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J1 (Invited)

OPTICAL SURFACES FABRICATED BY THE USE OF E-BEAM LITHOGRAPHY AND THEIR APPLICATIONS

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Summary

E-beam lithography is a highly flexible method for pattern origination in micro-lithography. This flexibility makes it possible to realize novel pattern for innovative ideas with the potential of high resolution. Furthermore, continuous profiles can be realized by e-beam direct writing or by using special mask e-beam writing. Its flexibility combined with an extremely high lateral accuracy of this type of lithography is unique today and gives the potential to work in different application fields.

Even though the progress of e-beam lithography was driven especially for the rapid progress of micro-electronics and therefore, the features of commercial writers focus on the typical features of this field, this technology can be used very successfully for optics as well. Due to the increased importance of optics, adaptations and even developments of e-beam writers especially for optical applications have been done.

On the one hand, the use of e-beam writing for optical surface fabrication is motivated by the scientific vision sketched in figure 1. According to this vision which is based on the knowledge of wave optics the realization of refractive and diffractive elements [1,2] as well as artificial materials [3] is desired. The smallest charac-

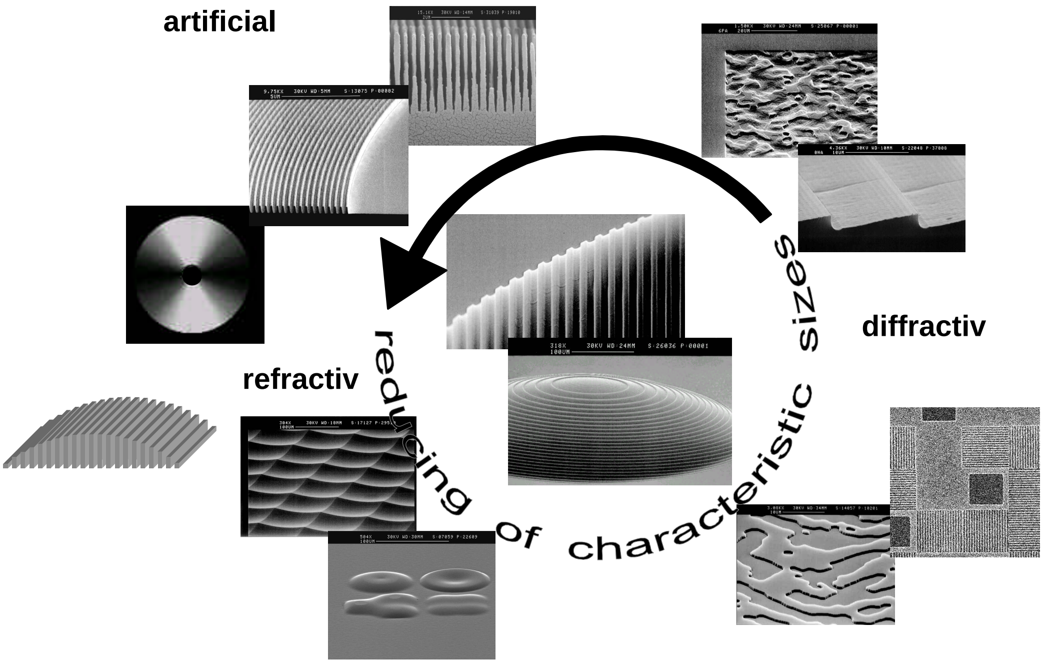

Figure 1: Vision for micro-lithography in the field of optics. Optical elements and even artificial materials can be made on the base of microstructures.

teristic size and highest pattern resolution respectively is needed for artificial materials which can be made of isotropic material and show changed index of refraction, birefringence, polarization and photonic band gap effects. Additionally, the combination of different types of optical surface profiles to *one* profile may increase the functionality of an optical surface and reduce the number of elements in a system. In this context, a big challenge is the use of an artificial material which is made by micro-lithography for the fabrication of refractive or diffractive elements.

On the other hand, e-beam writing is already applied in the industrial production of optical elements today. Typical elements are **c**omputer **g**enerated **h**olograms (CGH), linear and curved gratings, binary and gray tone masks.

The use of e-beam writing for optical element fabrication has shown attractive results in many cases (see figures 2-8), nevertheless, limitations still exist. One of the most prominent limitations is the long writing time which results in a high price of the fabricated element or even the unfeasibility of the fabrication. Stitching error and grid snapping generate parasitic grating ghosts even in zero order gratings. Furthermore the dynamic of the writing process results in thermal effects and intermittence effects which are disturbing especially the writing of continuous profiles.

The talk to be presented wants to give answers to general questions as: What kind of micro- and nano-structures are interesting for optics, which elements can be fabricated and which problems are observed in the field of e-beam writing? Strategies to solve some of these problems are discussed (e.g. [4,5]).

One example for such a solution is the fast e-beam writing of a linear grating by cell projection [4]. The writing of this grating was performed by an e-beam writer ZBA 320 (Leica Microsystems Jena). To reach a high throughput, this writer uses a variable shape beam combined with the vector scan principle. The cooperation strategy between beam and x-y-stage is “write on the fly” which means the stage permanently moves meander-like and the beam writes the pattern in a working stripe.

Usually, the variable shape beam is generated by cutting out a rectangular shape from the cross over of the electron beam. For this purpose, a rectangular aperture is imaged into the plane of a second one which is imaged again in the exposure plane. The image of the first aperture can be shifted by very fast electrostatic deflection systems (shift times below 1µs). This results in a rectangular shaped electron probe with a variable size. Every pattern has to be fractured by the available shape sizes into the minimal number of shapes and has to be “stamped” by the variable shape beam. The exposure time for a uniform dose is independent on the shape size because of the uniform current density across the shape for all sizes.

