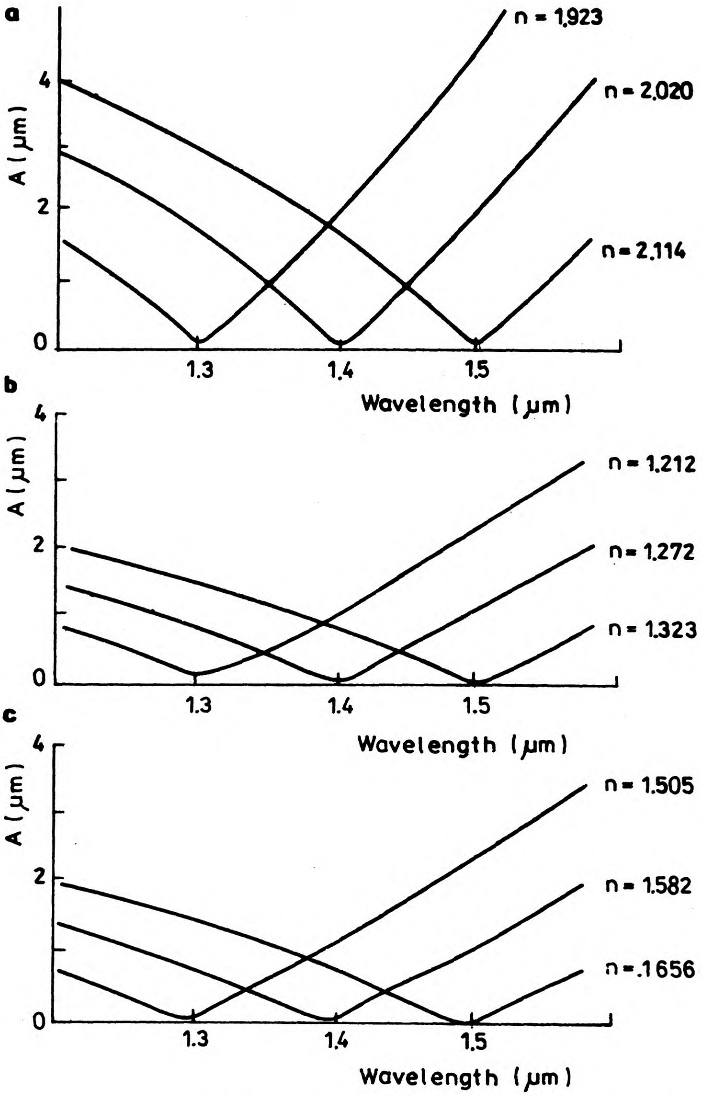

Fig. 3. Areal weighted aberration (A) of spherical aberration, coma and astigmatism of the hololens 1 (**a**), the hololens 2 (**b**), the hololens 3 (**c**) recorded at 0.488 μm wavelength after the refractive index matching to realize the Bragg condition in the wavelengths of 1.3 μm and 1.5 μm

5. Concluding remarks

Matching of the Bragg condition was made by using the data of the dichromatic gelating gratings, where the thickness of grating was 15 μm and the refractive index modulation being 0.042. The angle between the object and the reference point

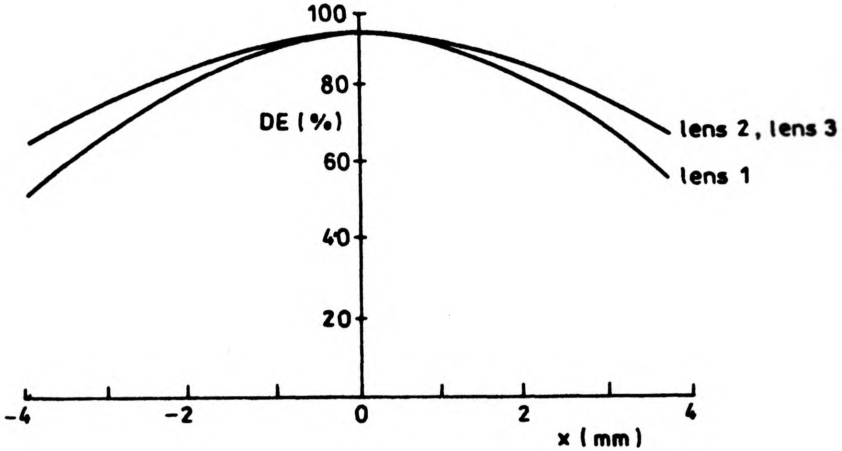

Fig. 4. Diffraction efficiency (DE) of the hololens 1, the hololens 2 and the hololens 3 after the refractive index matching to realize the Bragg condition as a function of lens aperture

sources was fixed in recording condition producing a hololens (numerical aperture NA = 0.2) with the grating spacing from infinity to 1.24 µm. The optimization results are indicating that the on-axis hololens of the 2 µm spectral bandwith with attenuation loss of −0.42 dB can be realized in the wavelength region from 1.3 µm to 1.5 µm.

However, fabrication of computer-generated hololens in pixel form is a complicated problem because the use of the focused laser beam distorts the direction of the grating fringes in hologram recording material decreasing the SN ratio of the lens. For that reason, we have investigated the copying applications of computer-generated amplitude holograms in thick recording materials.

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