Formation and Analysis of Dot-matrix Holograms

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In the present research we have fabricated and investigated dot-matrix hologram in the photoresist. Using X-Y motorized translation stage we have covered the substrate with diffractive pixels. Dot-matrix pixels in the photoresist where formed by laser beam interference lithopgraphy (LIL) employing He-Cd (441.6 nm) laser. A simplified Diffractive Optically Variable Imaging Device (DOVID) allowing quantative image analysis was formed from the array of two different orientation difractive pixels. The orientation of the diffraction grating in the single pixel was changed using rotational motorized stage. The sample was analysed opticaly demonstrating its capabilities of suppression and addition of the "LT" image and the baground. Diffraction efficiency of single pixels estimated using diffraction stand and employing three different lasers: He-Ne 632.8 nm, DPSS 532 nm and He-Cd 441.6 nm was performed to demonstrate efficiency of the simplified dot matrix hologram. The original microrelief of the DOVID formed in the photoresist could be transferred to the shim for the mass production by thermoembosing or UV imprinting.
Keywords: dot-matrix hologram, laser beam interference lithography, dot matrix origination, diffraction efficiency.

INTRODUCTION

The security printing and brand authentication make up over 60 % of the holographic market and are the most important for the holograms industry. Most of the security holograms are so called Optically Variable Image Devices (OVID) or Diffractive Optically Variable Imaging Devices (DOVIDs). The diffractive pixel or dot matrix holograms usually are used in OVID for image formation in security holograms [1]. Dot-matrix holograms are becoming an increasingly popular form of hologram for both security and decorative purposes. One of the important fields of application of synthetic diffractive structures is optical document security [2]. The hologram produced using dot matrix technology is considered to be the most secured hologram internationally. This kind of technology allows creating of originals of holograms with a resolution of up to 10 micrometers. Because they are designed on computer, dot matrix holograms offer the end-user greater design flexibility than more traditional forms of holography. Dot-matrix holograms consist of millions of tiny diffraction gratings, or "holopixels", oriented at different angles and arranged in a two-dimensional array, i. e. the images on a dot-matrix hologram contain many two-dimensional (2D) dots with different grating orientations and different grating pitches [3]. Controlling the angle, exposure, size, shape, and spacing of every holopixel in the hologram, allows the end-user a wide range of visual effects. When illuminated with white light the holopixels break up the light into a spectrum of colours and redirect the light at various angles to form a kinetic hologram image. The hologram includes elements that cannot be manufactured using other optical of printing technologies. The various kinds of features are possible in this type of origination (concealed images that usually have the form of very thin lines and contours; high resolution line patterns with continuous visual changes of colour along each separated lines, micro and nanotexts, covert laser readable image, etc.).

A dot matrix hologram comprising an array of small diffractive pixels is generated by laser beam interference lithography method. Each of diffractive pixels contains plane-wave diffraction grating i.e. the interference fringes (lines) recorded in the pixel are straight, parallel to each other and have specified orientation therefore each pixel can diffract light at a different angle [4].

The image generated by dot-matrix hologram depends on placement of diffractive pixels, diffraction grating orientation and period in each pixel [5]. Usually two techniques, spot-shaping and pixel-shifting, are adopted for improving sparkling and kinetic visual effects of dot matrix hologram in the experiments [6]. Pixel position, orientation and spatial frequency in such holograms can be determined in two ways: a) by bit-mapped computer images, b) by computer software algorithms. These processes are termed a dot-matrix origination. The first from above mentioned is the simplest one – this type of hologram can be generated from a single computer image.

In the present research we have fabricated and investigated dot-matrix hologram in the photoresist employing laser beam interference lithopgraphy. Using X-Y motorized translation stage we have covered the substrate with diffractive pixels. Diffraction efficiency of the single pixels, as a quantative parameter of the final dot matrix, was estimated using a diffraction stand and employing three different lasers.

EXPERIMENTAL

Fig. 1 illustrates the first two steps of the dot-matrix hologram origination process used in the experiment. At the first step, the original computer generated bit-mapped color image (Fig. 1, a) is converted to the 8-bit gray scale image (using Photoshop software) (Fig. 1, b). In the second step each pixel of the gray scale image is converted (Fig. 1, d) to the appropriate component of the virtual array. Each component represents the orientation angle

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value (Fig. 1, e), which corresponds to the gray level value (Fig. 1, c) of the appropriate pixel in the gray scale image. In the next steps all the data of the virtual array are used to drive the computer controlled motorized X-Y stage hereby positioning and illuminating each pixel area on the photoresist surface. In this manner, generation of one pixel after another continues until each diffractive pixel with defined orientation is created in the appropriate position.

