Multispectral CMOS Sensor for LED Color Feedback

Strategies in Light Europe

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Fraunhofer Institute for Integrated Circuits IIS

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Overview

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1. **Introduction:**
   Color sensors for LED monitoring
2. **Methodology:**
   Color and multispectral sensors in CMOS
3. **Experimental results:**
   Fabrication and characterization of test chips
4. **Application:**
   Detecting the color coordinate (chromaticity point) of a tunable LED luminaire
5. **Conclusions**

1. Introduction
Color sensors for LED Monitoring

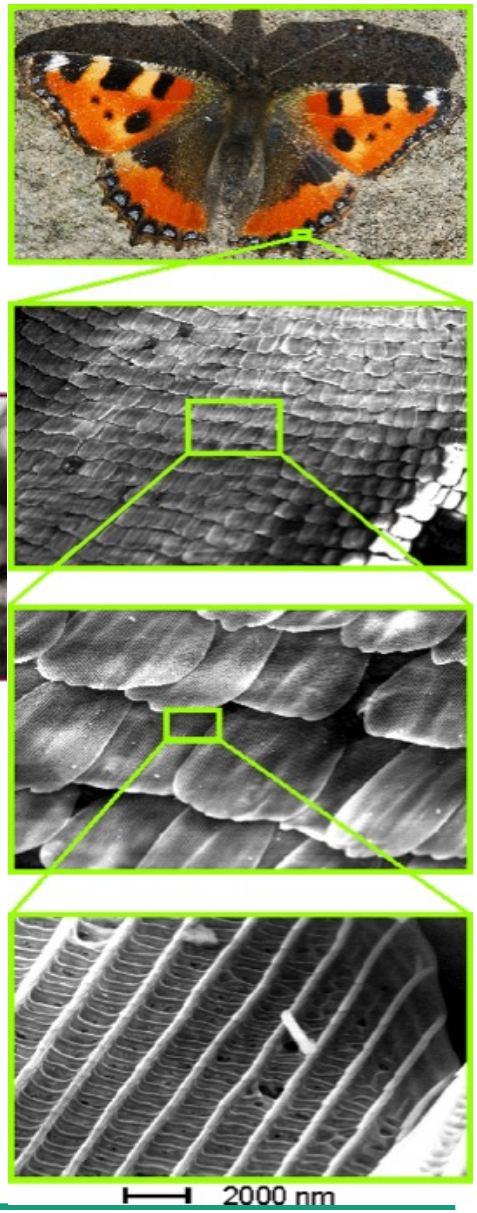
- LEDs are the ideal light source for many lighting applications due to lifetime, efficiency, and flexible color output
- High-quality illumination devices require precise color matching because of wavelength drift due to temperature change and aging
- Color-sensing feedback achieves better color accuracy than simpler junction-temperature feedback
- LED binning can be reduced
- ⇒ Cost-effective color and multispectral sensors are needed for high-volume illumination applications

1. Introduction
Technologies for color and multispectral sensors

- Various filter technologies are well established:
  - Absorption filters, e. g. red, green, blue pigmentfilters (Bayer filter)
  - Dielectric filters (thin film filters, interference filters)
  - In spectrometers: prisms, gratings, tunable filters

- Are there other approaches …
  - … feasible using CMOS semiconductor technolgy?
  - … enabling highly integrated sensors at low cost?

1. Introduction
Nanostructures in nature



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1. Introduction
Nanostructures in art

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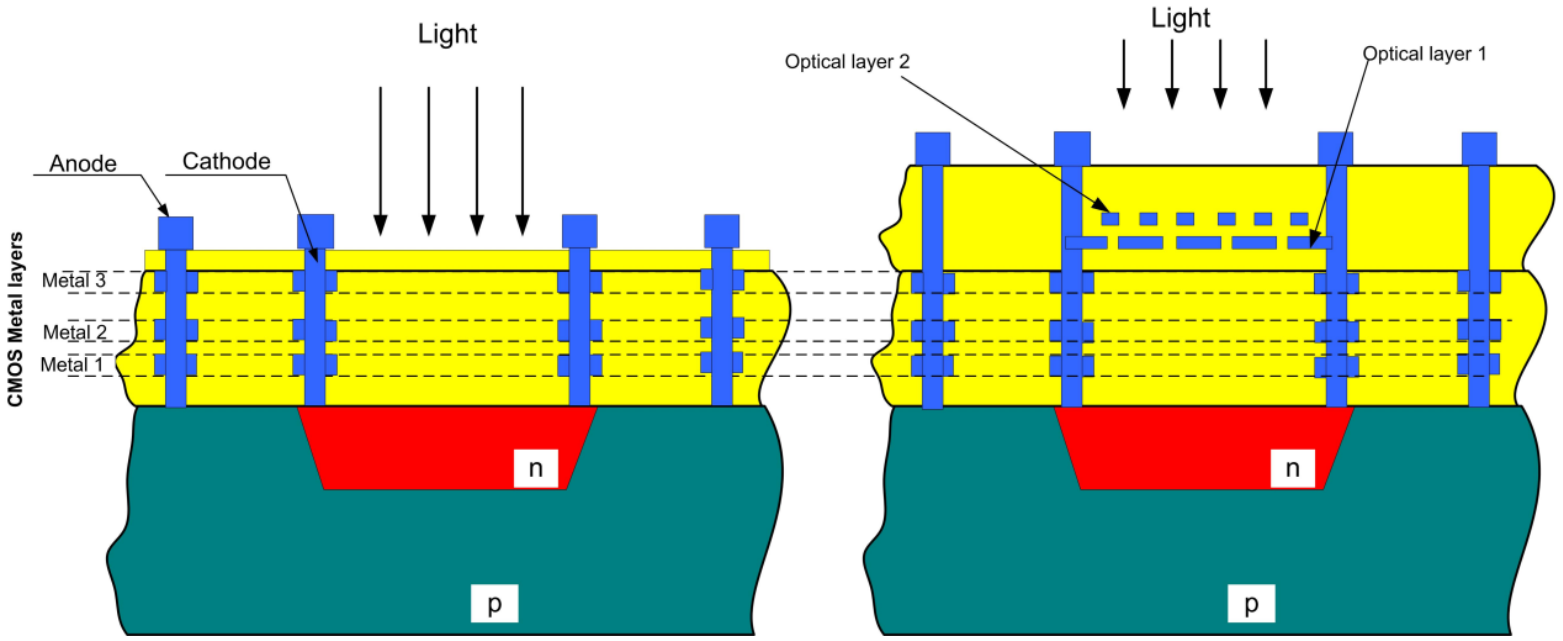
2. Methodology
Nanostructures as spectral filters



