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Flying phase mask for the printing of long submicron-period stitchingless gratings

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Abstract

Long and stitchingless gratings are printed by means of a read/write head comprising a phase mask illuminated by an intensity modulated laser beam and a reference grating displacement sensor which dictates the modulation period real time. A nearly perfect grating copying is achieved by fixing the sensor grating scale and the written grating substrate on a long platform sliding under the read/write head © 2001 Elsevier Science. All rights reserved

Keywords : optical lithography; phase mask; stitching; grating ;

1. Introduction

With the emergence of diffractive effects for white light processing in flat displays for lossless color separation [1] and lossless polarization [2] the finest feature size of a microstructured surface is imposed by the wavelength of the processed light regardless of the size of the display. It is recognized that light processing down to the blue range imposes grating periods down to just above 100 nm. This represents a big challenge for manufacturing technologies.

The present paper reports on a technique allowing the high productivity printing of large size submicron

gratings by means of a small area phase mask illuminated by an intensity modulated laser beam.

Unlike all laser beam pattern generators that write gratings line by line, the present writing scheme prints several thousands lines at a time in a continuous mode without stitching errors. Unlike in a widely used technique for Fibre Bragg Grating writing [3] and in the large grating writing scheme of MIT's Nanoruler [4] the projected interferogramme is not a propagating set of fringes generated by a phase modulator in one of the branches of a Mach-Zehnder, the interferogramme is here static and intensity modulated. This allows more compactness and stability, and does not require a strictly constant displacement velocity of the printed substrate.

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2. Principle

The principle of the technique is shown fig. 1.

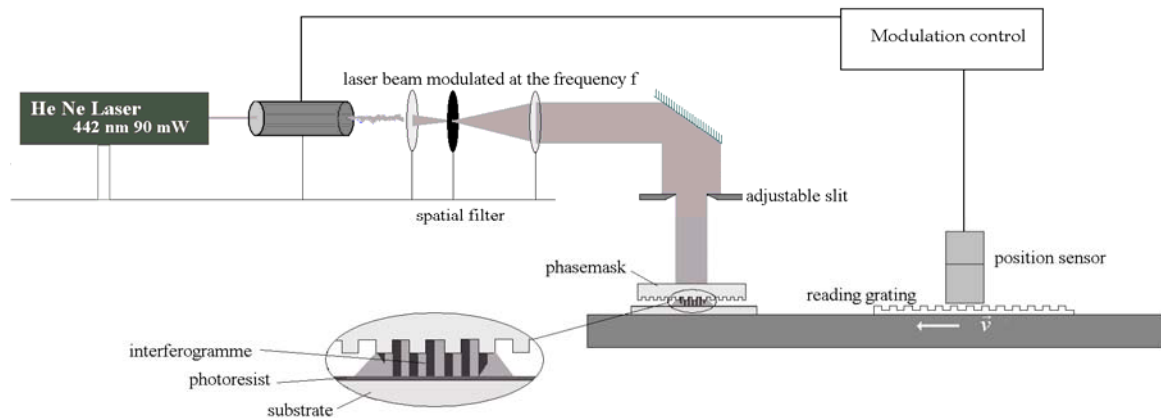


Fig. 1. Optical set up of the write on the fly technique

A photoresist spin-coated substrate is placed on a translation bench. The substrate is UV-exposed through a phase mask maintained at short and constant distance so that the two interfering diffraction orders have good spatial overlap on the resist layer. The exposure source is a He-Cd laser whose beam is modulated, filtered and enlarged. The fixed support of the writing head also holds a diffractive interferometric sensor. It is a massive steel piece fixed to the body of a heavy cast iron bench. The translation stage of the bench is a 500 mm long steel plate carrying a reference grating scale and the resist coated scale to be printed. Modulating the interferogram power permits a continuous writing of the grating regardless of the translation velocity : the modulator is driven by the signal delivered by the position sensor. The width of the adjustable slit depends on the exposure conditions i.e. the power of the source and the translation velocity of the bench.

