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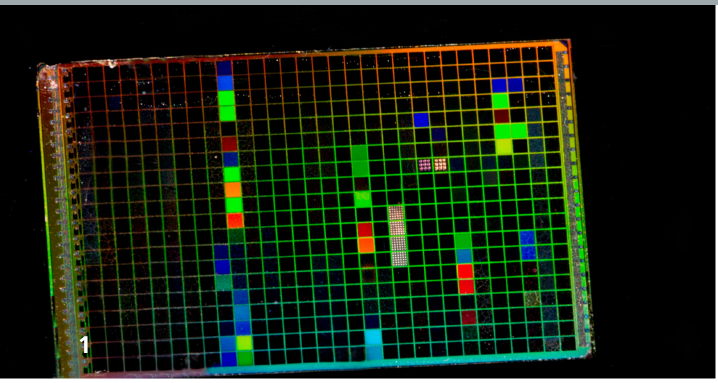

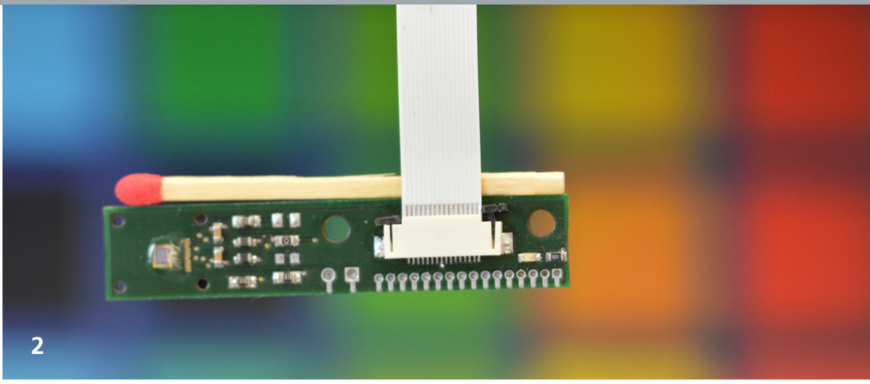

1 Demo nanoplasmonic filter array with several channels and integrated angular filter. © Fraunhofer ISC

2 Color sensor smaller than the head of a match mounted on a demo board. © Fraunhofer IIS

INTEGRATED LOW-COST COLOR SENSORS

FOR LED LIGHTING, DISPLAYS AND MOBILE DEVICES

In many optical applications with a high demand for the quality of light, color consistency is a key factor. A new highly integrated, ultra-thin and low-cost color sensor ensures best performance in a variety of applications. For high quality LED lighting, it can adjust the desired emission spectrum and compensate for the long-term changes due to aging. Other applications in the consumer range, such as display technologies and mobile devices, can also benefit from these new kinds of sensors, when e.g. used for color balancing in photography or calibration for displays.

Introduction

State-of-the-art color sensors typically rely on absorptive materials (pigment, dye, interference) that are mounted on top of photodiodes to monitor the incoming light spectrum. This approach renders them comparatively expensive and bulky, thus prohibiting their adoption for many application scenarios particularly in the consumer sector. Fraunhofer ISC and Fraunhofer IIS developed a new sensor solution to overcome these hurdles (Figure 1). This new sensor relies on nanoplasmonic resonances. Here, the incoming light is filtered by a hole array that is patterned into a thin metal layer. Depending on the shape, size and pitch of these holes, different plasmonic modes are excited in the metal which define the transmission of light impinging onto an underlying photodiode.

A combination of nanoplasmonic sensors (nanoplasmonic filter + photodiode) with different transmission characteristics allows a very accurate determination of the color of incoming light. These multispectral sensors are very small (Figure 2) and can be fabricated in low-cost CMOS processes.

