Bulgarian Chemical Communications, Volume 48, Special Issue G (pp. 67-70) 2016

Characterization of photoinduced periodic microstructures by digital in-line holographic microscopy

I. T. Peruhov and E. M. Mihaylova*

Department of Mathematics, Informatics and Physics, Agricultural University Plovdiv, Bulgaria,

Received October 10, 2016; Revised November 20, 2016

Digital in-line holographic microscopy (DIHM) was used for the first time for visualization and characterization of periodic microstructures in photopolymers. The method provides virtual focusing throughout the depth of the sample from a single hologram and quantitative information about the intensity and phase distribution can be obtained.

A digital in-line holographic microscope, developed at the Agricultural University Plovdiv, was used for characterization of periodic microstructures photoinduced in Bayfol HX200 photopolymer. Intensity and phase images of a photopolymer diffraction grating have been digitally reconstructed. DIHM proves to be an efficient new approach for visualizing periodic microstructures in holographic photopolymers.

Keywords: digital in-line holographic microscopy, photoinduced periodic microstructures, diffraction gratings, photopolymer

INTRODUCTION

Digital in-line holographic microscopy (DIHM) is a relatively new microscopic technique showing distinctive advantages over conventional microscopy. Unlike conventional light microscopy, in-line holographic microscopy proposed by Gabor [1] can give visual information about an object not only in the focal plane. It has the ability to acquire holograms fast and reliably and to extract the amplitude and phase of the optical field simultaneously. As the hologram is recorded digitally one can afterwards apply different image processing methods in order to extract information at will.

In contrast to off-axis setups, the in-line setup is less sensitive to vibrations because it does not involve beam splitters, mirrors or lenses. This imaging technique is also called “lensless imaging” [2, 3, 4], as it involves no lens between the object and the sensor.

Digital in-line microscopy is very suitable for investigating transparent objects. Separate images corresponding to different focal planes can be calculated from the hologram without time consuming mechanical scanning used in conventional microscopy. One can extract both amplitude and phase information by holography. It is possible to reconstruct a 3D image or a stack of 2D images.

Photopolymers are extensively studied advanced materials for holographic recording. The visualization of photoinduced periodic microstructures in photopolymers is necessary for their full characterization [5, 6]. Babeva et al. [5] employed White Light Interferometry (WLI) to visualize the formation of surface relief profile in photopolymerisable systems, when illuminated with a focused beam of light. Trainer et al. [6] used Atomic Force Microscopy (AFM) to scan the photopolymer layers immediately after holographic exposure in order to visualize the surface relief periodical profile.

Both of the methods described above are suitable only for visualization and characterization of the surface profile of periodic microstructures. Another common feature of the WLI profilers and AFM is the necessity of multiple scans, of the surface under investigation, in order to visualize its profile. We suggest an application of digital holographic microscopy as a quick and inexpensive, but very sensitive method to directly observe and characterize the periodic microstructures inscribed in a holographic photopolymer.

We used successfully digital in-line holographic microscopy for the first time to visualize in depth the intensity and phase modulation in volume diffraction gratings (VHGs).

*To whom all correspondence should be sent:
E-mail: emmihaylova@gmail.com

EXPERIMENTAL SET-UP

The DIHM presented in this paper was developed at the Agricultural University of Plovdiv. The light source is a diode laser (Lasiris) with wavelength of 673.2 nm and output of 6.98 mW. The intensity of the illumination, focused onto pinhole is controlled via a polarizer (Fig. 1). The spherical wave emerging from the pinhole illuminates the object. The perturbed by the object and the unperturbed wave interfere and are recorded as a hologram on a CCD sensor and stored in a computer. The monochrome camera WAT-902DM with resolution: 570TVL, effective pixels 768(H) x 494(V) and unit cell size 6.35 μm(H) x 7.4 μm(V) is used in the DIHM set-up.

The intensity and the phase of the object are reconstructed by numerical computer calculations [7].