The advantages of the proposed technique are compactness, thus low vibration sensitivity, balanced and very short optical path lengths, thus no sensitivity on the fluctuations of the refractive index of air. Moreover a blue or UV LED can possibly be used as the light source. Amplitude modulation can be adapted to give a large variety of grating groove profiles, and just needs to be locked to the signal of

the position reference sensor scale by a flexible interface electronics without the need of velocity control.

3. Interference pattern generation

The interferogramme needed for the grating printing is produced by a phase mask . In the present case this device is a simple transmission grating etched in a quartz substrate. The groove depth is optimized for maximizing the diffraction efficiency in TE polarization of two interfering diffraction orders. The overlap of the two resulting beams leads to an interference pattern under the mask. The phase mask can be used under normal or oblique incidence. In both cases, the resulting interferogramme period is wavelength independent, thus an illuminating source of broad spectral width can be used.

Ideally case, a phase mask of period Λ operating under normal incidence [5] should diffract only in the ± 1 orders as shown in figure 2. The resulting interference pattern period is $\Lambda/2$. This means that a 244 or 248 nm or even a 193 nm wavelength light beam with a 280 nm period phase mask can print the much wanted 140 nm period (70 nm CD) of a lossless broadband polarizer.

the same (0.5 μm), there is no need of any multiplication therefore the encoder signal is then directly send to the modulator driver.

In so doing, whatever the period ratio between the reference and copied gratings, and whatever the relative translation speed, each copied grating period will get the same total dose.

5. Experimental steps

5.1. Phase mask fabrication

The phase mask is a 500 nm period quartz grating optimized for operating in 0/-1 configuration. It was made by holographic exposure of a photoresist (Shipley SPR 505 A) layer. After development the grating was etched by RIBE (Reactive Ion Beam Etching) to the desired depth, i.e. 490 nm. Then the profile is checked by Atomic Force Microscope (AFM) and diffraction efficiencies are controlled optically.

5.2. "On the fly" exposure process

The "on the fly" exposure was made on a spin coated photoresist layer of 300 nm thickness on a 100 \times 100 mm² glass plate. The angle of incidence was 22° which provided the highest interference contrast. The -1st order Littrow is $\arcsin(\lambda/2\Lambda)$. The incident beam divergence, the parallelism between the substrate and the mask were controlled to avoid the parasitic fringes formation in the resist layer. The exposure dose control was adjusted by three parameters: the output power of the laser (90 mW), the slit width (1mm) and the velocity of the translation bench (1 mm.s⁻¹).

5.3. Results

The obtained 100 mm long gratings are sinusoidal with a period of 500 nm as shown figure 5. The groove depth is about 250 nm. The period uniformity along the grating track is likely to be very good as the reference grating scale is corrected. It will later be tested using a differential dual-sensor scheme allowing the determination of period variations to better than one picometer [9]. The groove profile

uniformity is good along the grating track; it is presently non uniform along the grating lines since the beam is essentially Gaussian. An improvement will be provided by giving the exposure beam a top hat profile in the direction normal to the grating track.

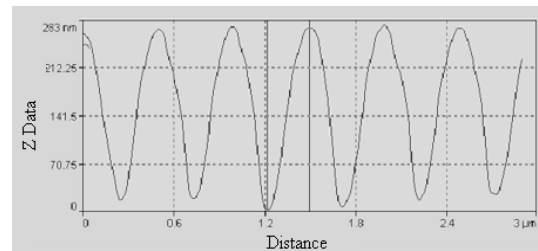


Fig. 5. AFM profile of a resist grating

6. Conclusion

In conclusion, the experimental results demonstrate the feasibility of an amplitude modulated phase mask continuous writing technique over a length which can now be easily extended to 500 mm and over. The present development is towards the measurement of the spatial frequency characteristics and a beam shaping for more uniform exposure.

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