# Micromilling for the Fabrication of Complex Optical Microsystems

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**Abstract**

The design of a complex system for fluorescence analysis is presented wherein the optical and mechanical components and surface structures are monolithically integrated in a transparent substrate. As a challenging part of its fabrication by ultraprecision micromilling the optimisation of the surface quality of the optical elements in order to avoid a degradation of the systems efficiency due to scattered light is considered.

## 1 Introduction

The application of MEMS devices in the fields of biotechnology, medical and pharmacological research has led to a large variety of design concepts, such as lab-on-a-chip systems. Martin *et al.* demonstrated efficient systems for the generation of microbial populations and their cultivation in so-called segmented-flow microdevices [1]. Herein, compartments with a volume of down to a few nanolitres are stored in a tube and are separated by a non-miscible carrier liquid. One of the main potentials for a further improvement of this technology platform is the additional integration of optical functionalities, e.g. for the optical detection of fluorescence signals.

The fabrication of optical elements [2] and highly integrated optical microsystems comprising freeform elements [3] by ultraprecision micromilling has been demonstrated previously. For manufacturing the integrated fluorescence detection system consisting of surfaces without any rotation symmetry and with high aspect ratios, again this process was chosen as it provides the necessary degree of freedom with respect to the machine kinematics. Nevertheless, the reliable detection of even weakest fluorescence signals demands a highly efficient concentration of the emitted light on the photosensor. Therefore, any losses need to be avoided such as stray light scattered from imperfections at the surface of the optical elements.

## 2 Optical System Layout

Figure 1 shows the principle set-up based on the concept of planar integrated optics. Two main light paths can be distinguished. One path (blue rays) serves for the excitation of fluorescence makers inside the cell cultivation segments. It consists of a LED source and a reflective toroidal surface to focus the light into the tube. The second path (red rays) collects the light emitted by the markers and focuses it onto the detector. This path comprises two spherical elements: a lens and a mirror. Two optical filters separate the excitation radiation from the fluorescence signal. The filters and electronic devices (LED, photodetector) are integrated in a hybrid way.

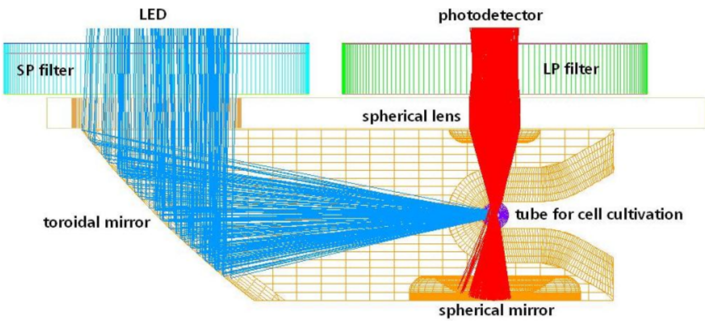


Figure 1: Set-up of the monolithically integrated fluorescence detection module

## 3 Fabrication

The fabrication is performed on a sophisticated 5-axis ultraprecision micromachining centre (Microgantry® nano5X, Kugler GmbH, Salem, Germany) at the Centre for Micro- and Nanotechnologies (ZMN). The machine provides a ps-pulsed laser source, a spindle for flycutting as well as a high frequency spindle for micromilling. The following results were obtained in preliminary tests during optimizing the manufacturing of the two coaxial spherical elements ($RoC_L$ = 1.05 mm, $RoC_M$ = 5.2 mm) concerning positioning tolerances, shape accuracies and surface quality.

### 3.1 Surface quality

The surface quality depends on parameters such as tool path distances, cutting edge radius, feed rate per revolution, tool vibrations, etc. Typically, right after the last cutting process an average roughness height $R_a < 40$ nm can be achieved showing regular structures with high spatial frequencies. By applying a manual polishing process (< 5 min per surface) the roughness was reduced from $R_a = 65.2$ nm down to $R_a < 2$ nm. The surface profiles are shown in figure 2. A 2nd order robust Gaussian regression filter was used to separate the different spatial frequency regimes.

