Engineers 3-D-print a miniaturized spectrometer

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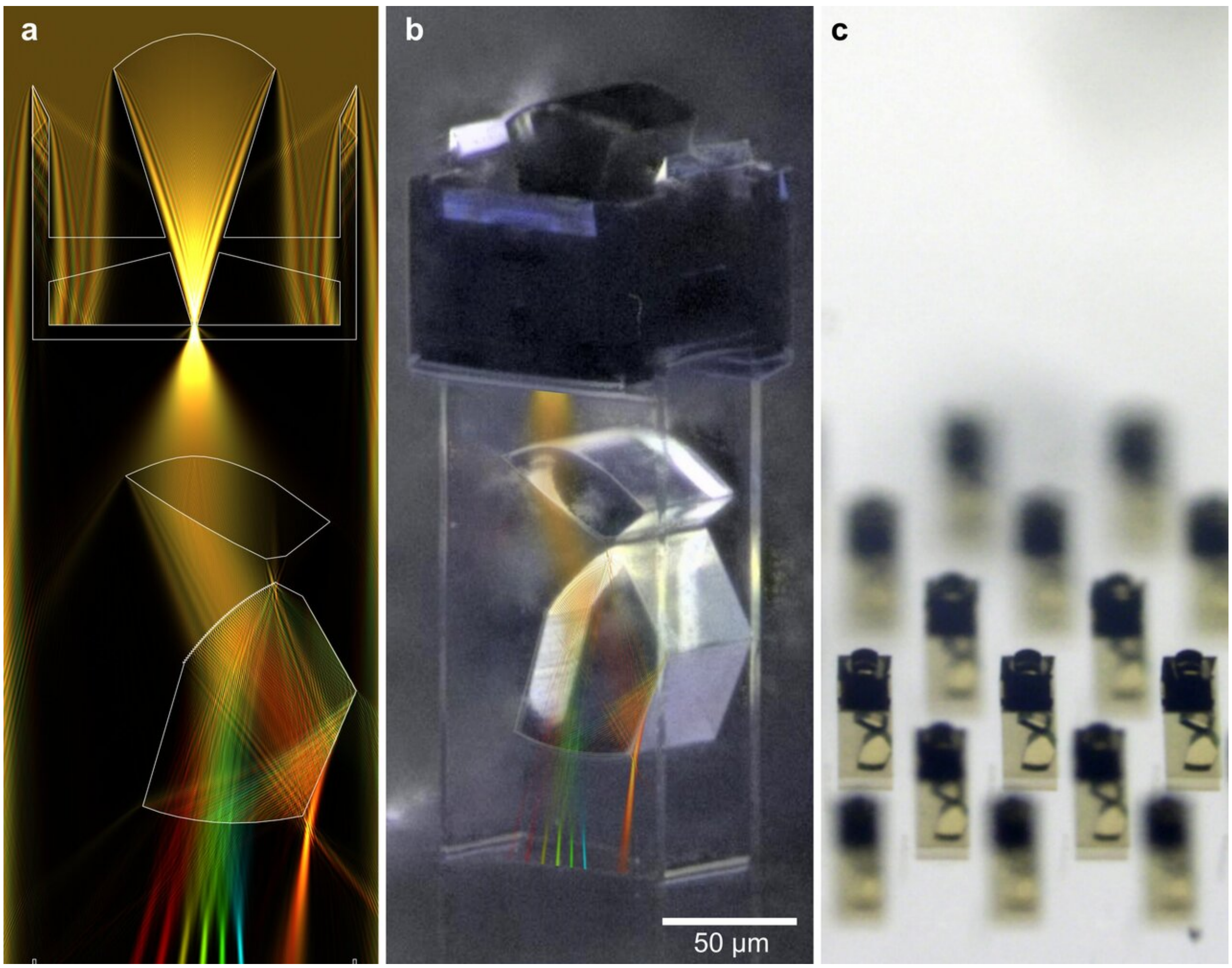


