Fabrication of positionable free-standing microstructures for applications in near-field microscopy

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We present an approach for the fabrication of free-standing microstructures using 2PP with large curvatures and high geometric accuracy. The capabilities of the approach are demonstrated on a microsystem of microspheres and linking structures. These microstructures can be used e.g. for near-field microscopy.

1 Introduction

The resolution in classical light microscopy is usually restricted to half the illumination wavelength (λ/2) [1]. In recent years, the resolution has been improved by using transparent dielectric microstructures such as micro spheres or solid immersion lenses (SIL) as near-field optics. The small size of these imaging systems allows them to be in direct contact with the sample surface and to interact with the evanescent fields. The shape of the microstructures appears to be important for the imaging properties as well as their small size and refractive index. An example of microsphere-assisted microscopy is shown in Fig. 1. The classical microscope setup was extended by a microsphere consisting of SiO_2 with a diameter of 11 µm placed on the sample surface, see Fig.1 a. Within the microspheres, see Fig. 1b, the typical structure of the BluRay surface with pits and lands with a spacing of 160 nm is visualized. With this type of setup, a resolution of < 50 nm (λ/10) has already been reported [2].

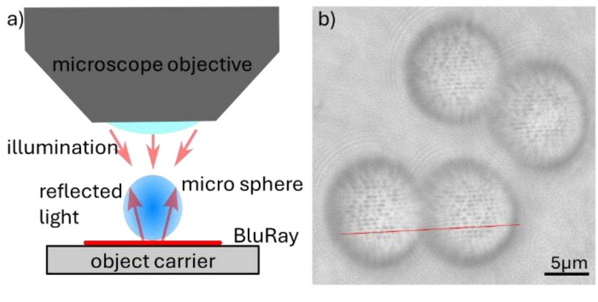

Fig. 1 *a) Schematic illustration of the enhancement of an optical microscope by a microsphere to improve resolution. b) Microscope image of a Blu-ray surface through four SiO_2-microspheres with a diameter of 11 µm. The red line is a guideline to indicate the direction of the BluRay tracks for better visualization.*

The dependence of the imaging properties on the shape of the microstructures prompt us to investigate the realization of precise optical imaging systems with dimensions in the range of a few micrometers for near-field-applications. This requires high standards in terms of shape accuracy and surface quality of the micro-optics. These requirements are currently satisfied only by SIL lenses (half spheres) or full spheres. However, the use of microspheres or SIL lenses is restricted by the limited positioning control of the micro-optics in relation to the object surface. For extending the geometry of microstructures with dimensions in the low micrometer range towards free forms and improving their positionability, 2-photon polymerization (2PP) offers a solution.

Therefore, we present an approach for the fabrication of an optical microsystem which offers position control of the microsystem relative to the object surface. 2PP can be used to produce almost any transparent microstructure with a high degree of geometrical accuracy and surface quality with suitable processing strategies.

2 2-Photon polymerization

For the fabrication of microsystems, we use a commercially available 2-PP lithography system “Photonic Professional” from Nanoscribe GmbH. The polymerization process uses a fs-laser with a pulse length of 120 fs and a 100x immersion oil objective with a high numerical aperture (NA = 1.4) to focus the laser into a UV-sensitive resin. We used the UV-sensitive resin “IP-Dip” from Nanoscribe. This process enables the limitation of polymerization to a highly localized area, the so-called “voxel” (volume pixel). These voxels typically have a diameter of about 150 nm and a height of about 1000 nm [3]. By moving the laser focus within the resin using a high precision xyz-piezo-axis-system, almost any 3D microstructures can be produced.

3 Results

Figure 2 a shows a desired geometry of our optical microsystem generated by CAD applications and consists of four microspheres with a diameter of 10 µm, which are connected by linking bars. The center microsphere is designed as an imaging optic. The three microspheres on the linking bars provide the positioning of the entire microsystem. The positioning of the system relative to the object surface can then be done, for example, via optical tweezers.

