Subproject B5: Development of a Spectral Imaging Technology Based on Microactuators with a Diffraction Grating

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1 Introduction

The accurate colour reproduction of an arbitrary original is a common problem in pre-press and the following printing process. The first important part in this workflow is the digitising of the original. The use of state-of-the-art RGB-based image capturing systems, however, is not sufficient for every application. Due to the known theoretical limitations of RGB-techniques, multispectral and spectral methods of image capturing using more than three colour channels have been introduced in the recent years.

Chemnitz University of Technology has presented one of these spectral imaging systems using an oscillating micro mirror with a diffraction grating [1, 2], where each pixel of an original image is recorded in a spectroscopic way. Because of the high oscillation frequency of the micro mirror, very high light intensities are needed. The aluminium layer of the mirror absorbs about 10 % of the incoming light intensity leading to a heating of the mirror surface. To solve this problem, the reflective grating will be replaced by a transmission grating. Therewith absorption losses should not occur, allowing the use of higher light intensities compared to a reflective mirror.

2 Optical design of the grating

The transmission grating will be realised with standard technologies of micro technologies. Therefore it is necessary to find materials which are transparent in the visible part of the electromagnetic radiation and can be structured using lithographic techniques. This leads to very thin layers of silicon dioxide or silicon nitride.

Besides the properties of the layers, the correct grating parameters are also very important. As silicon dioxide and silicon nitride will be used to realise the grating, it is only possible to create rectangular gratings. For this type of grating the main parameters are the grating period and the depth of the grooves. Considering the earlier results with the previous reflection gratings, the final transmission gratings must have a grating period of 1.6 µm. The optimal depth of the grooves depends on the refractive index of the used grating material and the so-called blaze wavelength. Figure 1 shows the calculated optimal groove depth depending on the refractive index of the used material.

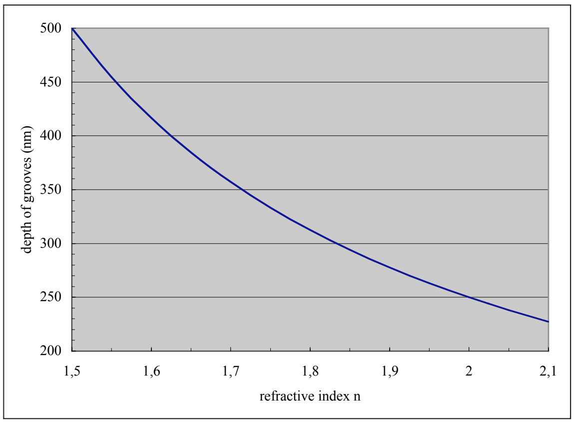

Fig 1: Optimal depth of the grooves versus the refractive index for a blaze wavelength of 500 nm

3 Manufacturing of a microactuator with a transmission grating

The micromechanical element comprises two wafers: a silicon actuator wafer and a glass wafer. Figure 2 shows the manufacturing of the microactuator.

The glass wafer carries the driving electrodes, bondpads and connecting lines. It has a round opening below the actuator for the incoming light beam.