Conventional CMOS photodiode

Photodiode with added metal layers as on-chip optical filters

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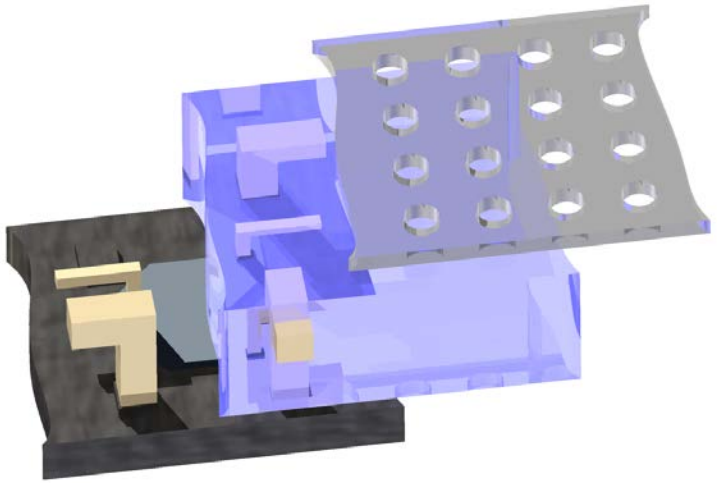
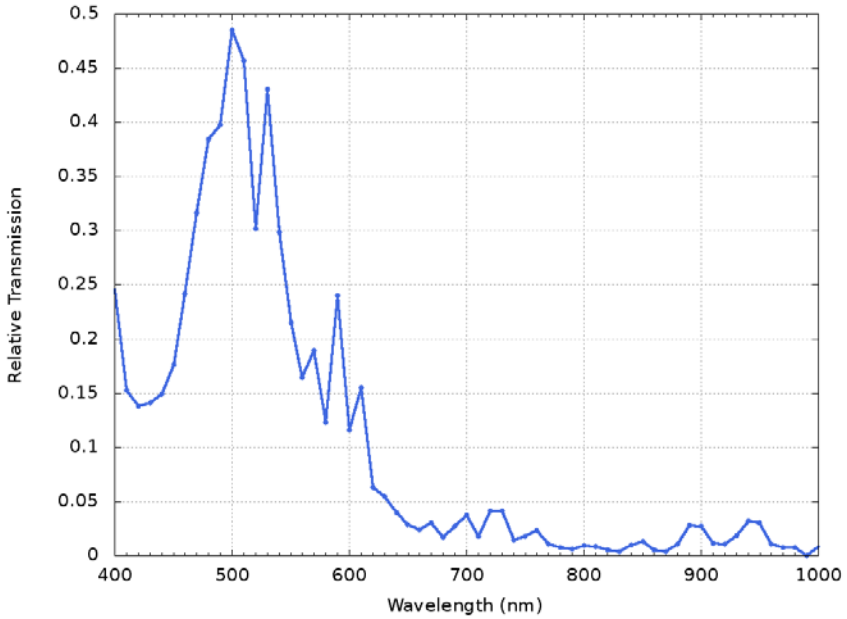
2. Methodology
Nanostructures as spectral filters

- Hole arrays with a typical period of 200 – 400 nm and »enhanced transmission« due to plasmon resonances are used
- Filter wavelength is tailored by varying the geometry





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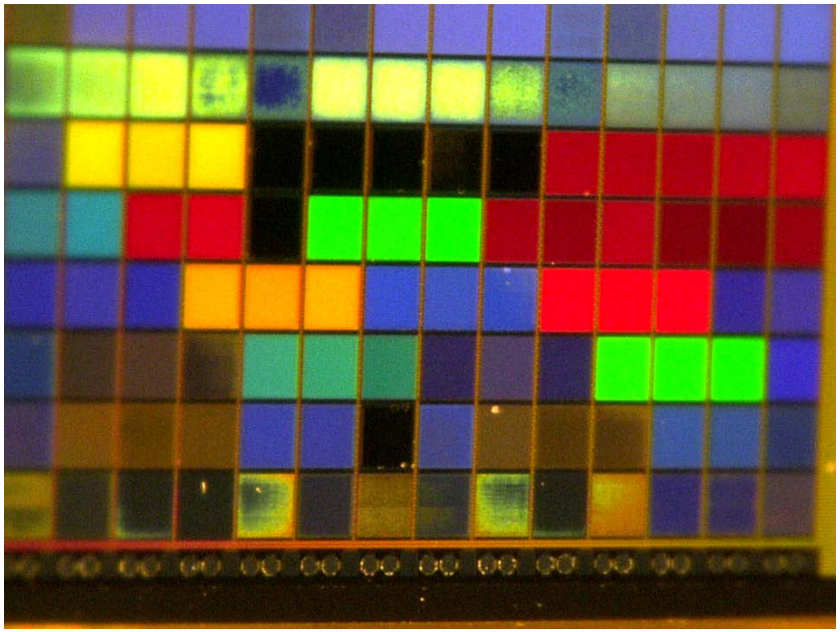
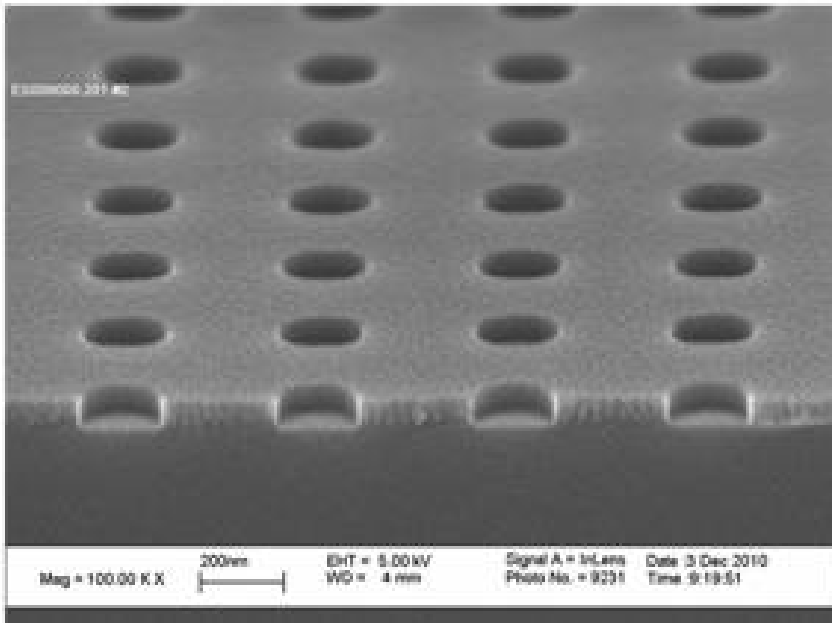
3. Experimental results
Test chips with nanostructured filters





Test chip fabricated using an extended CMOS process of X-FAB (Erfurt, Germany)

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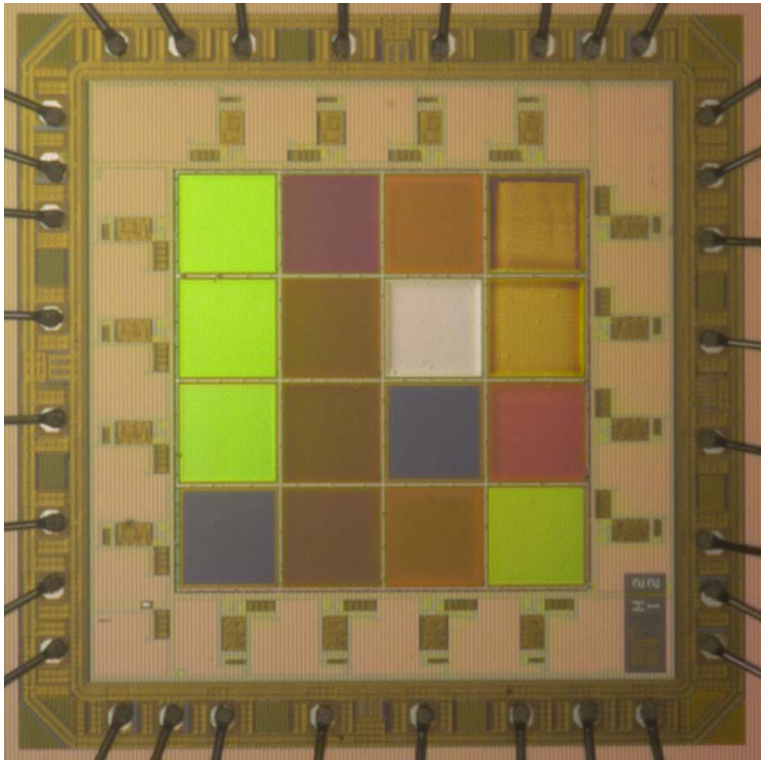
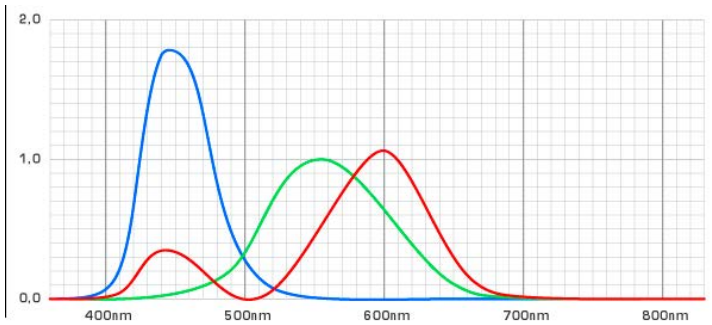
4. Application
Multispectral CMOS sensor with 16 channels



