Fabrication of rotational symmetric sub wavelength grating structures

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The direct writing lithography technology allows fast and flexible prototyping of diffractive optic elements. Conventional techniques usually suffer from only moderate resolution (direct laser writing) or relatively low writing speed (e-beam writers). We present a novel technique for the fabrication of rotational symmetric grating structures with sub wavelength feature size.

1 Introduction

Rotationally symmetric structures are of growing interest with applications in diffractive optics for imaging systems, laser beam shaping or optical metrology. In laser beam shaping, rotational symmetric gratings with a period smaller than the laser wavelength allow the highly efficient intra-cavity generation of radial polarization states [1]. This is of special interest for beam shaping in thin disk lasers since this type of laser is very sensitive to intra-cavity losses. Thus, for the production of such gratings it is important to maintain high rotational symmetry and low roughness. The setup we propose for their fabrication is based on scanning-beam interference lithography (SBIL). This technique combines a conventional direct laser writing setup with interference lithography. Since our system works in polar coordinates the produced structures do not suffer from staircase artifacts which occur in conventional systems that usually work in cartesian coordinates. Furthermore, our setup provides a much higher throughput since the gratings are not written line by line, but by a several micrometer wide interference pattern.

2 Scanning-beam interference lithography (SBIL)

Scanning beam interference lithography was formerly introduced for the production of high precision reference gratings for nanometrology setups [2].
Instead of using a tightly focused laser beam to expose the substrat, two coherent laser beams meet on the surface structures thus forming an interference line pattern. The period p of this pattern can be calculated as follows:

$$p = \frac{\lambda}{2 \cdot sin(\alpha)} \qquad (1)$$

where λ denotes the laser wavelength and α the half angle between the two beams. One can see that it is possible two reach periods around the laser wavelength with a half angle of only 30°. This technique allows the efficient fabrication of large area grating structures through phase matched overlap of many grating patterns. We adapted this principle for the integration into our CLWS300 polar coordinate lithography system [3] in order to fabricate large area rotional symmetric grating structures.The working principle is illustrated in figure 1.

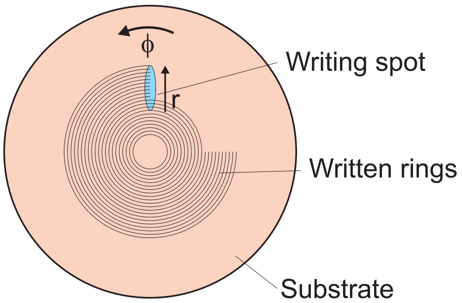

Fig. 1 *Scanning-beam interference lithography. The substrate rotates underneath the interference pattern. Thus ring patterns are generated at each rotation of the substrate.*

Since the lines are curved, the spot dimension plays an important role during the optical design of the writing system. On the one hand, to realise small grating radii it is necessary to use a narrow writing pattern. Otherwise the maxima at the spot edge would overlap the already written minima and thus would be averaged out. On the other hand, one would prefere a relatively wide spot to benefit from the advantage of writing many lines in parallel. It was found that the optimal solution is an elliptical, long and narrow spot as it can be seen in figure 2.
During the exposure, the first patch of rings is written with an arbitary radius. After one complete rotation the writing pattern is placed at another radius so that it overlaps the written rings and a second patch is written. For that operation the phase match of the distinct ring patches is very important. The

averaging of the rings in the overlap zone leads to a reduced contrast and spatial homogeneity of the grating when not placed exactly in phase.

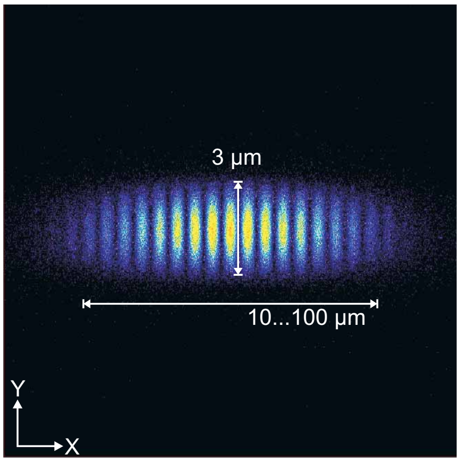

Fig. 2 *Interference pattern used for exposure. The elliptic spot shape allows ring radii of less than 50 μm without significant contrast degradation*

Moving interference fringes can be caused by a placement error of the linear stage moving in the radial direction or by phase shifts between the two interfering beam e.g. caused by air turbulences. In order to stabilize the interference pattern with respect to the radial coordinate, a fringe locking mechanism will be implemented which takes these two error sources into account.

3 Setup

A scheme of the very compact setup is shown in figure 3. It mainly consists of the following sections: radial placement, beam shaping, beam separation and recombination, phase modulation and detection. The radial placement is done by a linear air bearing stage whose position is controlled with a Mach-Zehnder-Interferomer. A set of cylinder lenses allows to independently shape the beam in two orthogonal directions, thus creating an elliptic pattern outline. The single laser beam is later split by a linear diffraction grating. A second grating diffracts the two separated beams back, parallel to the optical axis. The two beams are then directed into a microscope objective which recombines them in the focal plane. The second grating can be moved perpendicular to the line orientation. Thus, it is possible to create a phase shift between the two interfering beams, which in turn causes the fringe movement. The resulting intensity distribution can be expressed as follows:

$$I(x) = 4I_0 cos^2\left(\frac{2\pi}{\lambda} x sin(\alpha) + 4\pi \frac{\Delta z}{g}\right) \qquad (2)$$

in which *x* denotes the coordinate in pattern plane according to figure 2, λ the laser wavelength, α the angle between the interfering beams, Δz the displacement of the second grating and *g* the grating constant.

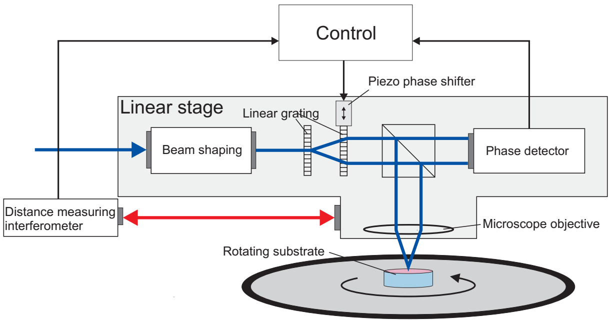

Fig. 3 *Scheme of the SBIL-setup*

The error signal from the linear stage interferometer serves as setpoint for the phase shift control. After setting an arbitary phase as reference, a movement of the linear stage will initiate a movement of the piezo actuator and thus shift the fringes accordingly. A phase detector closes the control loop and additionally allows to compensate any externally caused phase shift.

4 Conclusion

We have presented a new setup for the production of rotational symmetric grating structures with scanning-beam interference lithography. It uses a grating based approach for beam splitting and fringe locking which allows compact system design with only one moving element. With the shown setup we expect to be able to fabricate structures with periods as small as 500 nm covering a 300 mm wafer in less than one hour.

5 Acknowledgements

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References

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