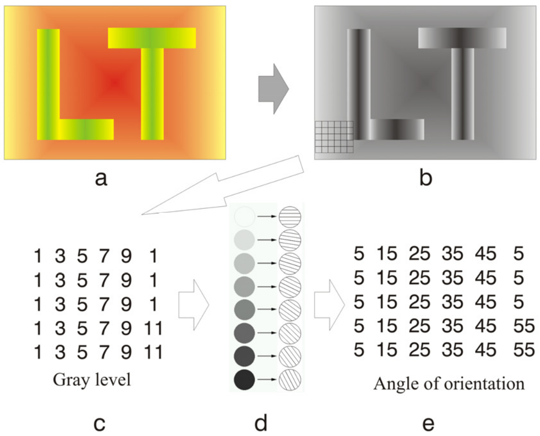


Fig. 1. Principles of the first two steps of the dot-matrix hologram origination process

To make a quantitative analysis of the dot matrix hologram we performed the simplified dot matrix hologram origination process using conversion of computer generated bit-mapped (Fig. 2, a) image to the black and white image (Fig. 2, b). In this manner the gray scale image contained only two levels of the gray scale value. It was followed by black and white image conversion to virtual two-dimensional array of components (Fig. 2, c) with defined orientation angle with respect to the vertical. An angle of 81° was used for orientation of the characters ”LT” and underling components (“A” type orientation). All components for the image background were orientated by 90° angle (“B” type orientation). Thus only first two orientation values from described hologram (Fig. 1, e) were used. Optical approach of the used experimental setup is presented in the Fig. 3, a. The glass substrate S (size 21 mm × 18 mm × 3 mm) spin coated with a Microposit® Shipley 1805® photoresist layer (PR) (thickness ~400 nm) was used for the hologram formation (Fig. 3, b). The image generated by a dot matrix technique (Fig. 4, b) was recorded with an optical microscope and analyzed employing ImageJ (1.33u version) software. The micrographs of the elements of produced dot matrix hologram (Fig. 5) were taken in reflection mode.

He-Cd laser with wavelength of 441.6 nm (~50 mW) was used for dot matrix hologram origination process. Laser beam radius was 1.2 mm approximately. Transmission diffractive grating were employed as the beam splitter (BS) (Fig. 3, a) as described in [7, 8]. From the beam splitter two beams of the He-Cd laser were converged into one point on photoresist surface by two aluminum-coated mirrors (ACM) (Fig. 3, a). The beams overlapped on the photoresist surface generating pattern of 1.1 square millimeters area approximately. Diffractive pixel formation was accomplished illuminating this area for 0.2 s. Next diffractive pixel was produced when the sample was

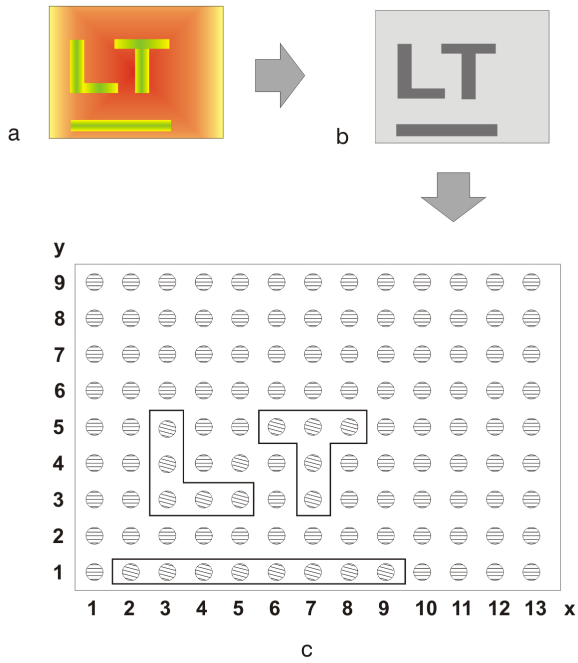


Fig. 2. Dot matrix hologram origination process with two levels of gray scale: a, b – conversion of computer generated image, c – two-dimensional array of components with the defined orientation angle