- 16 photodiodes with different filters
- 16 integrated preamplifiers (transimpedance amplifier with switchable gain and offset correction)
- Up to 16 spectral channels
- Chip size approx. 2,5 x 2,5 mm^2

4. Application
Detection of the chromaticity point

- Calibration against colorimeter
- Mapping of 12 sensor channels to the CIE tristimulus values X, Y and Z
- Measurement of the xy color coordinate



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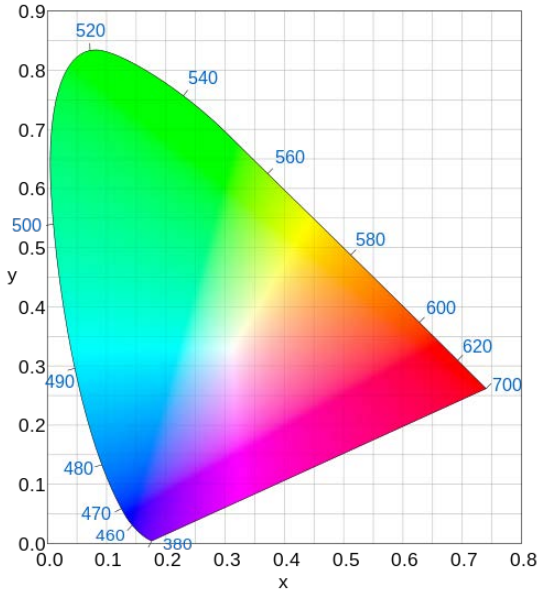

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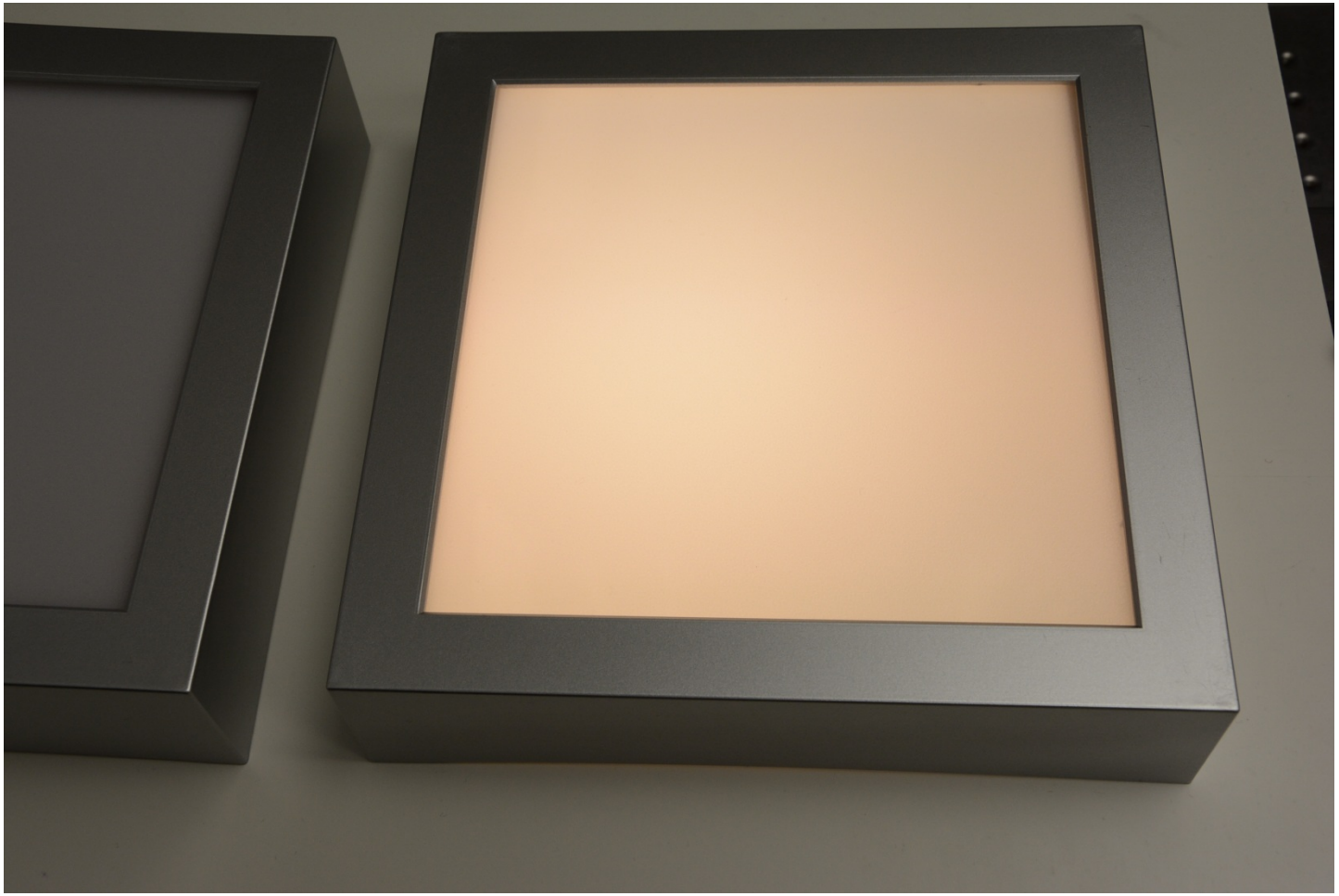
4. Application
Color feedback of a LED luminaire



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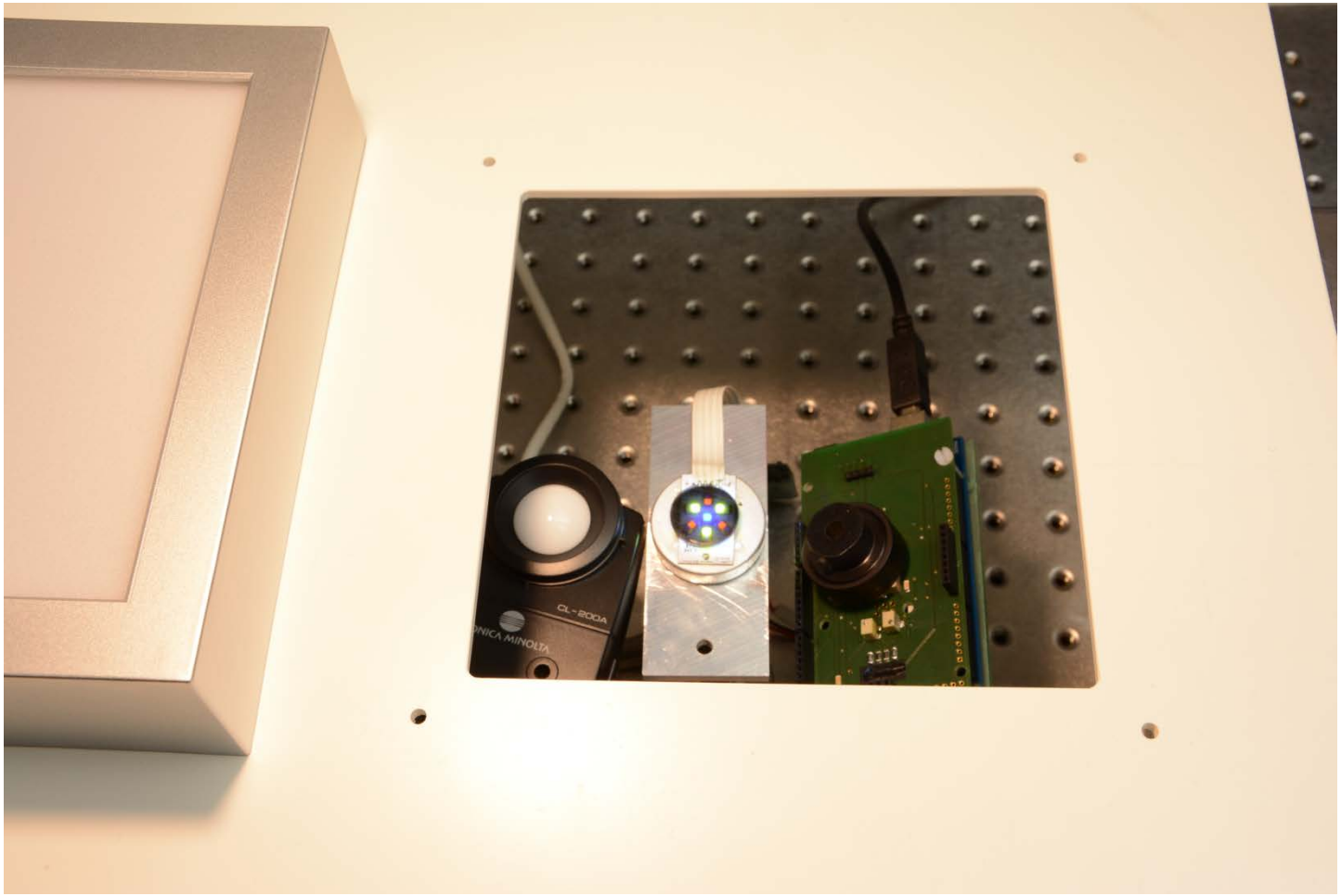

