Microactuator with Diffraction Grating

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Introduction

With the increasing importance of computer networks and the internet high quality methods to digitise images get more and more relevant. This can be done with the aid of image capture devices (ICDs) like colour scanners or digital cameras. Therefore the capturing method shall fulfil a few criteria. At first the accuracy of reproduction must be ensured. The structure and especially the colour information of the image have to be accumulated exactly. Further on, the image data shall look like the same on every output device, meaning that the capturing process has to be device independent. At last a small design is desired.
In the conventional RGB technique, the whole colour space is not available. Therefore the use of colourimetric values would be a better approach because they are standardised and they are also independent from the used device. The use of a diffractive optical element (DOE) like a prism or an interference pattern could be the better choice. Especially the use of diffraction gratings has several advantages. The dispersion by diffraction gratings is well known [e.g. 1] and the intensity of the spectral signals is high compared to other methods. Also the spread of the spectrum is linear and independent from material characteristics. Finally the integration of such a DOE in a micro-electromechanical system (MEMS) will allow a small device.
A lot of spectral intervals must be recorded to complete a multispectral image capturing process. By the use of a DOE the single spectral intervals have to be recorded from a monochrome ICD sequentially. Moving the spectrum by a mirror will be the easiest way to change the spectral interval recorded. The design of the ICD still has to be small. Therefore, an oscillating micro mirror driven by electrostatic forces will be used. The combination of such a micro mirror device (MMD) and a MEMS diffraction grating seems to be a promising approach for a small and integrated ICD.

System design of a ICD with diffraction grating

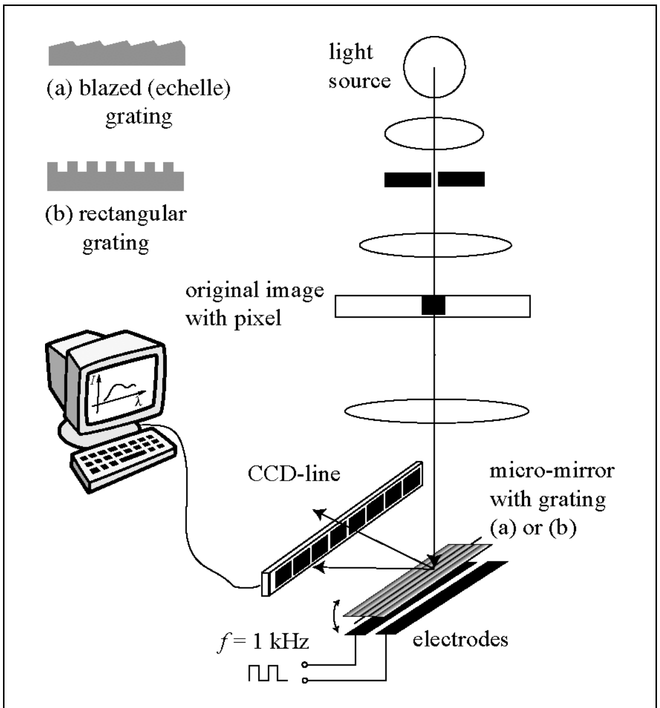

Fig. 1: Principle concept for a micro-mirror device with a diffraction grating as an image capturing device and the different grating types on the mirror surface

Different methods are thinkable to combine a MMD with a diffraction grating. In our case the grating is directly on top of the micro mirror to get a maximum of miniaturisation and integration of the ICD. The principal system design is shown in Fig. 1.
A through-light original modulates the intensity of a polychromatic light beam. The light from each pixel is guided by an optical system on the micro mirror. There it is diffracted in its spectral parts by the grating. Light of different wavelengths is diffracted into different angles. A photo sensor detects one spectral interval of the incoming light. Due to the oscillation of the mirror the spectrum moves along the sensor so that every spectral interval can be recorded. To increase the performance of the system it seems to be necessary to capture the colour signal of several pixels in parallel. That can be done since the MMD has a certain lateral size. It is shown that pixels in a line can be imaged as a sequence of spectrums. Using a CCD line, each spectrum corresponds to pixel of the original can be evaluated.
Considering all these physical properties and limitations given by the manufacturing process, we decided to use a diffraction grating with a period d of 1 µm.

Manufacturing of the MMD

The general working principle of the described micro mirrors is an elastically hinged mirror plate immediately actuated by an electrostatic field between plate and fixed electrodes on top of a carrier. The used micro mirror has an active optical area of 5.12 mm x 3.0 mm, a resonance frequency of about 1 kHz.

