*Matthias Burkhardt, Hans-Juergen Dobschal, Stefan Sinzinger,
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Imaging gratings for multiorder microspectrometers realized by interference lithography using supplementary holograms

Matthias Burkhardt*, Hans-Juergen Dobschal**, Stefan Sinzinger***, Robert Brunner*

** Carl Zeiss Jena GmbH, Carl Zeiss Promenade 10, 07745 Jena, Germany*
*** Carl Zeiss AG, BS Jena 10, Carl Zeiss Promenade 10, 07745 Jena, Germany*
**** Technische Universität Ilmenau*

mailto:m.burkhardt@zeiss.de

The strong demand for rugged and miniaturized spectrometers is driven by applications such as in-line process control in pharmacy or in agri-food business. In this contribution we present the concept and the experimental results of a realized miniaturized optical spectrometer working in a multi-order principle. This concept allows high optical performance while simultaneously the necessary construction space shrinks drastically.

1 Introduction

Several designs for miniaturized spectrometers have been introduced [1 - 5]. Starting from the requirement for adequate energy efficiency by a sufficient high numerical aperture, a space-saving spectrometer design premised on an imaging grating combined with a detector array is state of the art. However, a successive further downscaling results in a drop of spectral information due to the even downscaled region of best focus of the imaging grating. To satisfy the demands of a number of new application fields for miniaturized systems with good optical performance, the multi-order principle is an alternative concept.

2 The multi-order concept

For the multi order concept the grating equation (1) has two fixed parameters, the angle of incidence β and the period of the grating lines d. The angle of the diffracted light α remains the same if the product of diffraction order number m and wavelength λ is constant.

$$\sin\alpha = \frac{m \cdot \lambda}{d} - \sin\beta \tag{1}$$

In order to ensure a high resolution over a broad detectable spectral range the whole spectrum is subdivided into a set of spectral intervals corresponding to different diffraction orders. In Fig. 1 the optical setup is illustrated. The incoming light that passes the entrance slit with a width of 70 µm propagates to the spherical grating substrate. The diameter of the imaging grating is 5 mm and its imaging distance is 8.6 mm. The grating diffracts the light and focuses it into the image plane where the detector array is located. Only one single diffraction order (in Fig. 1 order n) is captured in the region of best focus. All the other orders can be neglected.

One gets unambiguous signals with no disturbing overlap if a kind of a spectral pre-selection is applied. This means, at a certain time the bandwidth of the incoming light has to be less than the spectral separation of the neighbouring diffraction orders. A suitable way is the sequential illumination of the target with light sources of neighbouring and limited spectral ranges e.g. by using light emitting diodes in temporal succession [6].

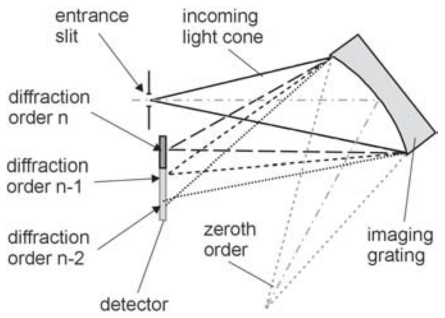

Fig. 1 *Multi order principle employing an imaging grating – a quasi-monochromatic light fraction gets focused onto the detector plane via different diffraction orders, only the dark grey shaded region (best focus) is captured*

The grating was manufactured by an adapted holographic recording process [7]. The grating profile is optimized for the appropriate angular region of best focus (up to 40% of the incoming light.

3 Experimental results

To prove the performance of the miniaturized spectrometer the system was assembled realizing an optical volume of 11 x 6 x 5 mm³.

In Fig. 2 the upper diagram shows a scan of the transmission spectrum of an optical filter glass

(BG type) from 300 nm to 1100 nm detected by a commercial Zeiss spectrometer (MCS 521). The four frames in the lower part show some examples of spectral intervals where the curve of the MCS (spectral resolution about 8 to 10 nm) is compared to the curves of the multi order spectrometer. In particular in the blue and green range, due to the behavior of the filter glass, the multi order spectrometer unveils far more details of the curve than the MCS. The red and infrared spectral intervals show a good agreement between the two spectrometers. Additional tests showed a spectral resolution of 2.3 nm in the visible range and 5 nm for the NIR range for the miniaturized spectrometer. These results are achieved by the multi order spectrometer even though the construction space is about an order less than that of the MCS optics.

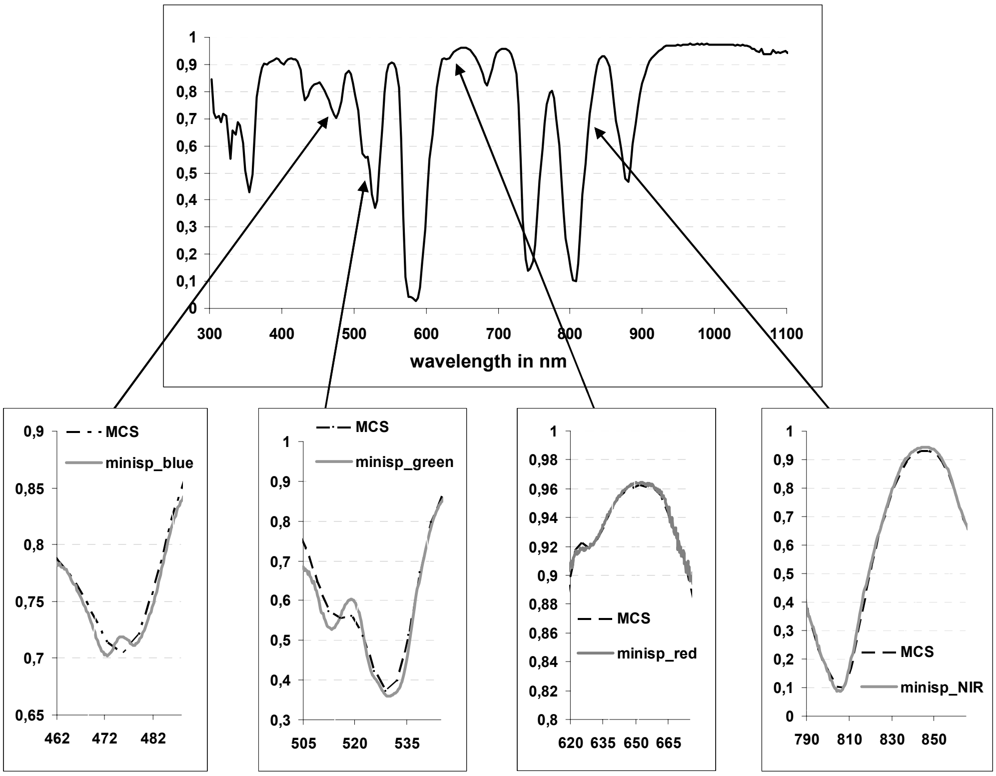

Fig. 2 *Experimental comparison of the calibrated miniature spectrometer and a commercial spectrometer (Zeiss MCS 521) as reference: The upper figure shows the whole detectable range of the filter curve by the MCS whereas the four lower figures show zoomed intervals comparing the results of both spectrometers*

4 Conclusions

A miniaturized spectrometer covering an optical volume of 11 x 6 x 5 mm³ was realized based on the multi order concept. An excellent spectral resolution in the VIS/NIR-range was proved experimentally. Future designs may utilize fewer diffraction orders associated with a moderate drop in spectral resolution or bandwidth and offer the possibility for simultaneous readout of the spectral intervals.

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