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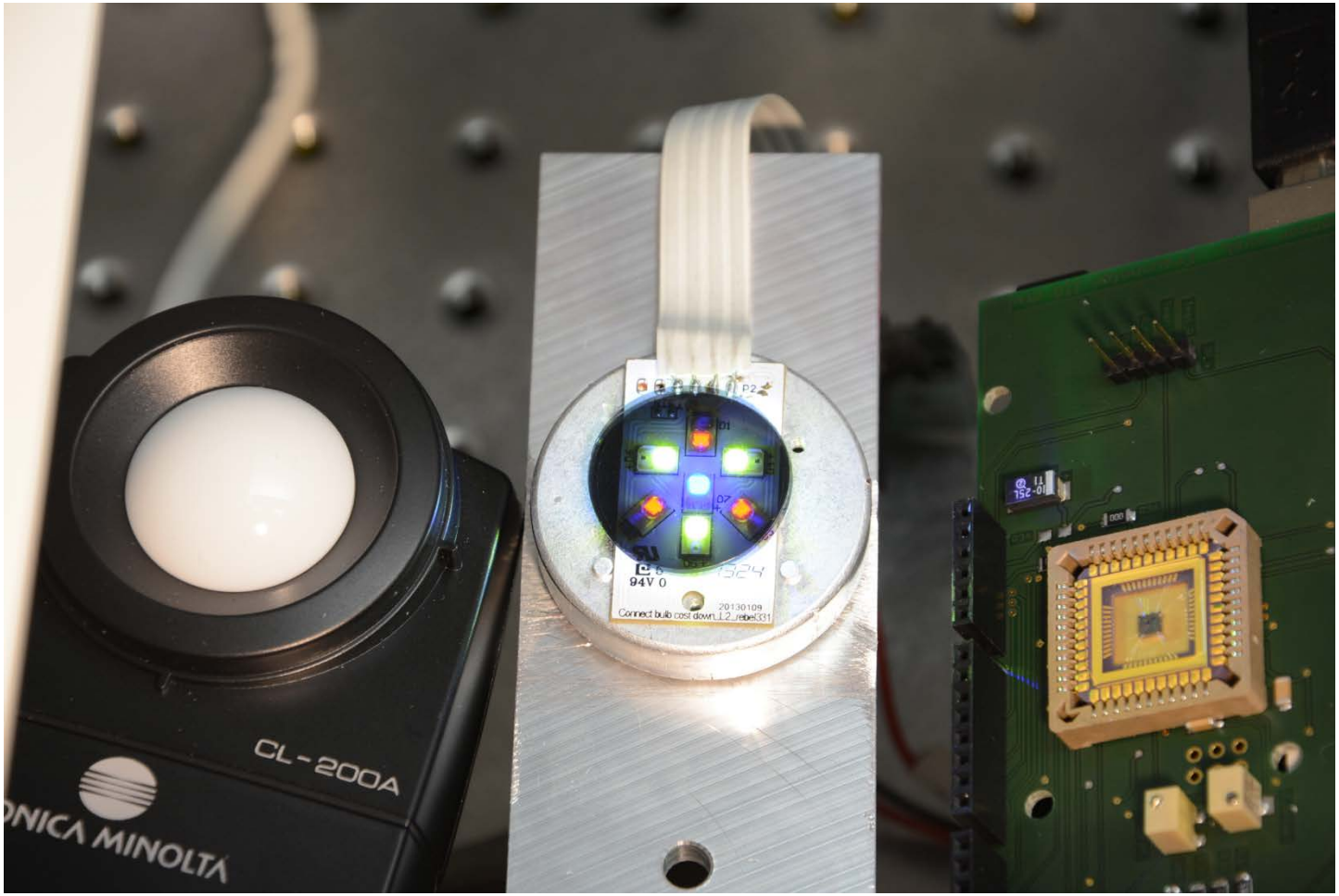

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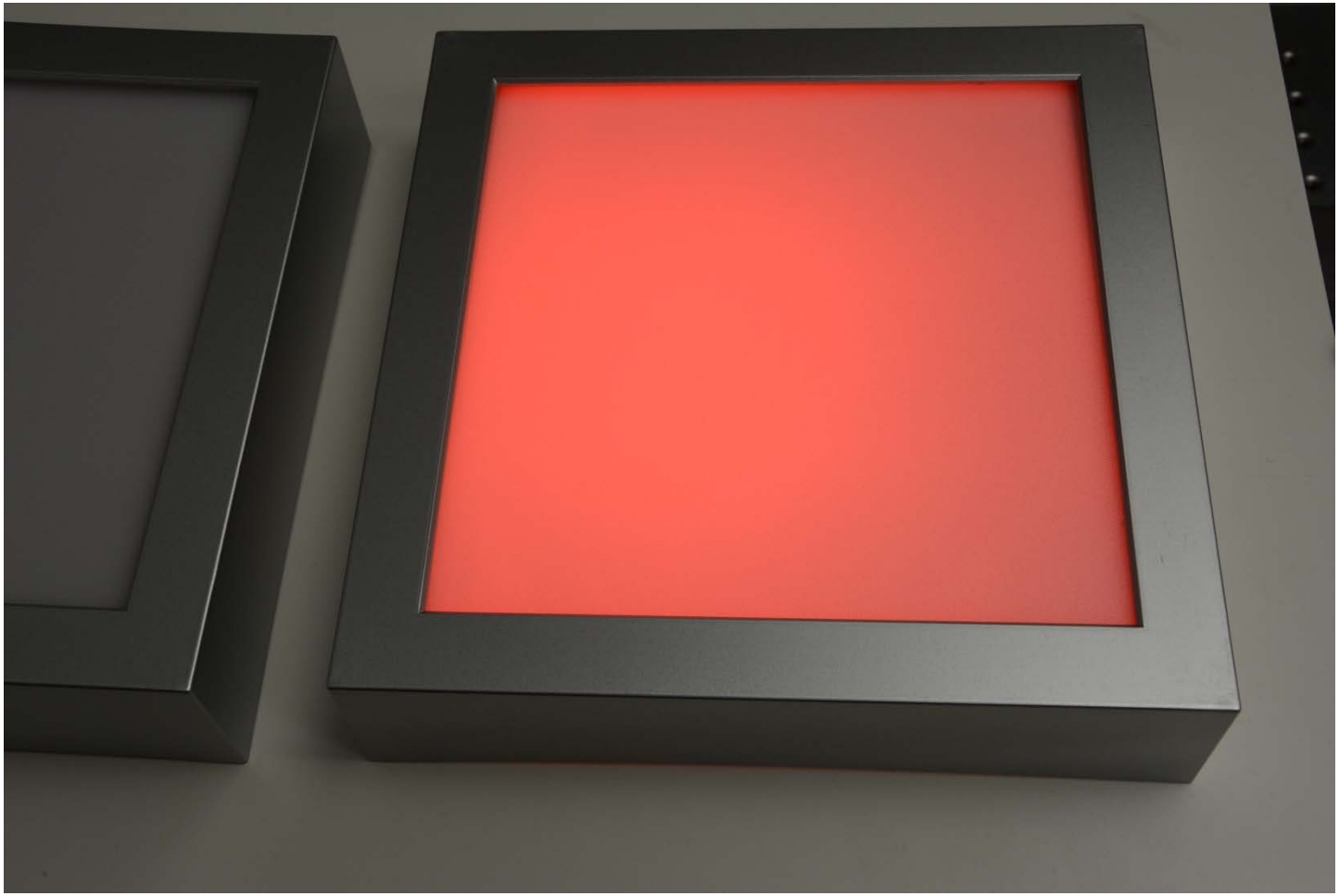

