Fabrication of Diffractive Optical Elements by FIB milling

Introduction

Diffractive optical elements (DOEs) are micro-structured surfaces that generate a required optical field at a specified location. Fabrication techniques like photolithography, micro-machining and molding, scanning laser lithography and electron beam lithography have been widely used for fabricating DOEs. However, DOEs fabricated using either photolithography or e-beam writing need to be transferred to a substrate using complex etching procedures. The Focused Ion Beam (FIB) milling process can directly etch materials of different depths or heights with a high degree of control in a single process step [1]. Compared to e-beam lithography, FIB milling is a direct-write patterning technique (maskless and resist-less process) and is a versatile technique for micro and nanofabrication of optical elements for various applications. Initial studies on the fabrication of DOEs like binary gratings, spiral phase plates and Fresnel zone plates carried out using Quanta 3D FEG dual beam FIB system are presented here.

Experimental Work

The intensity and phase profiles of the optical field were simulated before and after the diffractive optical element using scalar diffraction formulae and the optical field intensity profile was calculated at the image plane. Pattern generation was carried out using MATLAB. The generated pattern was converted to a 24 bit bmp file and loaded into the FIB system. In the case of multilevel patterns, multi binary masks were prepared and stacked. For gradient patterns, a grey scale mask was prepared. The grey values were correlated to the FIB dose values.

The material removal rate by sputtering is dependent not only on the substrate material, but also on parameters like the ion beam voltage and current, exposure time/pixel, spot size, resolution of the image etc. For FIB milling on substrates which are not good conductors, a proper conducting path must be given by a thin gold/aluminium coating on the substrate to ground the electrons generated and avoid beam deflection. In order to reduce the number of processing steps, ITO (Indium Tin Oxide) coated glass plates were used which has a thin conducting layer on one of the two surfaces, where the devices can be milled. The transmittance of these plates was only $\sim 85\%$. The conducting surface of the substrate is connected to the substrate using a conducting carbon tape.

The dose vs depth characterization revealed that the milled depth was only a small fraction of the set depth for Si material when glass substrates were milled. A surface profiler and an AFM, were used to measure the resulting depths. Experiments for optimization of the dose are in progress. The above experimental method was employed for the design and fabrication of binary elements like binary grating, binary Fresnel zone plates and multilevel structures like multilevel spiral phase plates etc. The SEM images of the fabricated devices are shown in Figs. 1 (a) – (d). Attempts were made for fabrication of gradient structures like blazed grating and gradient spiral phase plates. The dose variation has to be optimized. The SEM images of the two devices are shown in Figs. 2 (a) and (b) respectively.

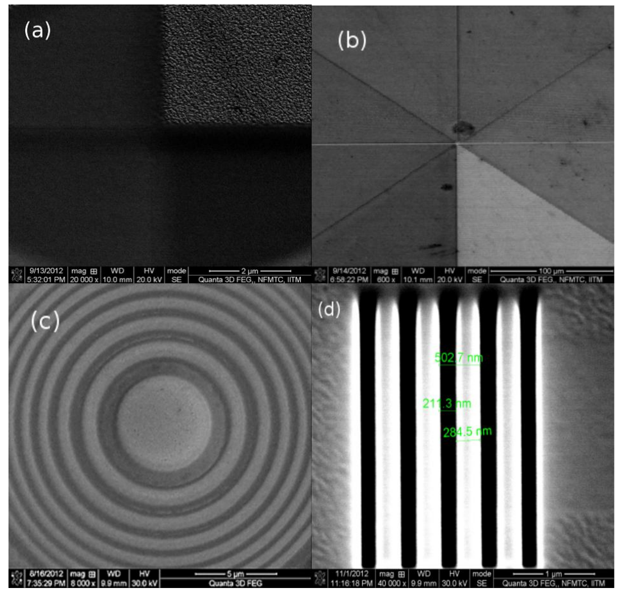

Figure 1. SEM images of (a) 4 level SPP (b) 8 level SPP (c) Fresnel zone plate (d) subwavelength grating ($\Lambda = 500\,\mathrm{nm}$).

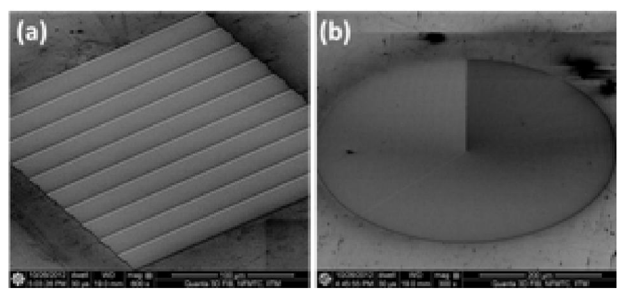

Figure 2. SEM images of (a) blazed grating (b) gradient spiral phase plate.

Conclusion

Initial studies on the fabrication of DOEs by FIB milling were carried out. Multilevel spiral phase plates, Fresnel zone plates and grating structures could be fabricated on ITO coated glass plates. We are making efforts to fabricate diffractive optical elements directly on optical fiber tip.

References

[1] Ampere A Tseng, "Recent developments in micromilling using focused ion beam technology," J. Micromech. Microeng. 14, R15–R34 (2004).

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