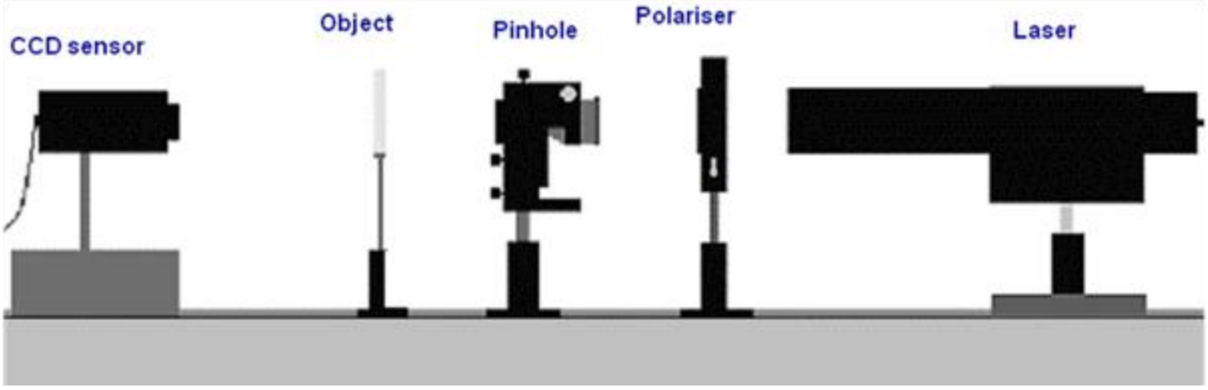


Fig. 1. Optical set-up of the digital in-line holographic microscope.

RESULTS AND DISCUSSIONS

A two-beam holographic optical set-up was used to record un-slanted transmission gratings using a 532 nm diode laser. Diffraction gratings were recorded in Bayfol HX200 photopolymer layers at a spatial frequencies of 100 l/mm. Bayfol HX200 is a light-sensitive, self-developing photopolymer film which can be used to produce phase holograms in the form of volume reflection and volume transmission holograms. Bayfol HX200 can be recorded with appropriate laser light within the visible spectral wavelength range from 440 nm to 671 nm. For hologram formation no further post-treatment is necessary, e.g. neither wet nor thermal treatment. The photopolymer can be used for recording of a variety of types of volume holograms.

Digital in-line holographic microscopy was employed to visualize the microstructure of the diffraction gratings. The diffraction gratings were positioned at a distance of 23.8 cm to the CCD sensor and 3.2 cm to the pinhole of the spatial filter.

Figures 2 – 4 show the experimental results for the visualisation of a diffraction grating by DIHM. Both the reconstructed intensity and the reconstructed phase give reliable information about the spatial frequency of the grating. The structure of the grating was investigated in depth. The reconstruction of the hologram was performed numerically at steps of 2 μm inside the photopolymer layer. It is clearly shown that the digital in-line holographic microscopy can be easily applied for in depth characterization of periodic microstructures photoinduced in holographic photopolymers.

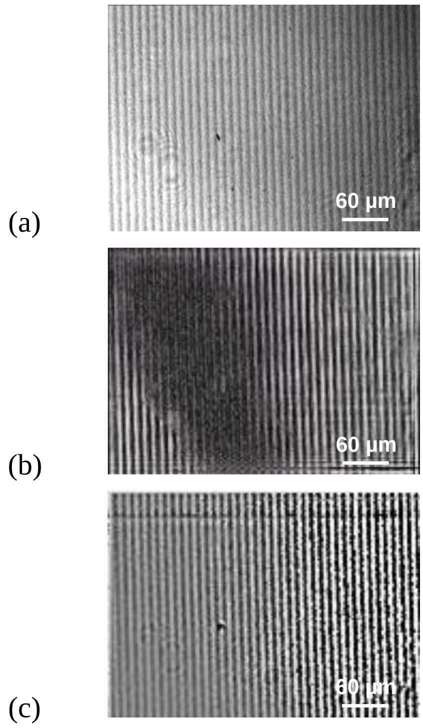
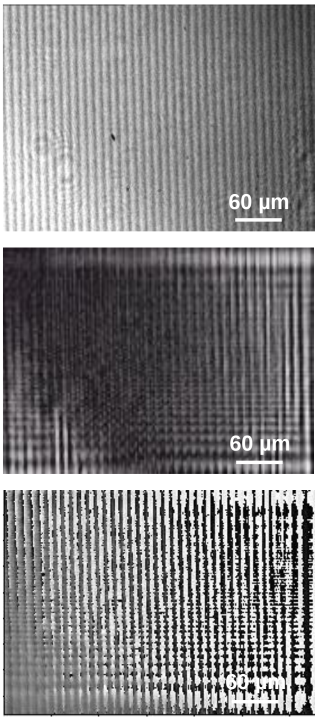


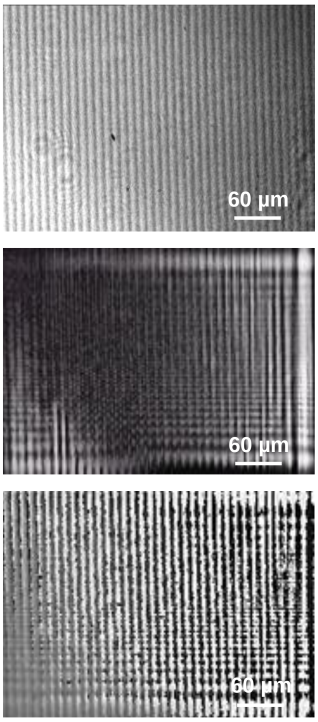
Fig. 2. Images of diffraction grating with spatial frequency of 100 lines/mm recorded in Bayfol HX200 photopolymer: a) a digital hologram; b) reconstructed intensity on the surface of the photopolymer layer; c)

reconstructed phase on the surface of the photopolymer layer.