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Color feedback of a LED luminaire

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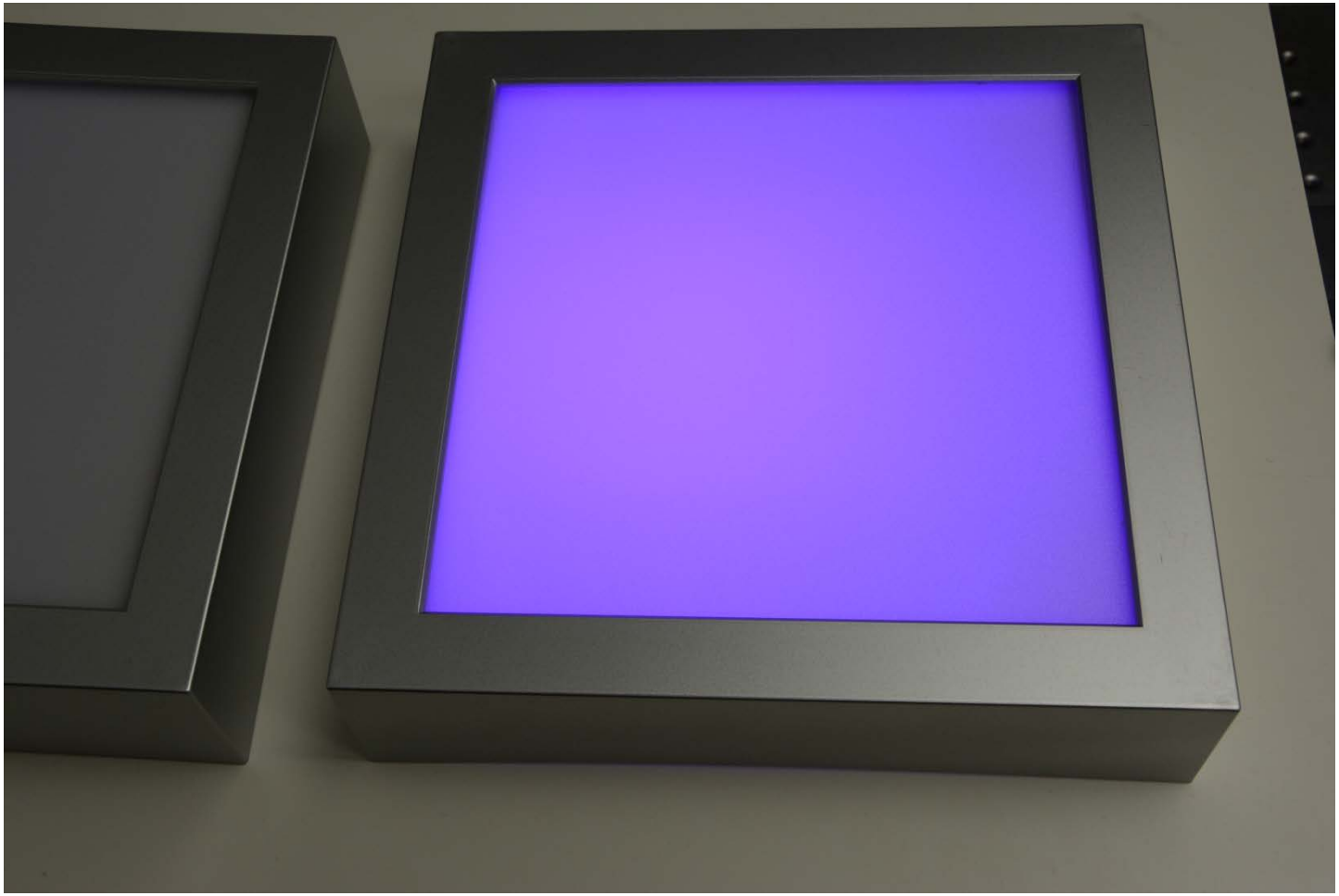

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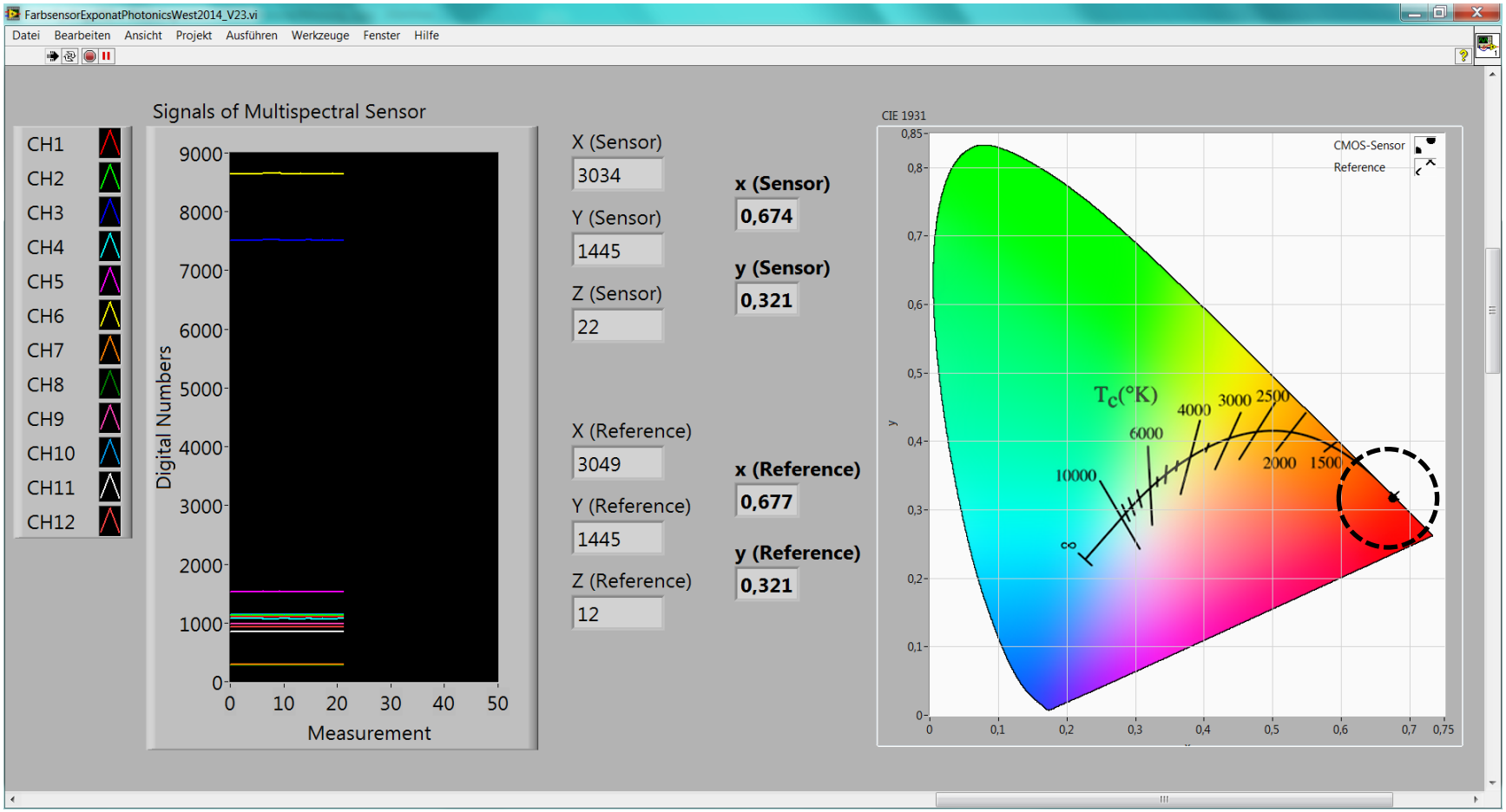