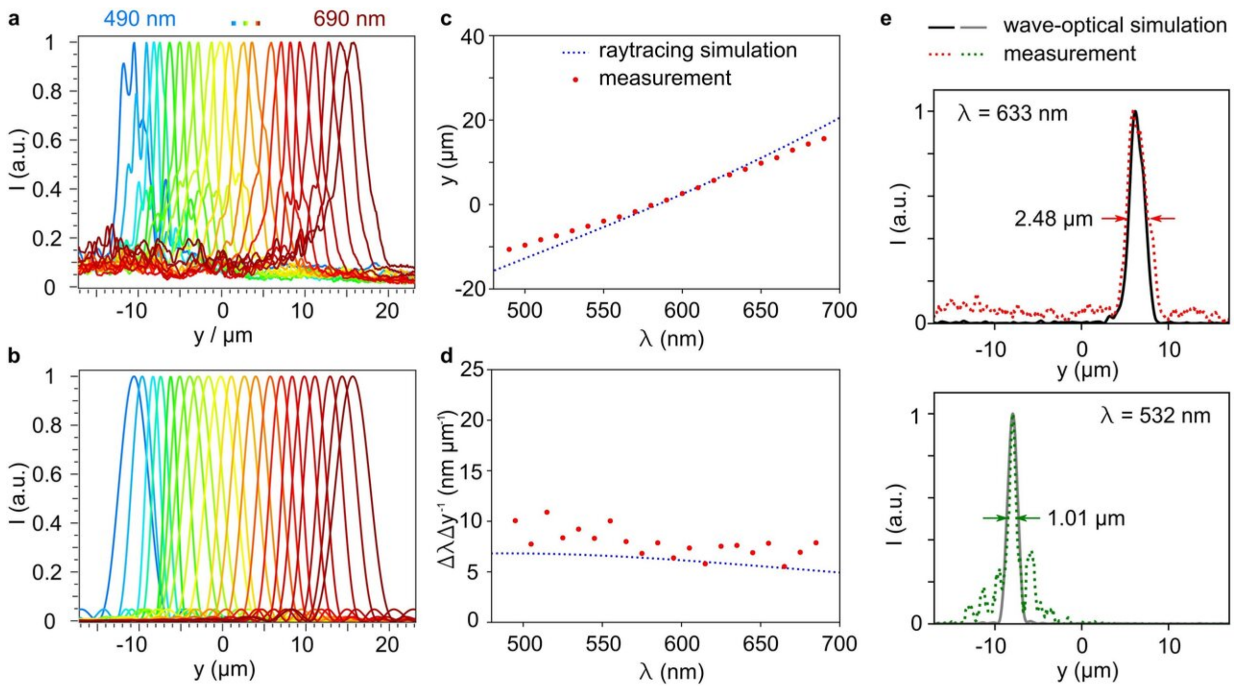
3D-printed miniature spectrometer. a, wave-optical simulation of the spectrometer. b, microscope image of the fabricated spectrometer overlayed with the intensity distribution from a. c, array of fabricated spectrometers. Credit: Andrea Toulouse, Johannes Drozella, Simon Thiele, Harald Giessen, and Alois Herkommer

The miniaturization of spectroscopic measurement devices opens novel information channels in medical science and consumer electronics. Scientists of the University of Stuttgart, Germany, developed a 3-D-printed miniature spectrometer with a volume of 100 by 100 by 300 μm^3 and a spectral resolution of up to 10 nm in the visible range. This spectrometer can be manufactured directly onto camera sensors, and a parallel arrangement allows for quick ("snapshot") and low-profile, highly customizable hyperspectral cameras.

Femtosecond direct-laser writing as a 3-D printing technology has been one of the key building blocks for miniaturization in recent years. It has transformed the field of complex micro-optics since the early 2000s. Medical engineering and consumer electronics benefit from these developments. It is now possible to create robust, monolithic and nearly perfectly aligned freeform optical systems on almost arbitrary substrates such as image sensors or optical fibers.

Simultaneously, the miniaturization of spectroscopic measurement devices has been advanced with quantum dot and nanowire technology. These are based on computational approaches, which have the drawback of being calibration-sensitive and require complex reconstruction algorithms.