(a)
(b)
(c)

Fig. 3. Images of diffraction grating with spatial frequency of 100 lines/mm recorded in Bayfol HX200 photopolymer: a) a digital hologram; b) reconstructed intensity at 2 µm depth inside the photopolymer layer; c) reconstructed phase at 2 µm depth inside the photopolymer layer.



(a)
(b)
(c)

Fig. 4. Images of a diffraction grating with spatial frequency of 100 lines/mm recorded in Bayfol HX Photopolymer: a) a digital hologram; b) reconstructed intensity at 4 µm depth inside photopolymer layer; c) reconstructed phase at 4 µm depth inside the photopolymer layer.

CONCLUSIONS

Digital in-line holographic microscopy was successfully used for in depth characterization of periodic microstructures photoinduced in Bayfol HX200 photopolymer. It was demonstrated that digital in-line holographic microscopy can be used to visualize photoinduced periodic microstructures, recorded in holographic photopolymers.

Unlike conventional light microscopy, the method of in-line holographic microscopy proposed here provides virtual focusing throughout the depth of the diffraction grating by the use of a single hologram.

Both the reconstructed intensity and the reconstructed phase give reliable information about the spatial frequency of the grating.

It is clearly shown that the digital in-line holographic microscopy can be easily applied for in depth characterization of periodic microstructures photoinduced in holographic photopolymers.

DIHM proved to be an attractive novel tool for in-depth investigation of volume holographic gratings (VHGs), which have been intensively developed for applications such as data storage, optical correlators, optical information encryption, fiber optic communication and spectroscopy.

Acknowledgements: *This work was supported through the grant "Digital Holographic Microscope for Biological Applications" from the Agricultural University of Plovdiv.*

REFERENCES

1. D. Gabor, *Nature*, **161**, 777 (1948).
2. L. Repetto, E. Piano, and C. Pontiggia, *Optics Letters*, **29**, 1132 (2004).
3. C. P. Allier, G. Hiernard, V. Poher, and J. M. Dinten, *Biomed. Opt. Express,* **1,** 762 (2010).
4. J. R. Fienup, *OSA Technical Digest*, IMD2 (2010).
5. K. Trainer, K. et al., *Conf. Proc. of the Intern. Commission for Optics Topical Meeting on Emerging Trends and Novel Materials in Photonics*, **1288**, 184 (2009).
6. T. Babeva, D. Mackey, I. Naydenova, S. Martin, V. Toal, *Conf. Proc. of the Intern. Commission for Optics Topical meeting on Emerging trends and novel materials inphotonics*, **1288**, 43 (2009).
7. M. Seifi, C. Fournier, L. Denis, HoloRec3D (2012).

ХАРАКТЕРИЗИРАНЕ НА ФОТОИНДУЦИРАНИ ПЕРИОДИЧНИ МИКРОСТРУКТУРИ ЧРЕЗ ЦИФРОВА ЛИНЕЙНА ХОЛОГРАФСКА МИКРОСКОПИЯ

И. Т. Перухов и Е. М. Михайлова

Катедра „Математика, информатика и физика", Аграрен Университет Пловдив, България

Постъпила на 10 октомври 2016 г.; коригирана на 20 ноември, 2016 г.

(Резюме)

За първи път използваме цифрова линейна холографска микроскопия (ЦЛХМ) за визуализиране и характеризиране на периодични микроструктури във фотополимери. Предложеният метод позволява виртуално фокусиране в дълбочина на образеца от една единствена холограма и получаването на количествена информация за разпределението на интензитета и фазата.

Цифров линеен холографски микроскоп, разработен в Аграрен Университет Пловдив, е използван за характеризиране на периодични микроструктури, фотоиндуцирани във фотополимер Bayfol HX200. Образи на интензитета и фазата на дифракционни решетки са реконструирани числово. Показано е, че ЦЛХМ е ефикасен нов метод за визуализация на фотоиндуцирани периодични микроструктури във фотополимери.