Microelectronic Engineering 87 (2010) 2332–2337

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

E-beam lithography of computer generated holograms using a fully vectorial 3D beam propagation method

Raimondas Petruškevičius [a], Jonas Baltrusaitis [b,*], Darius Kezys [a], Marius Mikolajūnas [c], Viktoras Grigaliūnas [c], Darius Viržonis [d,**]

[a] Institute of Physics, Savanorių pr. 231, LT-02300 Vilnius, Lithuania
[b] Department of Chemistry and Central Microscopy Research Facility, University of Iowa, Iowa City, IA 52242, USA
[c] Institute of Materials Science of Kaunas University of Technology, Savanoriu 271, LT-50131 Kaunas, Lithuania
[d] Panevėžys Mechatronics Center, Laboratory of Micro and Nano Technologies, Panevezys, Lithuania

ARTICLE INFO

Article history:
Received 21 September 2009
Received in revised form 23 February 2010
Accepted 5 April 2010
Available online 10 April 2010

Keywords:
Fully vectorial beam propagation method
E-beam lithography
Computer generated hologram

ABSTRACT

A fully vectorial 3D beam propagation method (BPM) has been applied to obtain a required pattern of computer generated hologram (CGH) with a variable profile of four phase levels. The computer reconstruction of the CGH image having one and two focal spots was performed by application of the fully vectorial 3D BPM method. After transferring the CGH by EBL technique an adequate phase profile was obtained. Inter-level parameter method was developed to obtain the estimated an electron beam dose required for the even topographical patterning. Using this method, an EBL exposure dose determined to achieve the required relief amplitude of 1.29 μm was 43 μC/cm^2. The manufactured holograms showed that the overall proposed production process, from the 3D BPM computer simulation to e-beam lithography, can be used to obtain good quality product with reasonable time and computational resources.

1. Introduction

In the recent years three-dimensional (3D) phase-profile structures became widely used in microelectronic devices, such as photonic band gap crystals, diffractive optical elements (DOEs), diffraction gratings, computer generated holograms (CGHs), opto-electromechanical micro- and nanodevices. The main distinguishing feature of these structures is variable profile [1–5]. The performance and properties of these devices depend on accuracy of the underlaying 3D manufacturing process. It is therefore very important that the fabrication processes of the 3D structures ensure the highest level of dimensional accuracy [6–8].

A well-known 3D lithography technique is based on the solidifying the liquid monomer in a layer-by-layer manner [9]. This common technique is time consuming (especially when many layers are needed) and has a low spatial resolution. Furthermore, this technique is not applicable to silicon substrates [9].

An alternative way of manufacturing the 3D phase-profile structures is a grey scale lithography [8]. Typical grey scale 3D lithography process consists of two phases: patterning of 3D structure in the resist layer followed by the substrate (usually silicon or quartz) etching through the remaining resist film. This method is used whenever the final structure should be formed in the substrate. During the DOE manufacturing another method is commonly applied: metal is deposited over the surface of the 3D structured resist film using the vacuum evaporation or electrochemical deposition technique, followed by nickel electroplating to make a master stamp. Fabricated metal master stamp then can be used to replicate 3D structures in polymers by UV hardening, hot stamping, die-casting or other techniques. Grey scale photolithography or electron beam lithography (EBL) can be employed for the initial patterning of 3D structures in the resist film. In both cases the exposure dose is controlled according to the grey scale level. In the grey scale photolithography intensity of the transmitted through the mask ultraviolet light (UV) is spatially controlled, e.g., by varying the size or density of opaque and transparent pixels [10].

Main advantage of EBL over the photolithography technique is a higher spatial resolution (within few nanometers for EBL, tens of nanometers for deep UV lithography and hundreds of nanometers for conventional UV photolithography). Additionally, a need for photomasking is eliminated. These advantages create a potential of much higher precision standards for patterning of phase-profile 3D structures, EBL becoming a powerful 3D lithography tool with a resolution of several nanometers [11].

Several computational methods have been developed to model the holograms, based on the iterative Fourier transform methods (IFTA) [12], Fourier modal method [13], boundary integral method

* Corresponding author. Tel.: +1 319 335 8142; fax: +1 319 384 4469.
** Corresponding author. Tel.: +370 45 434247; fax: +370 45 516161.
E-mail addresses: raimisp@ktl.mii.lt (R. Petruškevičius), jonas-baltrusaitis@uiowa.edu (J. Baltrusaitis), marius.mikolajunas@ktu.lt (M. Mikolajūnas), viktoras.grigaliunas@ktu.lt (V. Grigaliūnas), darius.virzonis@ktu.lt (D. Viržonis).