Despite these indisputable advantages, nanoplasmonic multispectral sensors suffer

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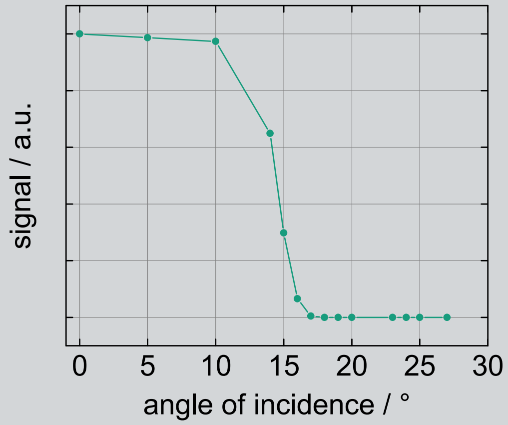

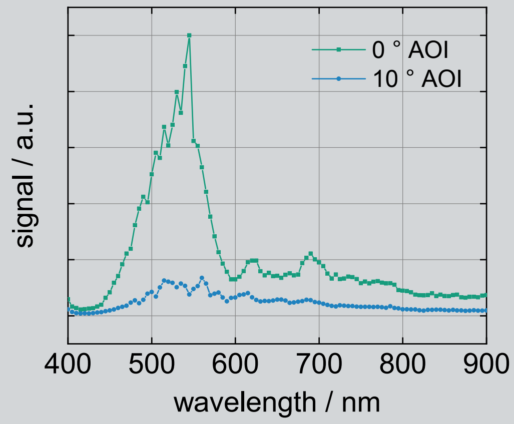

from one significant tradeoff which is also present in many other filter designs: angular dependence. The transmitted spectrum of the nanoplasmonic filters shifts significantly, if the angle of incidence exceeds 10°. This prohibits the use of a stand-alone chip for color sensing applications.

A typical solution would be the confinement of the incoming angular spectrum by attaching a cylinder with a hole aperture to the sensor. Unfortunately, this construction renders the entire device impracticable, as it increases the height to several millimeters.

Function and Features

The new concept developed by Fraunhofer ISC and Fraunhofer IIS relies on a microoptical approach that can be implemented either directly on the CMOS fabricated nanoplasmonic sensor or as a monolithic angular filter. It significantly narrows the angular acceptance of the device (Figure 3 and 4). As the realization is based on microscopic structures, the entire sensor device is still very thin, thus preserving its applicability in lighting, displays and mobile devices.

The microoptical elements are fabricated by two-photon polymerization (2PP), a 3D additive manufacturing technology. It exploits the strongly confined solidification of photopolymers which is triggered by femtosecond laser pulses. 2PP can be used to generate arbitrarily-shaped 3D microoptical elements on any substrate, particularly on CMOS chips (Figure 1).

The entire color sensor (= nanoplasmonic sensor + angular filter) can still be manufactured in a very cost-effective way, despite 2PP being a serial and comparably slow process. The reason for this is that 2PP-written structures can be replicated easily by imprint technologies.

Hence, the combination of CMOS fabrication of nanoplasmonic sensors with microoptical angular filters enables ultra-compact and low-cost color sensing for several applications down to the consumer market.

Benefits and Technical Data

- Confinement of angular spectrum to +/- 10 °
- Very thin: < 200 µm
- Low-cost: < 1 Euro for CMOS chip
- Small footprint: 1.5 x 1.5 mm^2
- Variable number of possible channels: 6 to 1024
- Operation wavelength: 300 ... 1000 nm
- Image sensors with spectral filters on pixel level
- Information: Color coordinates + spectral estimation → Between RGB sensors and spectrometers
- Sensor includes amplification, signal processing, and standard interfaces like I2C or SPI
- Robust with respect to temperature and ageing
- Applicable to existing light or image sensors

Further Applications

- Automotive ambient light
- Daylight harvesting
- Monitoring of gases and liquids
- Agriculture; smart farming; food monitoring
- Medical point-of-care applications
- Industrial automation

Other applications apart from color sensing can benefit from the solution if they suffer from angular dependence in a similar way the nanoplasmonic filters do. Solutions for other applications and designs can be developed with manageable effort, considering that the shape of the employed microoptical elements can easily be modified, as 2PP is a rapid prototyping tool for the micro scale.

3 *Measured filter effect of angular spectrum*

4 *spectral transmisison of plasmonic filter with angular filter, incident angles at 10° or above are supressed efficiently, and do not contribute to the signal*