HIGH RESOLUTION REVERSIBLE HOLOGRAM RECORDING IN PHOTOREFRACTIVE CRYSTALS

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The optimizing of the recording geometry for pulsed-laser hologram recording in silicosillenite crystals allows for the improvement of lateral resolution in the images and interferograms up to 1 μm.

Introduction

Photorefractive crystals have been proved to be useable as high resolving recording media for a reversible storage of double exposure holographic interferograms. At the Laboratory of Biophysics of the University of Münster, a holographic double exposure interferometer with 25 Hz interferogram repetition rate has been realized in the transmission-type geometry based on photorefractive crystals.

To apply such an interferometer for investigations of biological tissue and cells in life sciences, a lateral resolution in microscopic range is necessary. Here, the results of investigations on test targets and biological tissue samples are described which have been obtained using different microscope optics and a Q-switched Nd:YAG laser in the reflection-type geometry by means of a nominally undoped BTO crystal as recording device. In addition the lateral resolution of object structures in the reconstructed holographic images is determined.

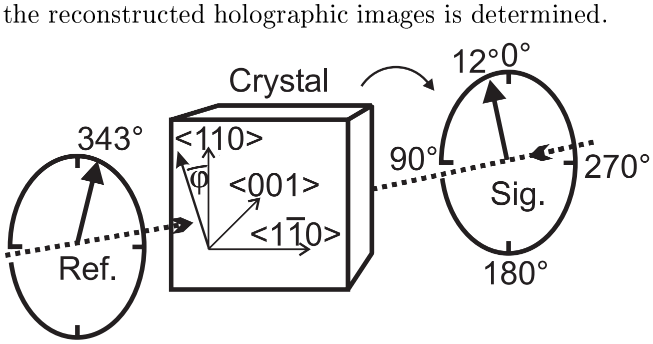

Fig. 1. Orientation of the applied BTO crystal in the reflection-type geometry

1. Crystal Orientation — Polarity

The crystal used for this experiment was a nominally undoped Bi_{12} TiO_{20} (BTO) (size 2.4 × 14.2 × 12.3 mm, [001] × [110] × [1$\bar{1}$0]) with a maximum diffraction efficiency $\eta = 0.5$ % measured in the optimum orientation (see Fig. 1). The effective trap density is $N_{\rm eff} = 8.5 \times 10^{16}$ cm^{-3}. Because of the optical activity of $\rho = 10.2°$/mm the polarization planes of incident laser beams are tilted for compensation. No external field is applied.

Nominally undoped BTO material is preferred because of several advantages:
— high diffraction efficiency in the reflection-type geometry,
— short response times,
— high trap densities $N_{\rm eff}$,
— low optical activity.
In addition, the effect of anisotropic diffraction leads to an improved signal-to-noise ratio in the holographic reconstructed images.

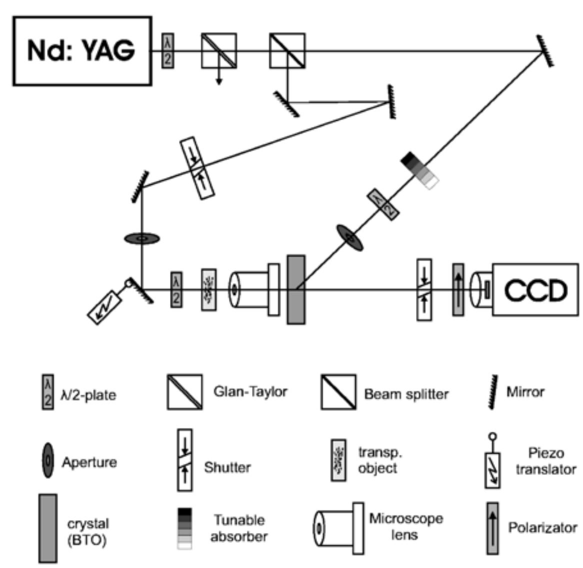

Fig. 2. Experimental setup for the recording of double exposure interferograms in the reflection-type geometry