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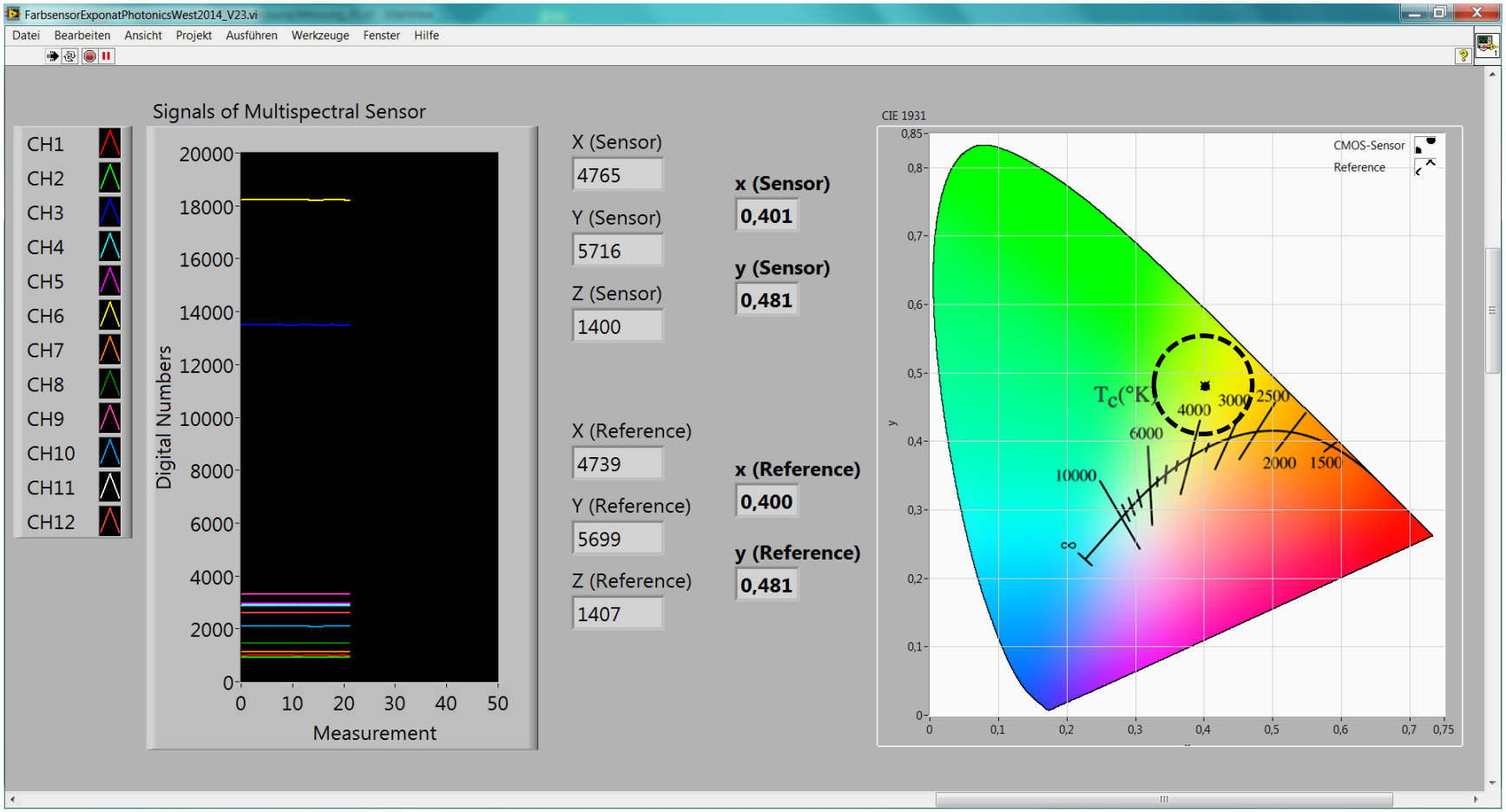

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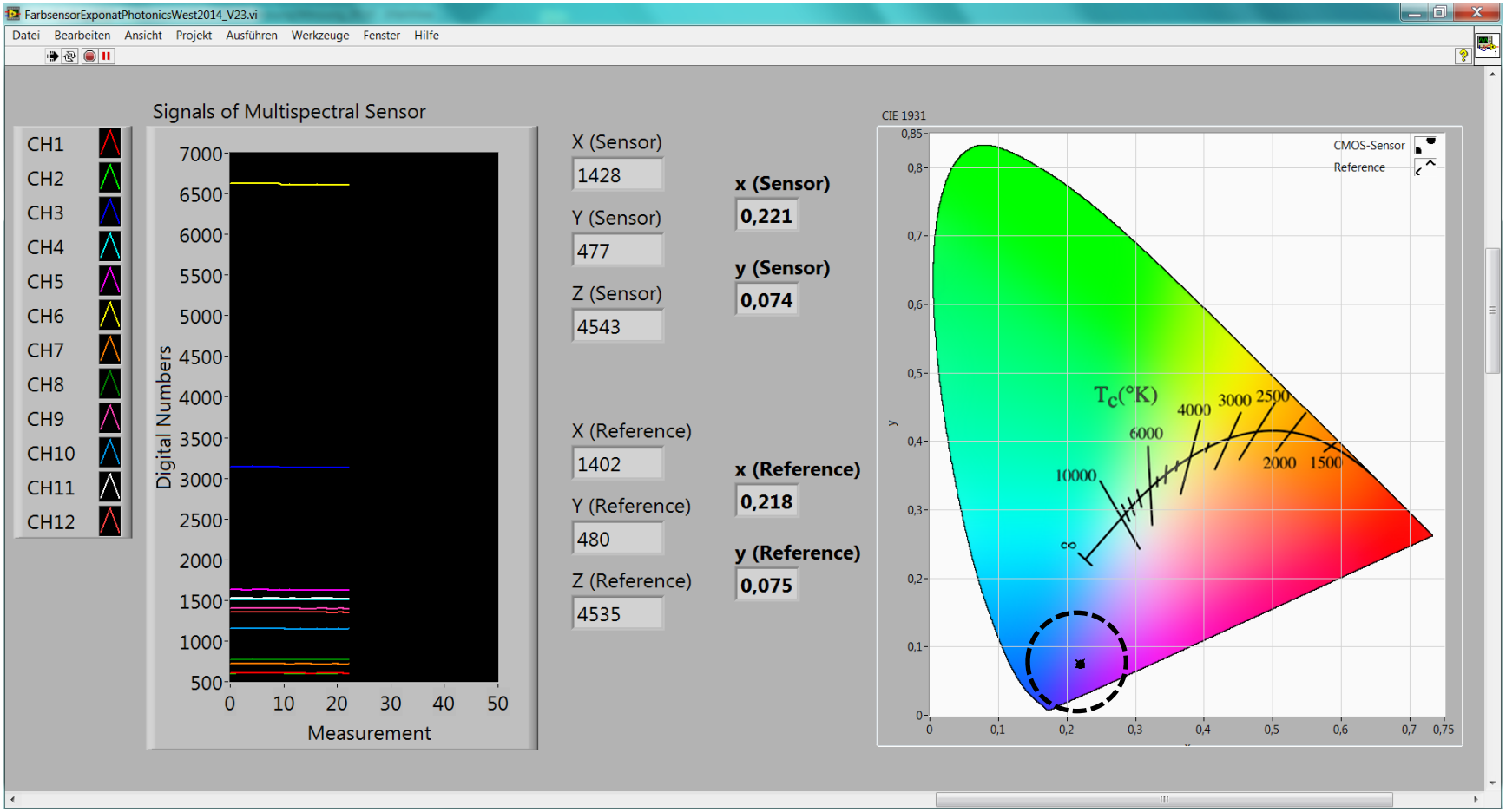