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Figure 2 b shows a scanning electron microscope (SEM) image of the resulting microstructure fabricated directly from the desired geometry in Fig. 2 a. The section at the top right shows a cross-section of one of the fabricated microspheres and the outer contour of the desired geometry (dashed line). The microspheres have a lateral diameter of 10 µm but show a significant oval deformation in the vertical direction and have a large contact area with the substrate. The deformation can also be clearly identified on the linking bars. This distortion results from the high aspect ratio of the voxel and the related extension of the structure. To achieve a low aspect ratio of the voxel, the resin IP-Dip was used.

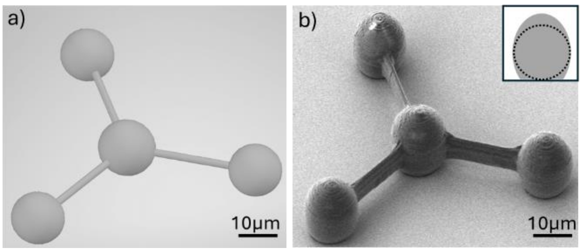

Fig. 2 *a) CAD model of the desired geometry for 4 microspheres with a diameter of 10 µm. b) SEM image of a microstructure fabricated according to the desired geometry using 2-PP lithography. These microstructures show a clear distortion in the vertical direction. The section at the top right shows a cross-section of one of fabricated microspheres and the outer contour of the desired geometry (dashed line).*

The small size of the microstructures of < 20 µm required by the proposed field of application of micro-optical imaging system and the high aspect ratio of the voxel require an adaptation of the design geometry.

To compensate the deformations, the design geometry must be modified depending on the fabrication constraints, such as voxel size. To realize a full sphere using 2PP, for example, the target geometry must be compressed in vertical direction by the voxel height. In order to minimize the area of contact between the substrate and the fabricated microstructure below 1 µm², the microstructure has to be lifted in relation to the substrate surface. For these adaptations of the desired geometry a detailed analysis of the voxel size is necessary. With detailed information about the voxel size, it is possible to consider possible deformations of the fabricated microstructures already during the design process of the desired geometry. This allows the fabrication of geometrically accurate microstructures with almost arbitrary geometries. Further deviations caused by the fabrication process, such as shrinkage, can also be considered and compensated for in the adaptation of the desired geometry. Fig. 3 shows an SEM image of microspheres which were fabricated with an optimized desired geometry. The microspheres have a diameter of 10 µm. On the surface of the spheres there are deposits of polymer residues, which were not completely removed during the development process. The Focused Ion Beam (FIB) cut shows the significant improvement in shape accuracy compared to fabrication with non-adjusted design geometry.

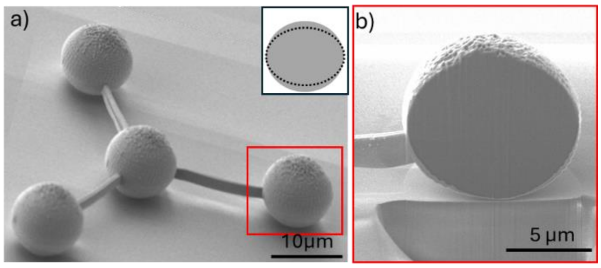

Fig. 3 *a) SEM image of microspheres fabricated with optimized design geometry. The microspheres have a diameter of 10 µm and a contact area of < 1 µm² to the substrate surface. The section at the top right shows a cross-section of the structure and the outer contour of the desired geometry (dashed line). The FIB cross-section b) shows the spherical geometry of the structures*

4 Conclusion

We present an approach for the fabrication of microspheres using 2PP. To ensure the shape accuracy of the fabricated microstructures, it is necessary to modify the desired geometry to a slicing geometry, under consideration of the fabrication conditions (voxel size, shrinkage). Once these fabrication parameters are determined, it is possible to fabricate accurate shaped structures with various target geometries by adapting the slicing geometry. The proposed microsystem may be used as a near-field lens and can be positioned via the microspheres on the holding arms.

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