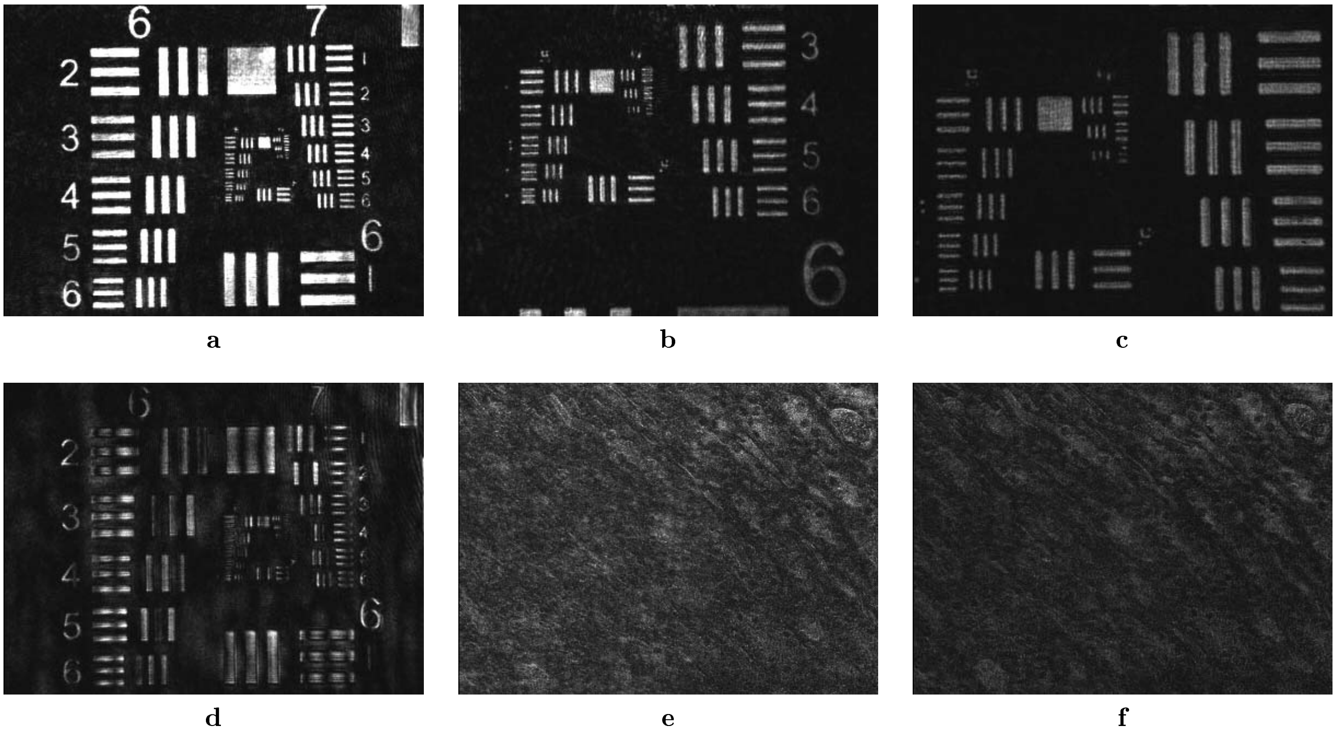

Fig. 3. Reconstructed holograms of an USAF 1951 test target with 20x (*a*), 40x (*b*) and 63x (*c*) microscope lens; *d* — interferogram recorded with a 20x microscope lens and carrier frequency; *e* — white light recording and *f* — hologram of a section of a cat kidney (40x microscope lens)

2. Experimental Arrangement

The setup in Fig. 2 shows a typical holographic arrangement for the recording of double exposure interferograms in the reflection-type geometry. The light source is a frequency doubled Q-switched Nd:YAG laser with pulse length of 3 ns and 90 cm coherence length. The beam profile is flat topped with a diameter of 10 mm. The $\lambda/2$-plates are inserted for the compensation of the optical activity. Two apertures limit the illuminated area on the crystals surface to reduce undesired scattering. An additional absorber in the reference beam optimizes the beam ratio. The polarization filter is used for the exploitation of anisotropic diffraction.

During recording with an opened object shutter, the camera must be saved by a camera shutter to avoid a damage of the CCD chip. The piezo translator tilts the object illumination between object states to add an adapted carrier frequency while recording. This will be used later to extract the direction of deformation for the spatial phase shifting algorithm.

The reflection-type geometry is used because of the following advantages:

— extended spatial frequency spectrum leads to higher resolution,
— small distance between the crystal and the object results in a large light collection, and an “in contact” arrangement can be realized.

The actual experimental procedure includes the following steps:

1. recording of object state 1 by multiple pulses,
2. (if requested) tilting of object illumination beam in order to generate a carrier frequency to determine the object deformation direction,
3. recording of object state 2 with half the number of pulses of the first hologram recording (for the intensity matching),
4. read out with one pulse,
5. erasure by multiple pulses.

3. Results

The following Fig. 3,$a-f$ demonstrates the capability of the described setup for the recording of single and double exposure holograms in the reflection-type geometry of test targets and biological tissue samples.