0167-9317/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.mee.2010.04.001

[14], finite-difference time-domain (FDTD) method [15] and others. While Fourier transform based methods suffer from parasitic coherent interference effects related to the periodic boundary conditions [13], the boundary integral and FDTD methods are

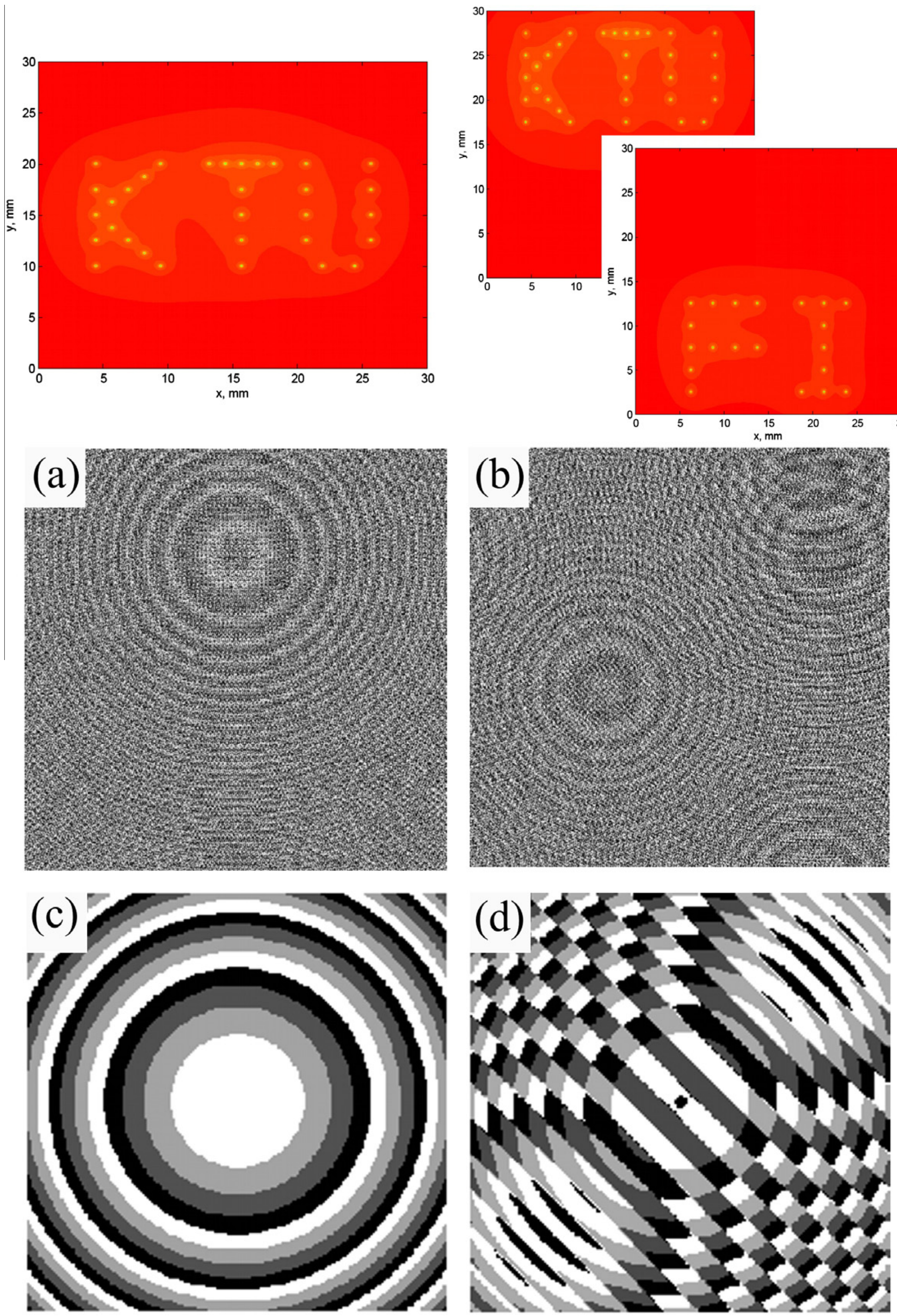

Fig. 1. CGHs presented as a grey scale raster images: (a) 2D hologram; (b) 3D hologram; (c) DOE of one 50 μm focal spot; (d) DOE of two 50 μm focal spots. 30 × 30 mm initial computer graphics used to generate 2D hologram ("KTU") and 3D hologram ("KTU" and "FI") is shown above of the corresponding hologram.