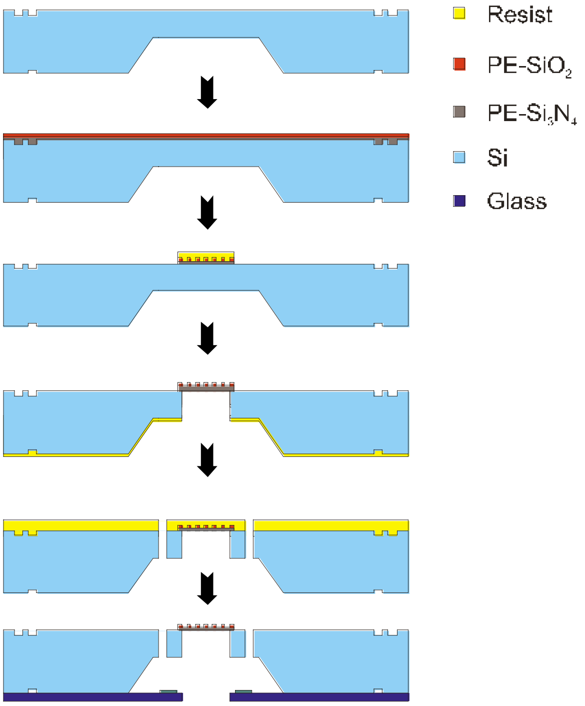

Figure 2: Realisation of micromirrors with transmission grating

The silicon wafer carries the microactuator with the optical transmission grating. The actuator is fabricated by bulk micromachining using a double side polished silicon wafer. At first the silicon membrane for the microactuator is fabricated by wet etching in potassium hydroxide. After that the optical layers, which consist of PE-SiO_2 and PE-Si_3N_4, are deposited on the front side of the wafer. The lower layer serves as the carrier layer, the upper layer is used for the grating. The optical layers were masked using stepper lithography. Then the grating is dry etched only in the PE-SiO_2 layer. After removing the resist on the front side, the whole backside of the wafer is masked with the exception of a round opening in the centre of the membranes. Hereafter the silicon is dry etched, finishing the spanned transparent membrane with a grating. Figure 3 shows such a membrane; Figure 4 displays it in greater detail.

To fabricate a movable mirror, the silicon is dry etched again from the front side using a resist mask. After removing the mask, the silicon wafer is attached to the glass wafer by anodic bonding. Finally, the wafer is divided into individual actor chips with a diamond saw.

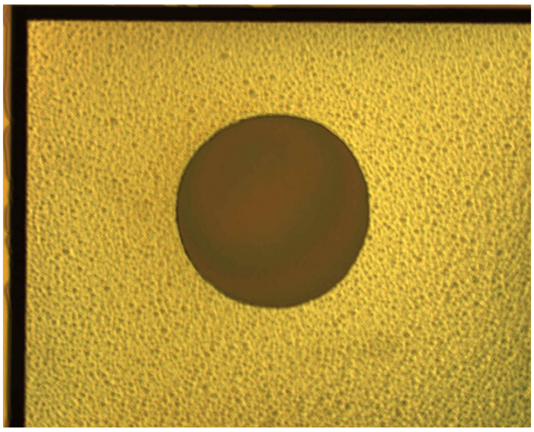

Figure 3: Wet etched silicon membrane with round transparent optical membrane

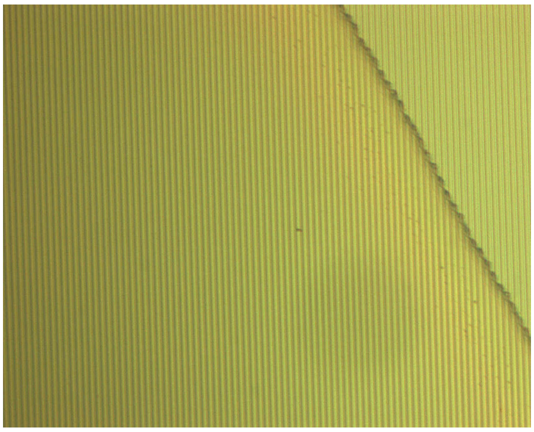

Figure 4: Detail of the optical membrane, partly on silicon (upper right corner), partly spanned

4 Optical Characterisation

The realised optical gratings have to be studied regarding their optical properties. Important parameters are the spectral resolving power and the diffraction efficiency of the gratings. For the first experiments a glass wafer that is 685 µm thick has been used. On one side of the wafer are rectangular gratings with a grating period of 2 µm and a groove depth of 510 nm. They have been structured in a silicon dioxide layer. The used experimental methods and results of the optical characterisation of these gratings are presented below.

