3D-printed miniature spectrometer for the visible range in a volume of 100 x 100 x 300 µm³

Andrea Toulouse*,***, Johannes Drozella*,***, Simon Thiele*,***, Harald Giessen**,***, Alois Herkommer*,***

*Institute of Applied Optics (ITO), University of Stuttgart
**4th Physics Institute, University of Stuttgart
*** Research Center SCoPE, University of Stuttgart

mailto:andrea.toulouse@ito.uni-stuttgart.de

We present a 3D-printed ultra-compact spectrometer in a volume of less than $100 \times 100 \times 300$ µm³ fabricated by femtosecond direct laser writing in combination with a super-fine inkjet process. The spectrometer features a spectral range from 490 nm to 690 nm at a resolution around 15 nm enabled by a chirped high-frequency grating and highly tilted aspherical surfaces.

1 Introduction

The miniaturisation of spectroscopic measurement devices opens novel information channels for size critical applications such as endoscopy or consumer electronics. Computational spectrometers in the size-range of micrometres have been demonstrated, however, these are calibration sensitive and based on complex reconstruction algorithms [1, 2]. Herein we present an angle-insensitive 3D-printed miniature spectrometer with a direct separated spatial-spectral response in a volume of only 100 x 100 x 300 µm³ [3].

2 Optical and mechanical design

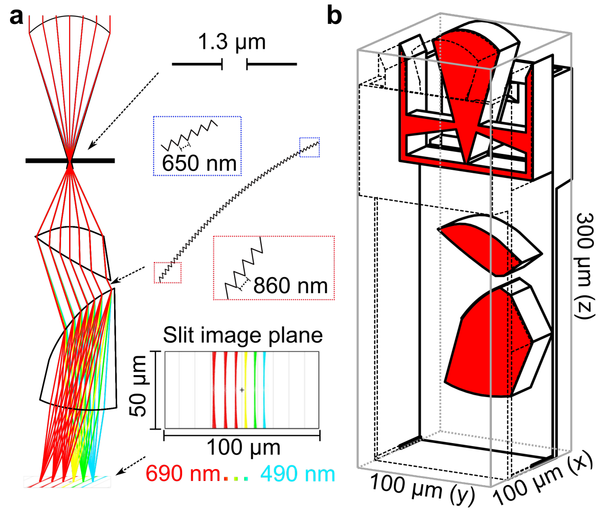

***Fig. 1** Optical (**a**) and mechanical (**b**) designs of the spectrometer. The slit, grating surface and dispersed image plane are highlighted.*

A ray tracing model was designed using *Zemax OpticStudio* (Fig. 1). The design freedom of 3D printing was exploited by using chirped grating periods as well as highly tilted and freeform surface geometries. The grating period ranges from 650 nm to 860 nm and is highlighted in the figure. A mechanical model was derived and equipped with a microfluidic basin around the spectrometer's slit. The optical performance was validated with wave-optical simulations [4] for the center plane of the mechanical model highlighted in red. The wave-optical simulation and the complete fabricated spectrometer as well as a spectrometer array are shown in Fig. 2.

3 Fabrication

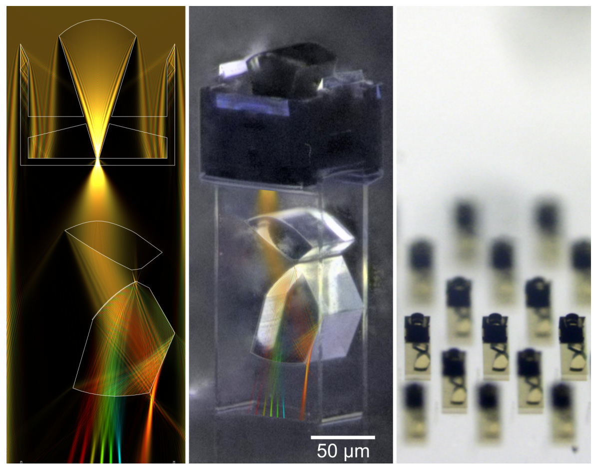

***Fig. 2** Wave-optical simulation of the color separation, a micrograph of the 3D-printed spectrometer, and a fabricated microspectrometer array. A single spectrometer has a width of 100 µm.*

The spectrometer was fabricated via fsDLW with a Nanoscribe 3D printer from its proprietary photo resist IP-Dip. In a post-processing step, the slit was realized with a super-fine inkjet printer making use of previously defined microfluidic structures [5]. A micrograph of the final spectrometer is shown in Fig. 2 (middle) with an overlaid wave-optical simulation for visualization.