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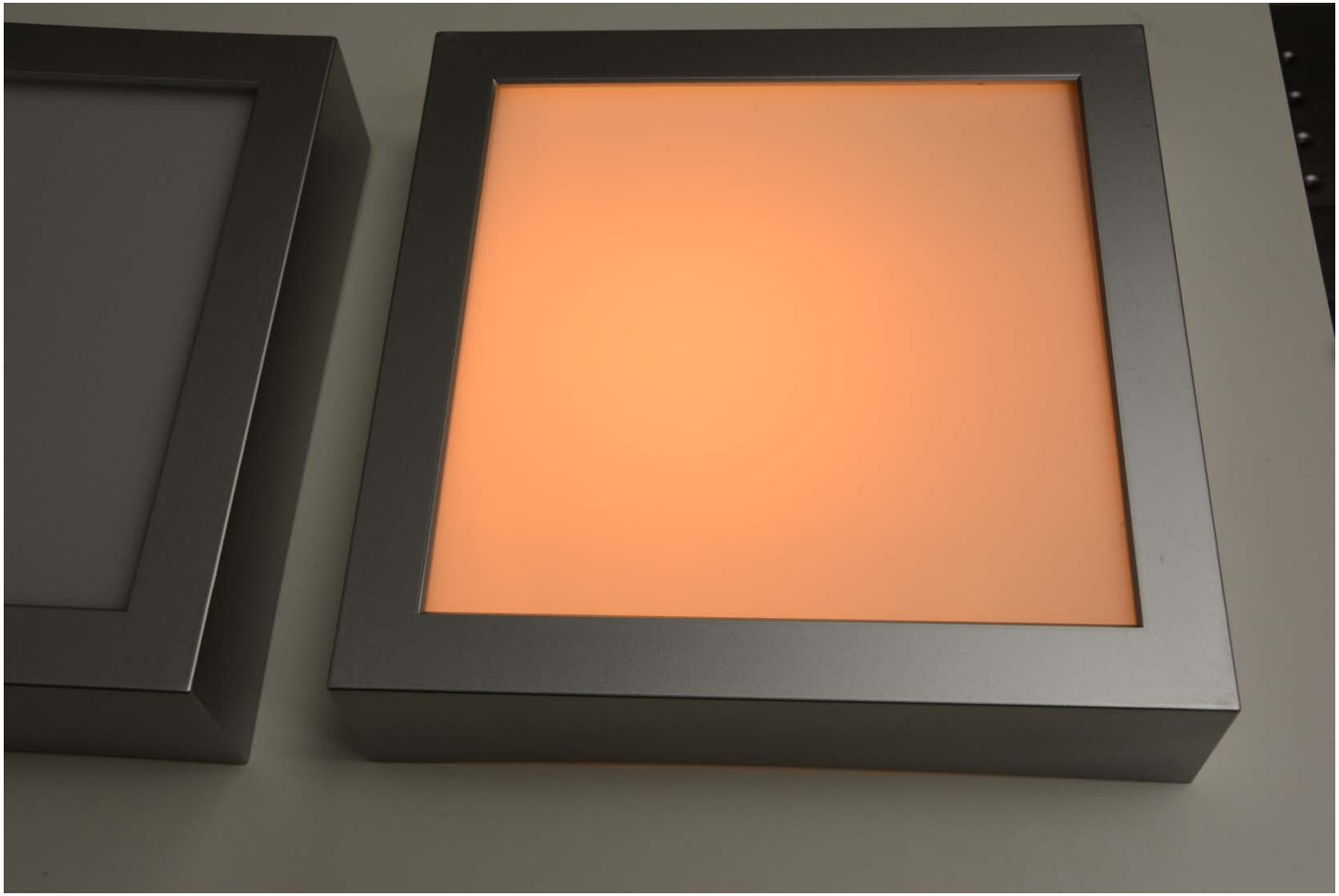
4. Application
Color feedback of a LED luminaire: »2000 K«



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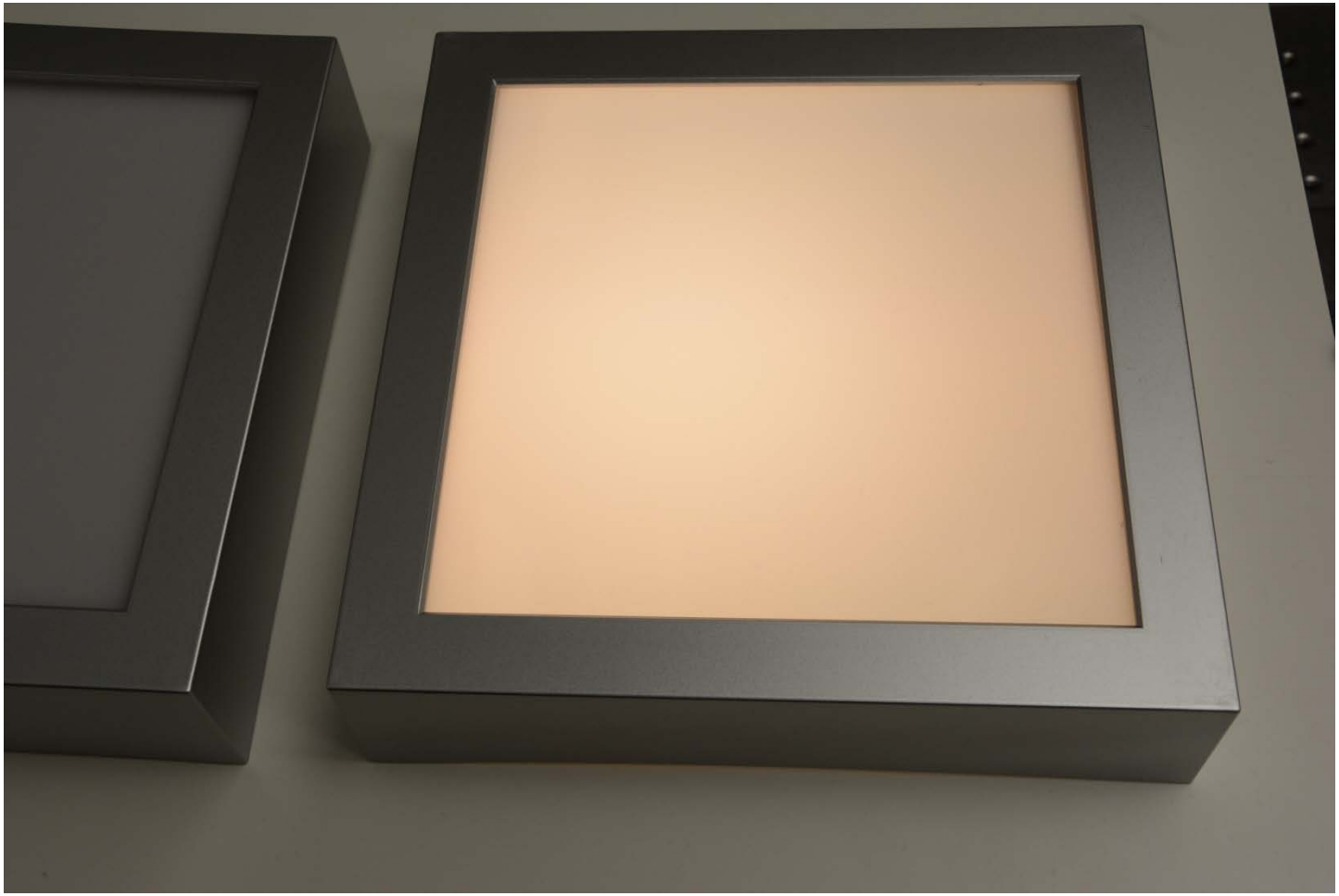
4. Application
Color feedback of a LED luminaire: »3000 K«