Under the condition of frequent repetitions of small patterns, the resulting fast e-beam writing can be topped by the cell projection. In our special case of a linear grating, the aperture system of the ZBA 320 was completed by an additional special grid aperture. It was designed to realize a grating shaped electron beam with a 5µm × 5µm clip (cell) of a 500nm period grating which means 10 grating lines were generated in parallel. Thus, we have got a gain of 10 in the writing speed.

Using the cell projection described above, 500nm period gratings with a size of 100mm × 100mm have been written on mask blanks which were coated with 280nm ZEP electron resist (Zion Nippon Corporation). In order to get smooth grating lines by averaging, we decided for a four-path exposure run – each with a dose of 4.25µC/cm^2 (at 2A/cm^2 current density) and a lateral shift of 2.5µm in x and y. As a result, we measured a total writing time of 3.5h for the 100mm × 100mm grating field. The quality of the whole grating has been measured interferometrically in LITTROW mount. Due to a very low stitching error of the e-beam writer we measured a wave front accuracy of better than 30nm.

References

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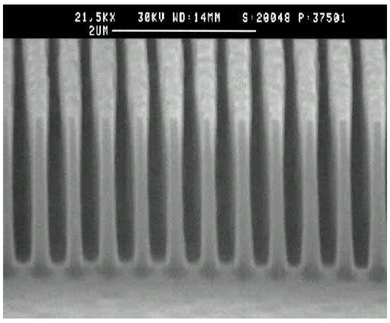

Fig. 2: 440nm period grating in quartz, 2000nm depth

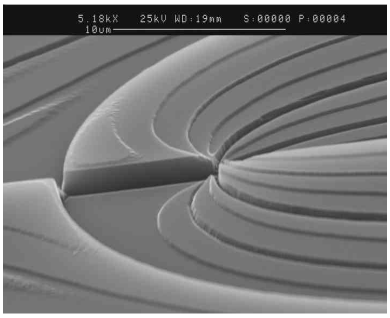

Fig. 3: Phase dislocation in quartz

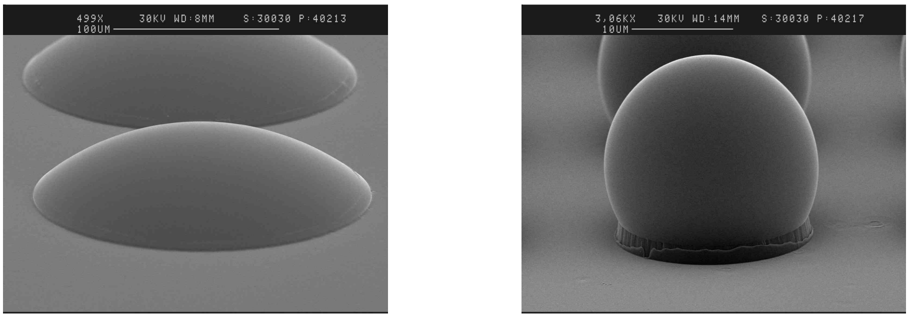

Fig. 4: Quartz lenses on a quartz substrate, diameter 20 µm

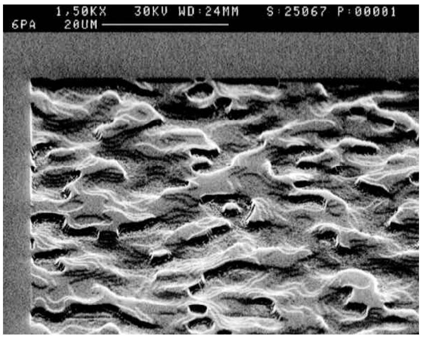

Fig. 5: Diffractive optical element 8 level, 250nm pixel size

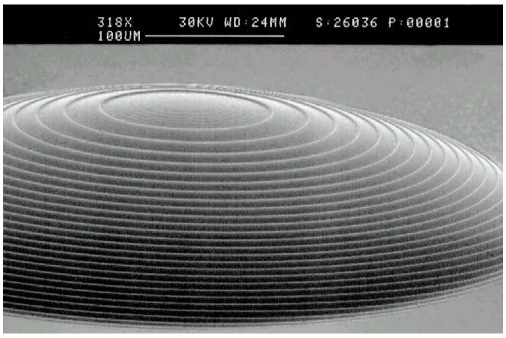

Fig. 6: Diffractive lens on a refractive lens, 50µm height

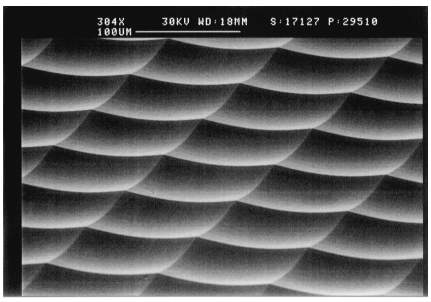

Fig. 7: Concave micro lens array single lens 100µm×100µm

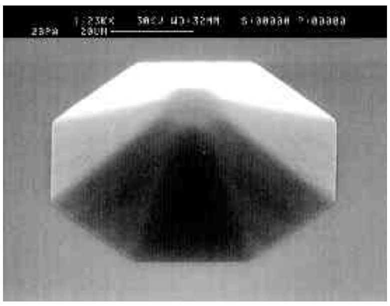

Fig. 8: Multifaceted micro prism 20 µm height