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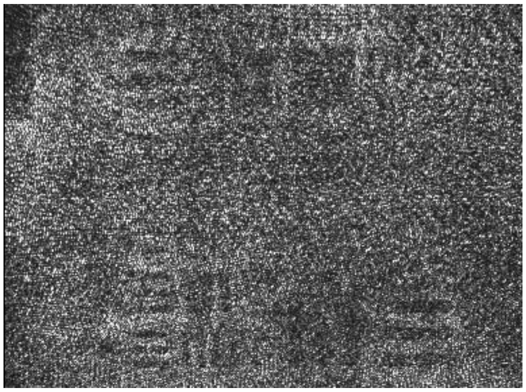
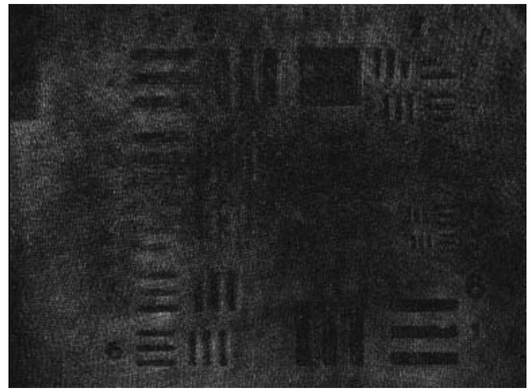


a



b

Fig. 4. Reconstructed hologram with isotropic (*a*) and anisotropic (*b*) diffraction by suboptimal intensity ratio on the crystal surface of about $I_{\rm Ref}/I_{\rm Sig} = 40:1$

Figs. 3,*a* — *d* shows negative USAF 1951 test charts recorded with microscope lenses between 20x and 63x. It is visible that group 9.3 corresponding to 0.8 micrometer lateral resolution can be resolved. Because of the decreasing object light, the brightness decreases with higher magnification. This correspondence is the same limit which is given by the numerical apertures of the used microscope lenses. This means that not the photorefractive crystal but the optical system is the limiting factor of the arrangement concerning the lateral resolution.

Fig. 3,*d* shows the test chart together with an additional carrier frequency which is caused by tilting the direction of the object beam by about an angle of 2°. Because of no object movement the fringes are oriented normally to the tilting plane.

Figs. 3,*e* and *f* show a section of a catkidney with white light and a hologram. The contrast is reduced but all details can be recognized. This means that the recording of holograms of biological tissue is possible and the reconstructed images show a sufficient contrast.

Fig. 4,*a* underlines the advantage of anisotropic diffraction. Scattering on the crystals surface in the direction of the camera systems can be suppressed and a sufficient contrast can be achieved although the beam ratio was suboptimal.

Fig. 5 shows a double exposure interferogram of a section of onion cells with a 20x microscope lens. The time between the 1st and 2nd holograms was 500 ms. The fringes at the borders of each onion cell are caused by a drying process.

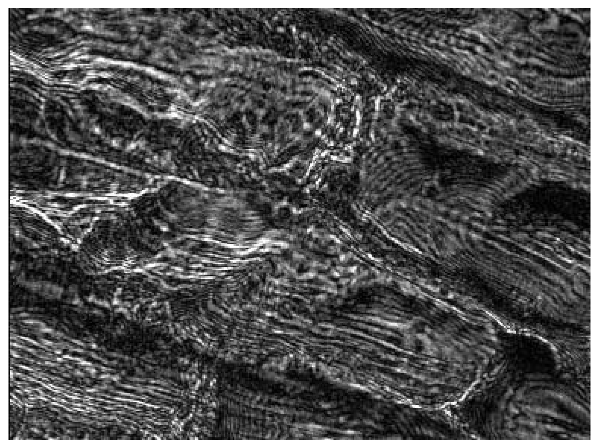


Fig. 5. Deformation fringes of an onion tissue probe due to drying process are recorded by double exposure interferometry using a 20x microscope lens

4. Discussion

With the described double exposure interferometer, the recording of single holograms and double exposure interferograms is possible which show object structures with a lateral resolution in the range of 1 μm and a sufficient contrast in the reconstructed holographic image. Reconstructed holographic images of living biological tissue for life science applications are possible as well. Image quality and contrast can be considerably improved by using anisotropic diffraction. Thus, double exposure interferometry for the analysis of biological objects in microscopic dimensions is possible in vivo by means of photorefractive crystals.

The authors wish to dedicate this contribution to Prof. Dr. Marat Soskin, Institute of Physics, National Academy of Sciences, Kyiv, Ukraine at the occasion of the 75th anniversary of his birthday.

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РЕВЕРСИВНИЙ ЗАПИС
ГОЛОГРАМ З ВИСОКОЮ РОЗДІЛЬНОЮ
ЗДАТНІСТЮ В ФОТОРЕФРАКТИВНИХ КРИСТАЛАХ

Г. фон Баллі, Р. Тін, Б. Кемпер

Р е з ю м е

Наведено результати оптимізації імпульсного голографічного запису в фоторефрактивних кристалах силікосиленіту, які дозволили одержати зображення та інтерферограми з роздільною здатністю, наближеною до 1 мкм.