The single scanner design comprises two wafers: a silicon actuator wafer and a glass carrier wafer (see Fig. 2 for a cross sectional drawing). The glass wafer carries the electrode system (driving electrodes, connecting lines and bondpads). A 150 nm Si_3N_4 layer is deposited on the glass carrier wafer by using a PECVD process in order to fabricate a barrier between the glass and the driving electrodes. The 1 µm thick metal layer for electrodes and wiring is sputter deposited and patterned.

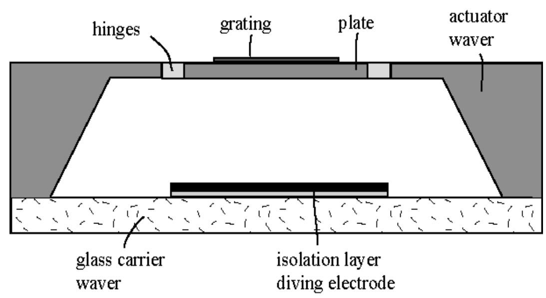

Fig. 2: Cross sectional drawing of the micro mirrors with gratings

The silicon wafer contains the original micro mirror component with the optical grating on its surface. The actuator wafer is fabricated by silicon bulk micromachining using a double side polished 100 mm silicon wafer with a thickness of 400 µm. Silicon membranes (40 µm thick) for the mirror plate and the hinges were etched using KOH (30 % / 80 °C). The etching is carried out from the backside of the actuator wafer using SiO_2 and Si_3N_4 as an etch mask. The silicon membranes were patterned into mirror plates and torsion springs by dry etching from the front side of the compound. An aluminum layer (55 ... 70 nm) is deposited on both sides of the wafer compound using sputter masks. This layer serves as a reflector on the mirror front side and as a conducting and stress compensation layer on the mirror back side. The wafer compound is attached to the glass bottom wafer by anodic bonding. Finally, the wafer is divided into individual actuator chips with a diamond saw and the chips are completed by mounting on a component carrier, by chip-bonding and encapsulation of the actuators.

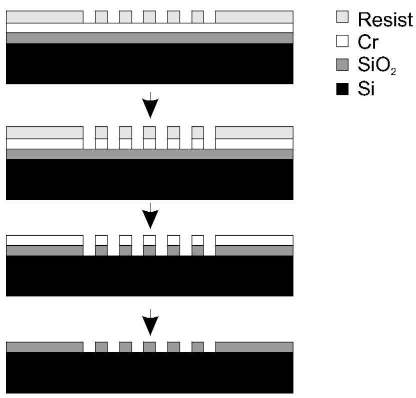

Fig. 3: Realisation of gratings in SiO_2

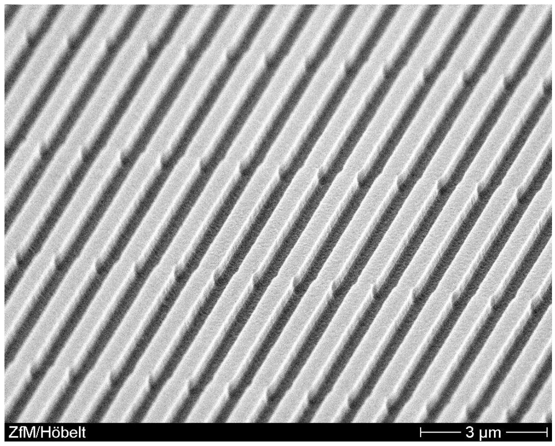

Fig. 4: Rectangular grating in SiO_2

The rectangular gratings are fabricated using e-beam lithography and dry etching (Fig. 3). The grating pattern is transferred from the photoresist into a chromium layer (thickness 20 nm). This layer is used as a hard mask to dry etch a SiO_2-layer on top of the actuator wafer, which defines the height of the grating. Figure 4 shows a SEM-Picture of such a grating.

Several other ways are also possible to realise the grating. We have also tested:

- wet etch of a blazed grating by use of a wafer with an orientation that differs from {100} and
- mechanical scribing of a blazed grating in a sputtered layer on top of a wafer.

There are problemes because of the gratings on top of the silicon wafer, more exact: on top of the silicon micromirror. Due to the mechanical stress build in (the missmatch of the thermal co-efficient of expansion between silicon and thermal oxide), the surface of the micromirrors bends into a convex form. Normally an easy way to compensate this is to use the stress of the surface coating, in our case aluminum. But in this project there are gratings on the surface. Therefore the coating cannot have any desired thickness.

