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Integration of an ultraviolet direct write laser and its red differential confocal probe.

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The maskless photolithography method direct laser writing (DLW) can achieve sub-100-nm writing resolution if the photoresist is kept well on the plane of best focus of the optical system. Deviation from this plane leads to larger than intended or loss of developed areas. Here we present an approach to account for this problem through a Bessel-Gauss beam for the exposure.

1 Introduction

Especially in academic scope and small companies flexible and high resolving photolithography methods are often favourable over the large batch mask process. Essentially, a focussed laser beam is scanned over the photoresist and only turned on in areas as given by the designed structure. While this is much slower, this opens for the possibility to optimize the employed exposure optics to the highest possible resolution. Thereby, the environment can be held at standard conditions maintaining a high usability. The successful exploitation of linear absorption and non-linear absorption of the photoresist enabled the manufacturing of 3D-structures in the nanometre range [1]. Currently still uncommon is the realization of structures on arbitrarily-shaped 3D-substrates.

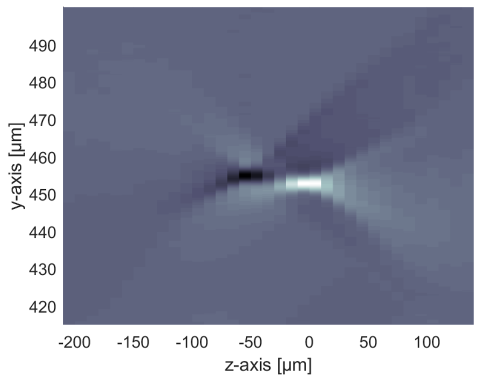

Fig. 1 *Differential plot of measured spots of the exposure- (black) and probe-beams (white). Artificial lateral spot displacement has been added for better visibility.*

Maintaining a uniform shape and a high resolution for the developed structures requires continuous tracking of the substrate surface. Otherwise the defocus of the exposure spot lead to a widening of the structures or an undesired amount of developed photoresist as the dose is lowered. Figure 1 shows focussed spots of a $M = 20\,\times$, *NA* $= 0.3$ SLWD objective measured by the knife-edge method [2]. For the spot of an 405 nm laserdiode, the intensity maximum is spread below $50\,\%$ after $\Delta_z = 10\,$µm even at this low *NA* .

This emphasises the demand for a measurement probe that can track the current surface height. A probe should work in non-contact mode, not expose the photoresist and have a to the exposure beam comparable high resolution. Highest axial sensitivity and a for control suitable signal is offered by differential arrangements such as laser focus sensing [4] or differential confocal microscopy [5]. The latter is employed in the here given system. From the second demand for the probe stems the requirement to employ a longer wavelength starting from red. This large difference lets residual axial chromatic aberration become significant [3]. Besides the exposure beam at 405 nm, figure 1 also shows a confocal probe beam of 633 nm. Both beams are axially separated by $\Delta_{12} \approx 50\,$µm.

If the probe signal is used to bring the substrate into its focal plane, the initial problem of a defocused exposure beam persists. In order to solve this, we present here our approach to employ a Bessel-Gauss beam to create a much longer axial spot for the exposure beam to include the focal plane of the probe.

2 Generating a Bessel-Gauss beam

The Bessel beam offers a very long axial spot length while maintaining and even exceed the lateral resolution capability through a thinner lateral waist for its main lobe. As a drawback it comes with a pronounced side lobes. For its advantages, the now Bessel-Gauss beam has already found its employment in measurement and material processing [6].