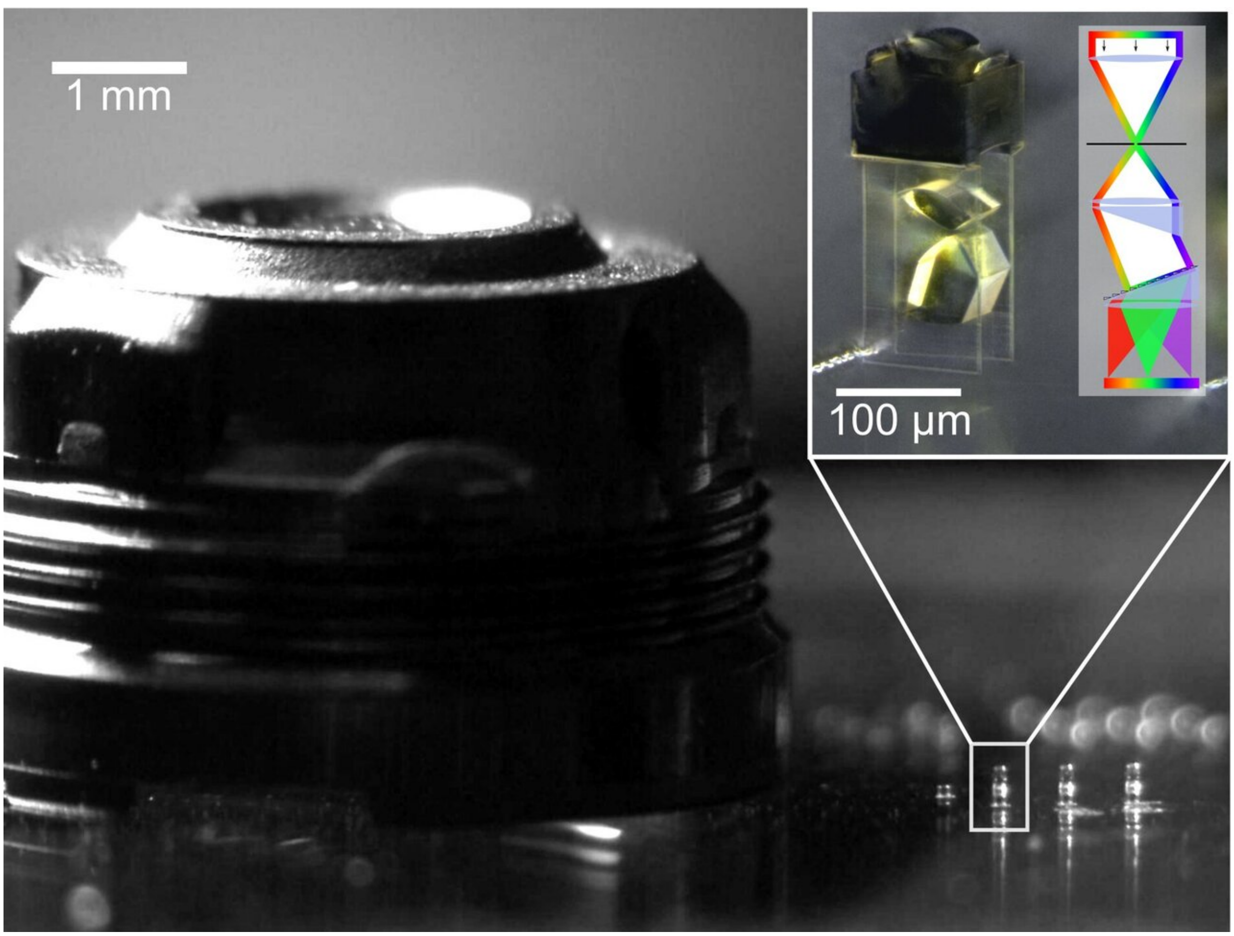
In a new paper published in *Light: Advanced Manufacturing*, a team of scientists, led by Professor Alois Herkommer from the Institute of Applied Optics and Professor Giessen from the 4th Physics Institute, University of Stuttgart, Germany, have demonstrated an angle-insensitive 3-D-printed miniature spectrometer with a direct separated spatial-spectral response. It has a volume of less than 100 by 100 by 300 μm^3.



a Measured normalised intensity profiles at the image plane of the spectrometer for illumination wavelengths ranging from 490 nm to 690 nm in 10 nm steps (monochromator, profile position is indicated in Fig. 3b). b Sinc^2 fits of the intensity profiles from a. c Centre positions of the sinc^2 fits per wavelength. d Wavelength shift per micrometre deduced from c. e Linewidth simulation and measurement with a red or green laser, respectively. The measured full width at half maximum is indicated with a pair of arrows. The combination of measurements d and e yield a spectral resolution of 9.2 ± 1.1 nm at 532 nm and 17.8 ± 1.7 nm at 633 nm wavelength. Credit: Andrea Toulouse, Johannes Drozella, Simon Thiele, Harald Giessen, and Alois Herkommer

The design is based on a classical grating spectrometer and was fabricated via two-photon direct laser writing combined with a super-fine inkjet process. Its tailored and chirped high-frequency grating enables strongly dispersive behavior. The miniature spectrometer features a wavelength range in the visible from 490 nm to 690 nm. It has a spectral resolution of 9.2 ± 1.1 nm at 532 nm and 17.8 nm ± 1.7 nm at a wavelength of 633 nm.

Leading author Andrea Toulouse says, "With its volume of less than 100 by 100 by 300 μm^3 we explore a whole new size range for direct spectrometers. An order of magnitude this small could only be realized by computational approaches until now. In contrast, we translate the spectrum directly into a spatially encoded intensity signal which can be read out with a commercial monochromatic image sensor."



The inset (white box) shows a microscope image of the fabricated spectrometer (left) and its optical design principle (right). Credit: Andrea Toulouse, Johannes Drozella, Simon Thiele, Harald Giessen, and Alois Herkommer

"For 3-D-printed microoptics, the complexity of the optical design marks an innovation. Refractive, diffractive and spatially filtering elements have never been combined in such a small volume to create a complex and monolithic measurement system."

"Our spectrometer could be fabricated directly on a miniature image sensor as the tip of a distal chip endoscope. This way, regions in the human body could be examined with extremely high bending radii that were not accessible before" the scientists forecast. "It could also be an interesting approach for hyperspectral imaging where the spectrometer would be used as a unit cell (macro pixel). The redistribution of spectral energy instead of high-loss Fabry-Perot-filtering could thus enable highly efficient hyperspectral imaging sensors. The ever-growing world population could benefit from such a camera if it was used for spectral mapping in precision farming, for instance."

More information: Andrea Toulouse et al, 3D-printed miniature spectrometer for the visible range with a 100 × 100 μm^2 footprint, *Light: Advanced Manufacturing* (2021). DOI: 10.37188/lam.2021.002

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