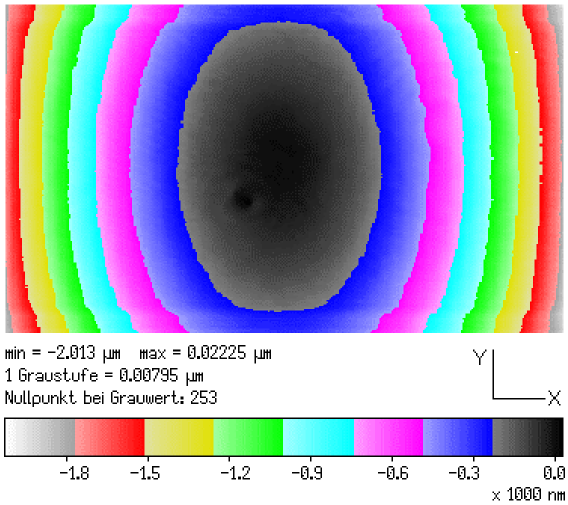

Fig. 5: Micromirror surface before compensation
Bow in X-Direction: -300 nm
Bow in Y-Direction: -1800 nm

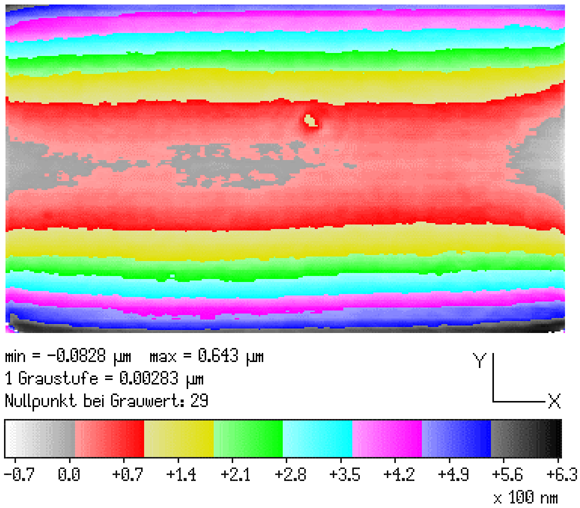

Fig. 6: Micromirror surface after compensation
Bow in X-Direction: +50 nm
Bow in Y-Direction: + 500 nm

Our solution is to deposit a PE-Oxide on the backside of the micromirrors. The stress of this oxid is negative and can be adjusted by a well defined tempering of the wafer. Figure 5 shows the surface of a micromirror before compensation, figure 6 after compensation with the PE-Oxide. A full compensation of the bending (in both directions) is not possible, because of the grating: the strucure of the grating oxide effectuates a different stiffness in X- and Y-Direction. According to the application needs we made the mirror planar in X-Direction, this is the direction of the grating, too.

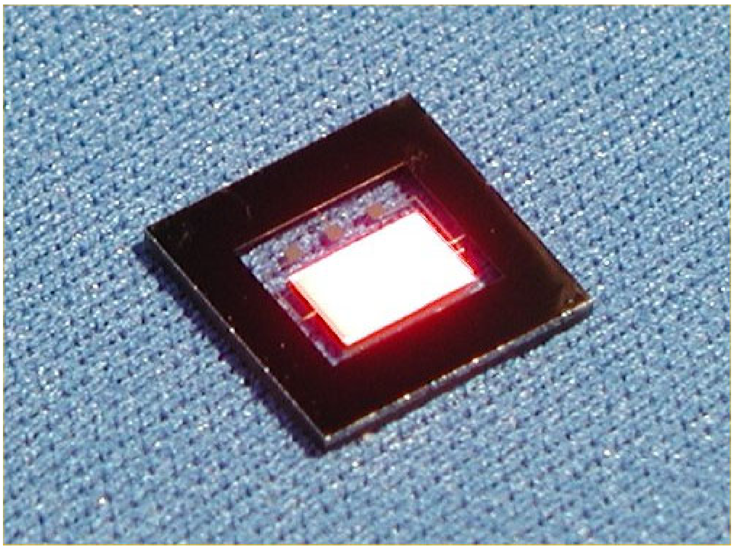

Fig. 7: Realised micromirror with grating

Conclusion

For an ICD based on a diffraction grating it is necessary that the different spectral intervals can be separated.
Measurements shows that the physical properties of our diffraction gratings will be good enough to separate sufficient spectral intervals.
The bending of the surface caused by the stress of the thermal oxide can be compensated with a PE-Oxide on the backside of the micromirror.
A picture of the released microelectro-mechanical system with a mirror including a grating is shown in Fig. 7.
Therewith, the basic step for a realisation of a multispectral ICD based on a MMD is done.

References

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