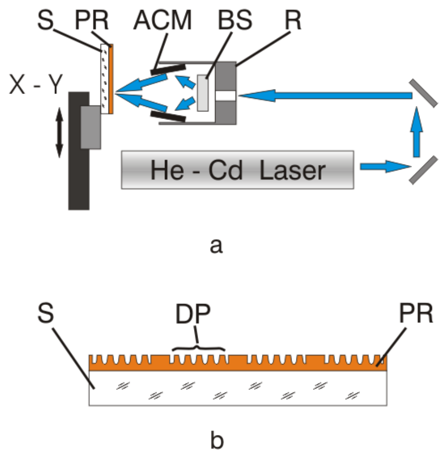
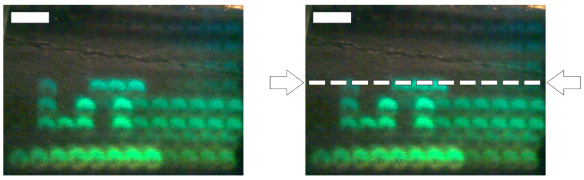


Fig. 3. Dot matrix hologram origination process: a – experimental setup (X-Y – translation stage, S – substrate, PR – photoresist, ACM – aluminum-coated mirrors, BS – beam splitter, R – motorized rotation stage); b – simplified cross-section view of produced transparent surface relief dot matrix hologram (DP – diffractive pixel)

moved (by 1.5 mm step) to the appropriate pixel position by the computer controlled motorized X-Y translation stage. The appropriate grating orientation angle for each pixel was achieved by rotation of two aluminum-coated mirrors mounted on a motorized rotation stage (R) (Fig. 3, a). All the coordinates of each pixel position and orientation angle values were taken from the above mentioned computer generated two-dimensional virtual array. When all the positioning and exposure steps were accomplished the illuminated areas of the photoresist were developed in an appropriate developer producing a simplified transparent surface relief dot matrix hologram with ordered distribution of the diffractive pixels (DP) on the photoresist surface (Fig. 3, b).

RESULTS AND DISCUSSIONS

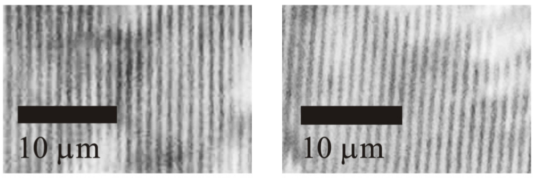
Fig. 4 represents view of the produced simplified transparent surface relief dot matrix hologram. It consists of 117 diffractive pixels in 13 columns and 9 rows (Fig. 4, a) with “A” and “B” type orientations of the pixels as was described above.



a b

Fig. 4. View of the recorded simplified transparent dot matrix hologram: a – illuminated with incandescent lamp and viewed at normal angle to the hologram surface; b – image measurements were accomplished along the dashed line between two arrows as described in the text below (length of the white marker is 3 mm)

Micrographs of two diffractive pixels are presented in the Fig. 5 (a and b). Both pixels contain diffraction grating of equal period with predefined “A” and “B” type orientations (Fig. 5, a and b respectively). Analysis of the micrograph showed that period of the produced gratings (~1.1 µm) is close to the commonly used values (1125 nm…1250 nm) in DOVIDs [6].



a b

Fig. 5. Micrographs of dot matrix hologram: the diffractive gratings of “A” and “B” type orientations

This simplified transparent dot matrix hologram posses OVID capability to select different wavelengths (Fig. 6, a and b). The hologram also demonstrates capability of suppression (Fig. 6, a, b and d) and addition (Fig. 6, c) of the different images when it is viewed from the different angles. Just two types of orientation of the pixels in the hologram enabled us to make a simple control of the generated image. Intensity distribution of diffracted light measured along the virtual line between two arrows (Fig. 6, a and c) was used to describe optical properties of the hologram. From Fig. 7 (ImageJ analysis of the micrographs of the hologram) one can see that in the case of background image suppression (Fig. 7, upper line with the circles) the intensities of main image – characters ”LT” are significantly higher then in the case of characters LT and background images addition (Fig. 7, continuous line below). Image addition from the differently oriented pixels takes place when illuminating light comes along the direction corresponding to the mean line of normal for both orientations. In this case the illumination angle for both pixels are away from the optimal therefore the diffraction efficiency is rather low.