4.1 Spectral resolving power

The diffraction properties of a grating are measured using the experimental setup shown in Figure 5. The CCD-line is arranged in the first

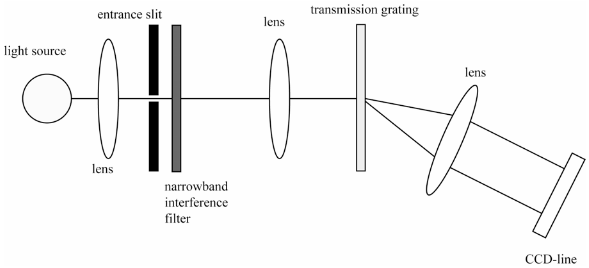

Fig. 5: Schematic experimental setup for the measurement of the spectral resolving power.

diffraction order parallel to the spectrum.

Various narrowband interference filters are placed successively in the optical path in front of the grating. The distribution of the transmission characteristics against the wavelength of each filter forms a sharp Gaussian distribution with a full width at half maximum of about 15 nm. The additional lens after the grating improves the sharpness and intensity of the spectrum on the detector.

The diffracted intensity distributions measured by the CCD-line are shown in Figure 6. The spectral resolving power of the grating is sufficient for a 2-µm grating. Furthermore the Gaussian transmission characteristic of the interference filters is reproduced very well.

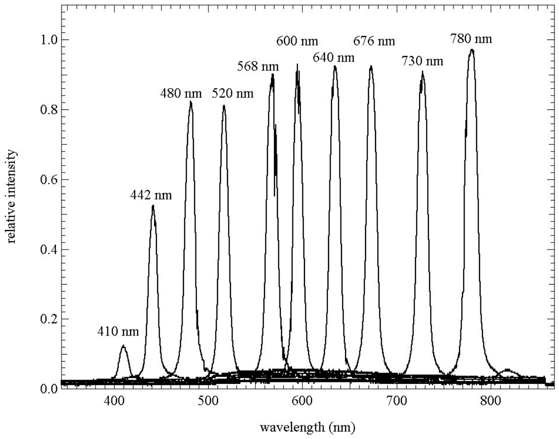

Fig. 6: Relative intensity measured by the CCD-line versus the wavelength for a rectangular transmission grating. The specified wavelengths are the appropriate central wavelengths of the filters.

4.2 Diffraction efficiency

Another important optical parameter is the diffraction efficiency of the gratings. In the image capture device that shall be realised later, the light exposure times last less than 5 µs for each spectral interval. Therefore a small diffraction efficiency of a grating can have a negative influence on the system capability.

The diffraction efficiency is measured using an experimental set-up similar to the one shown in Figure 5. First of all the luminous flux passing through the transmission grating is measured in dependency on the wavelength. Therefore different narrowband interference filters are placed successively in the optical path as described in section 4.1. A photometer is positioned directly behind the grating insuring that the detector collects all of the transmitted light. Afterwards the photometer is positioned in the first diffraction order. The diffracted luminous flux is measured against the wavelength using the different interference filters. The quotient between the diffracted and incident light is the relative diffraction efficiency. The measurement results are shown in Figure 7.

The measured diffraction efficiencies of the first gratings are in a range between 16 % and 29 % depending on the wavelength. Compared to the previous reflection rectangular gratings [3] and the theoretical maximum diffraction efficiency of a rectangular phase grating of 42 % [4], these are already very promising values.

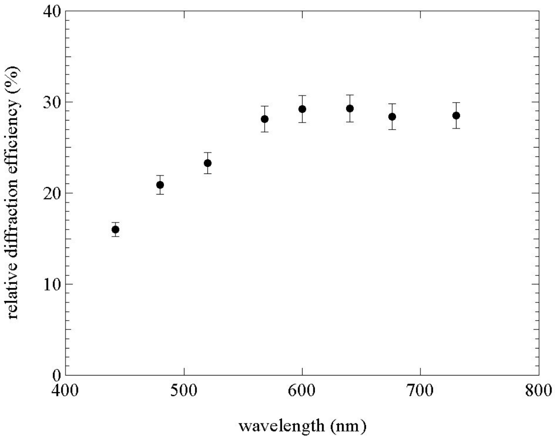

Fig. 7: Relative diffraction efficiency depending on the wavelength.

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