The Bessel-Gauss beam in this case is generated by axicons. The schematic in figure 2 shows the built exposure beam path. A Gaussian beam is generated from the collimation of a fiber-coupled 405 nm laserdiode. Two axicons are used to allow for an adjustable ring-size. To relay the Bessel-Gauss

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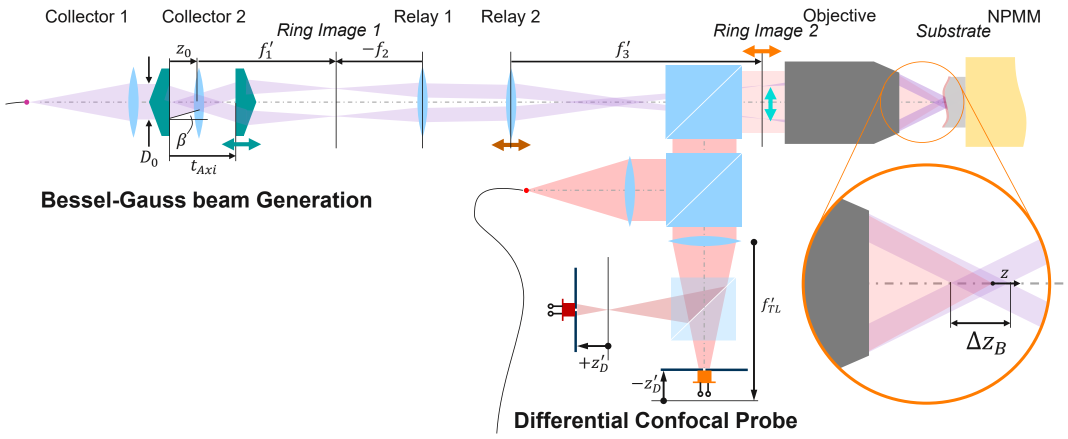

Fig. 2 *Schematic of the beam-path to generate an adjustable Bessel-Gauss beam to integrate with a given differential confocal probe.*

beam in front of the first axicon, the second collector forces the creation of the ring image. The ring image must be relayed to the back focal plane of the employed microscope objective in order to create the afocal conical beam along the substrate. By the employment of two relay lenses, this plane can be adjusted without major losses to the imaging quality.

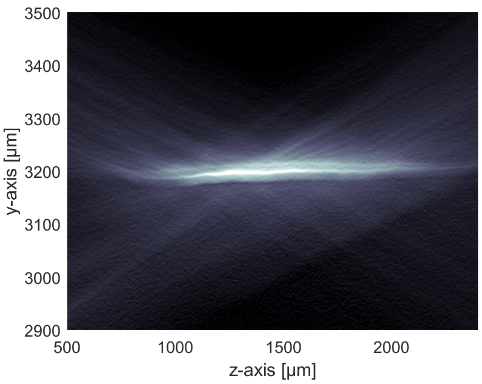

Fig. 3 *Measured focal spot of generated Bessel-Gauss beam.*

A generated Bessel-Gauss beam with very long focus is presented in figure 3. Employing the knife-edge method again, even the overlapping of the conical collimated beams can be recognized. The full-width at half-maximums are in the lateral direction $\Delta_y \approx 7.76$ µm and in the axial direction $\Delta_z = 1.09$ mm. Apparently, the beam overachieves the desired long depth of focus and would even erase the need for a surface probe. The size of the lateral spot however does not yet meet the expectation from numerical simulation. It is about four times larger. Furthermore, the lateral spot lacks uniformity over its depth. There are two major sources that caused this imperfections. Starting at the beams origin, the input Gaussian beam does not have a perfect circular cross-section, but is rather elliptical. This causes the resulting Bessel-Gauss beam to partially loose its lateral Bessel shaped spot. The second challenge arises from the co-linear adjustment of the two axicons that must be performed for the lateral dimensions as well as for tilt and jaw.

3 Conclusion

The employment of a Bessel-Gauss beam potentially can ease the integration of a processing beam with a surface probe system by its long axial spot. Our here proposed setup can already show a flexible generation of such a beam as shown in the state of the art for laser ablation. However, further improvements must be undergone to make it suitable for maskless photolithography. Besides the aforementioned imperfections, this includes the adjustment to smaller ring widths, so that the axial beam length is reduced. This should also shrink the lateral size of the generated Bessel-Gauss beam.

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