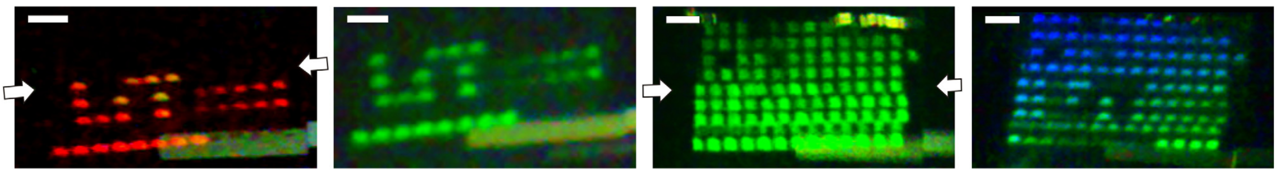
Diffraction efficiency measurements for the single pixel of “A” (Fig. 2, c; column 13 row 1) and single pixel of “B” (Fig. 2, c; column 3 row 4) type orientation were done to define quantitatively quality of the dot matrix image. Three lasers with wavelengths of 633, 532 and 441 nm and a photodiode were employed in a diffraction measurement stand. More detailed diffraction efficiency measurements are described in [8, 9].

The relative diffraction efficiency measured for “A” type orientation and different light wavelengths is shown in Fig. 8. The summarized results of calculated absolute diffraction efficiency for the first diffraction order (averaging both “–1” and “+1” efficiencies) are presented in Table 1.

Table 1. Calculated absolute diffraction efficiency for the first diffraction order

Angle, degrees	Absolute diffraction efficiency		
	Wavelength, nm		
	633	532	441
90	13 %	13 %	3 %
81	5 %	11 %	5 %

The calculated absolute diffraction efficiency values presented in the Table 1 are comparable with the maximum theoretical value (33 %) for thin photoresist phase holograms [10].



a b c d

Fig. 6. Images generated by a dot matrix hologram and viewed at different angles. A white marker in a left upper corner of image is 3 mm long. The white arrows indicate the place of virtual line (see Fig. 4, b) along which the image measurements were performed

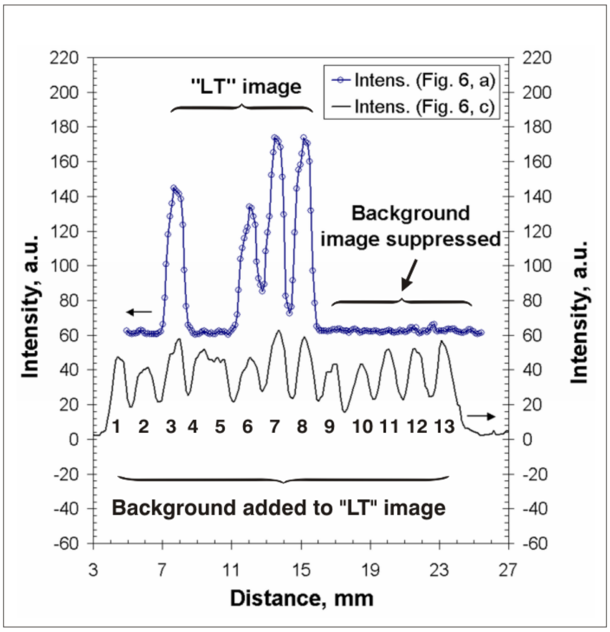


Fig. 7. Suppression (Fig. 4, a) and addition (Fig. 4, c) of different images by dot matrix hologram. At the bottom of the graph the numbers of columns are indicated (accordingly to numbers in Fig. 2, c). Intensity for the first line with the circles was normalized adding constant value (60) for picture clearance

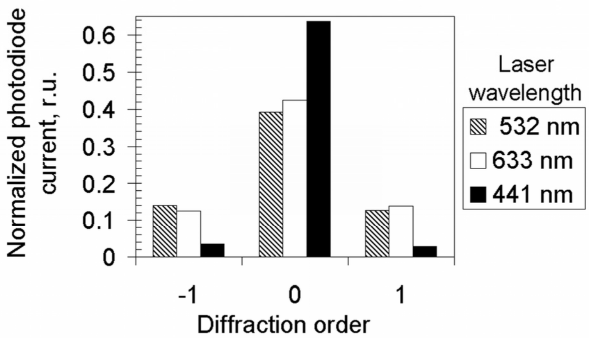


Fig. 8. Relative diffraction efficiency measured for different light wavelengths

CONCLUSIONS

In this work we present the application of laser beam interference lithography for dot-matrix hologram origination processes. The simplified dot-matrix hologram was produced using He-Cd laser and photoresist coated glass substrate. The grating period of diffractive pixels was 1.1 μm. Produced dot-matrix hologram demonstrates its capability of suppression or addition of different images (OVID capability). Transmission diffraction efficiency measurements showed 13 % of absolute diffraction efficiency in the first diffraction order with highest efficiency for the green wavelength (532 nm).

Acknowledgments

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