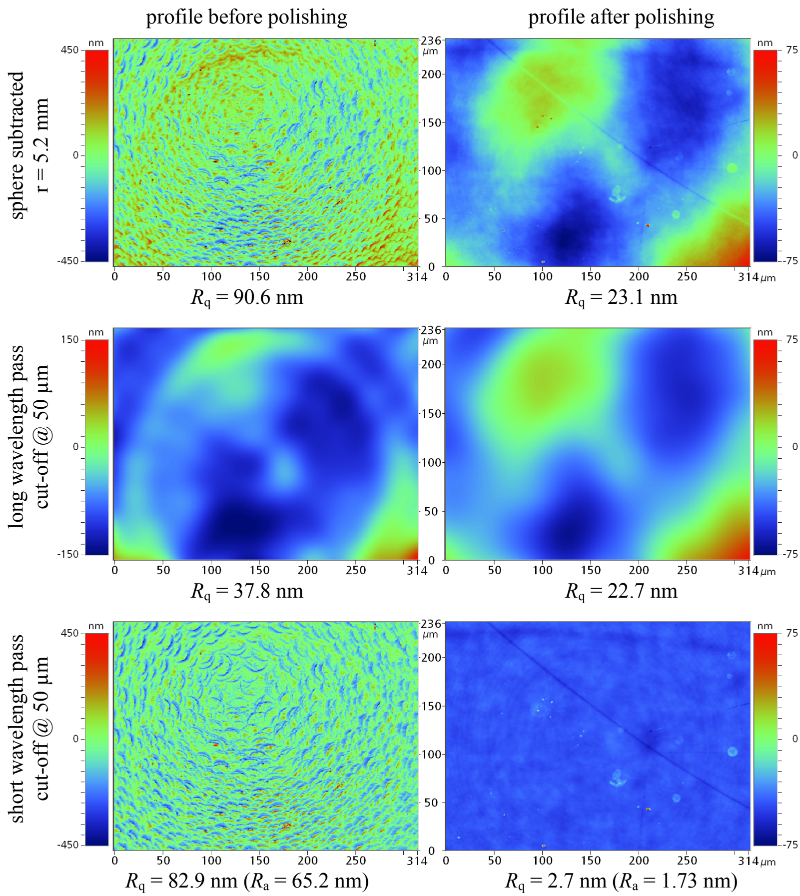


Figure 2: Surface quality before and after polishing (WYKO NT9300 opt. profiler)

### 3.2 Shape accuracy

Even though the optical elements are rather used for the concentration of light in areas of tens to hundreds of µm² than for more critical imaging tasks, the achievable shape accuracy is of importance. Within an inner diameter of the spherical mirror of

1 mm the deviations from the ideal shape were determined to be $\Delta z_{\mathrm{RMS}}$ = 127 nm and $\Delta z_{\mathrm{PV}}$ < 820 nm. Figure 3 shows the well matching profiles in x- and y-direction.

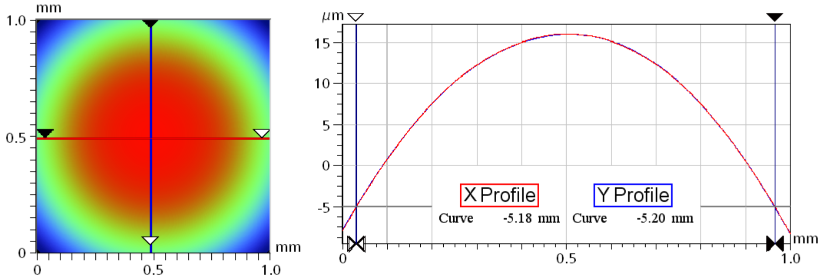


Figure 3: Shape accuracy

## 4 Conclusion and Outlook

Within this paper we presented the principle design for a monolithically integrated optical module that will lead to a further improvement of the segmented-flow technology platform. But generally this solution can be adapted to many applications that demand for optical analysis of agents flowing through transparent tube-like structures at easily changeable positions. The fabrication of different parts of the system by ultraprecision micromilling has led to very promising results concerning the surface quality and shape accuracy.

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