DGaO Proceedings 2021 – http://www.dgao-proceedings.de – ISSN: 1614-8436 – urn:nbn:de:0287-2021-H003-7
submitted: 29.10.2021 – published: 17.11.2021

4 Characterization

The performance of the spectrometer was assessed in an experimental setup consisting of a monochromator as illumination source and a microscope for magnification of the spectrometer's image plane. The measured intensity profiles along the dispersion direction are displayed in Fig. 3 for a range of 200 nm from 490 nm to 690 nm, also showing some residual noise.

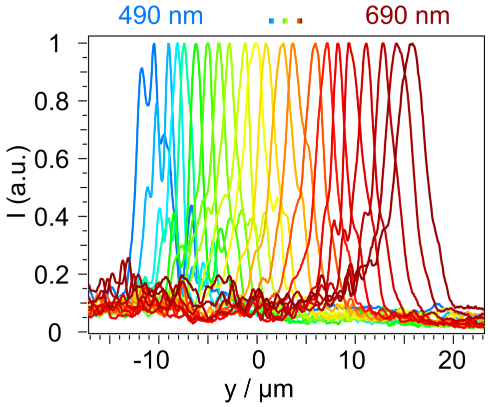

Fig. 3 *Spatial-spectral response measurement. The wavelengths are separated in the image plane of the 3D-printed spectrometer.*

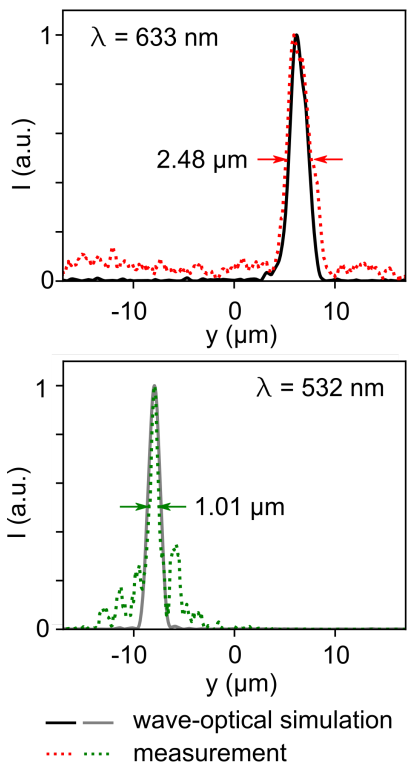

Fig. 4 *Spectral resolution measured with red and green laser sources, respectively.*

The spectral resolution is determined with a similar measurement setup, this time using narrow-band laser sources for illumination (Fig. 4). Taking the spatial-spectral shift from Fig. 3 into account, the spectral resolution can be determined to 9.2 ± 1.1 nm at 532 nm wavelength and 17.8 ± 1.7 at 633 nm wavelength.

5 Conclusion

In summary, we have proven the functionality of a complex optical measurement system, namely a spectrometer, on a miniature footprint using 3D-printing technology. While the spectrometer still suffers from some noise, it marks a novelty both for miniaturized spectrometers and for complex 3D-printed micro-optics. It could readily be used as a wave-meter, e.g. for laser wavelength stabilization. The optical characteristics of available photo resists [6] enable a transfer of the presented design principle to further wavelengths in the NIR. Arrays of such spectrometers could be used as macro pixels for hyperspectral imaging.

For further details and funding, please refer to reference [3]. Figures and text have been reproduced and adapted in parts from this reference.

References

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