4. Application
Color feedback of a LED luminaire: »4000 K«

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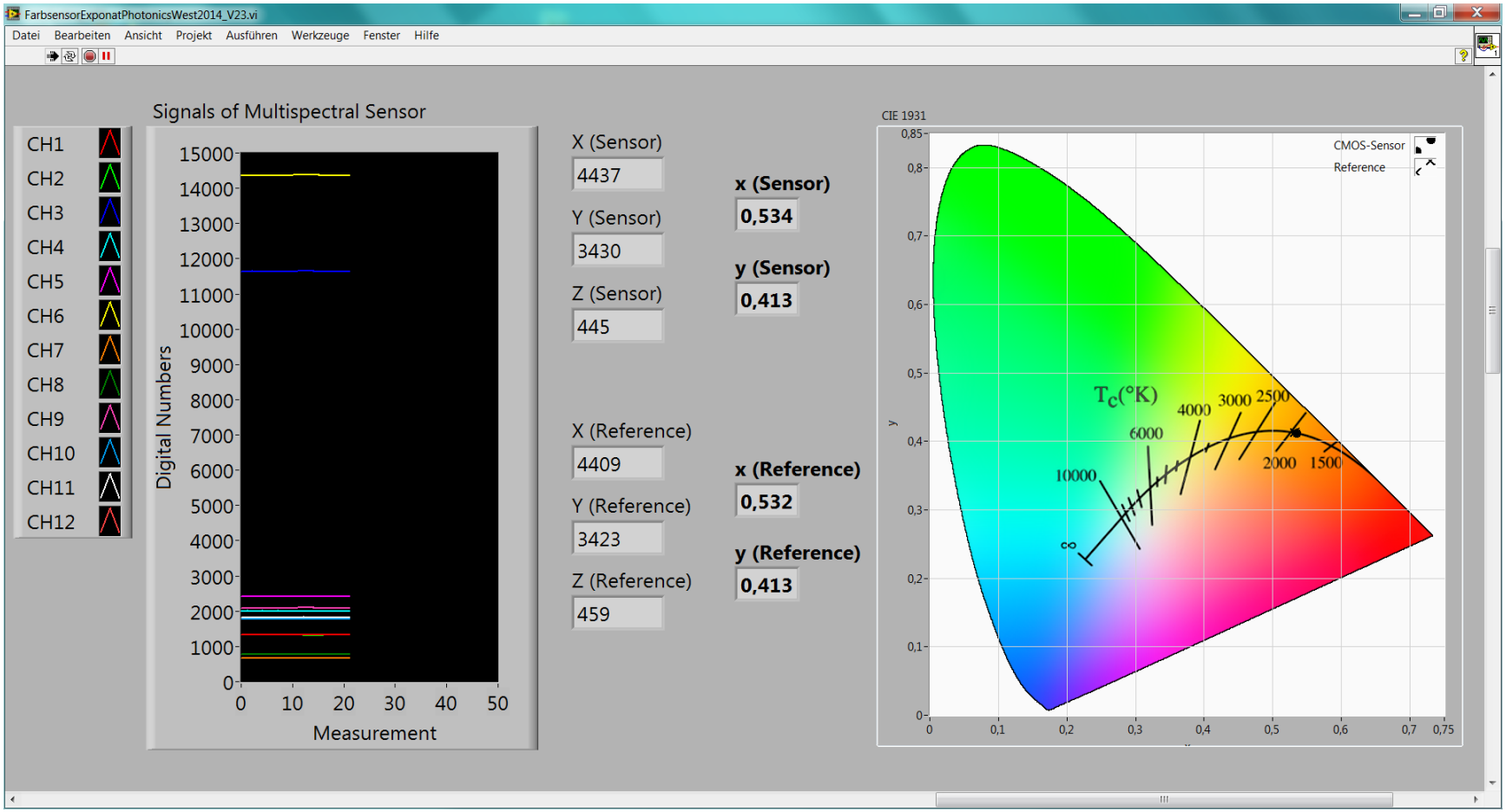
4. Application

Color feedback of a LED luminaire: »5000 K«

4. Application
Color feedback of a LED luminaire: »2000 K«



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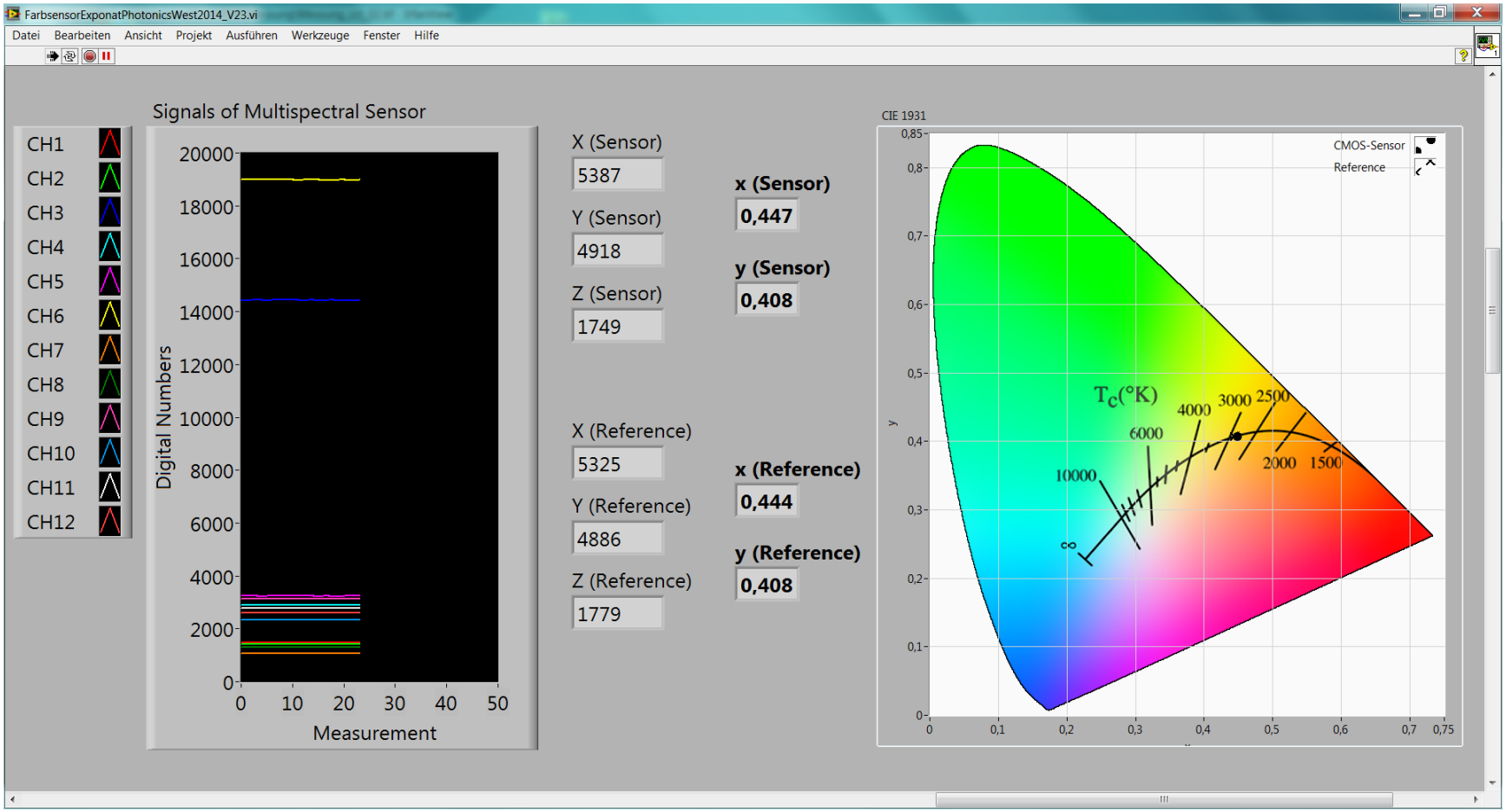
4. Application

Color feedback of a LED luminaire: »3000 K«



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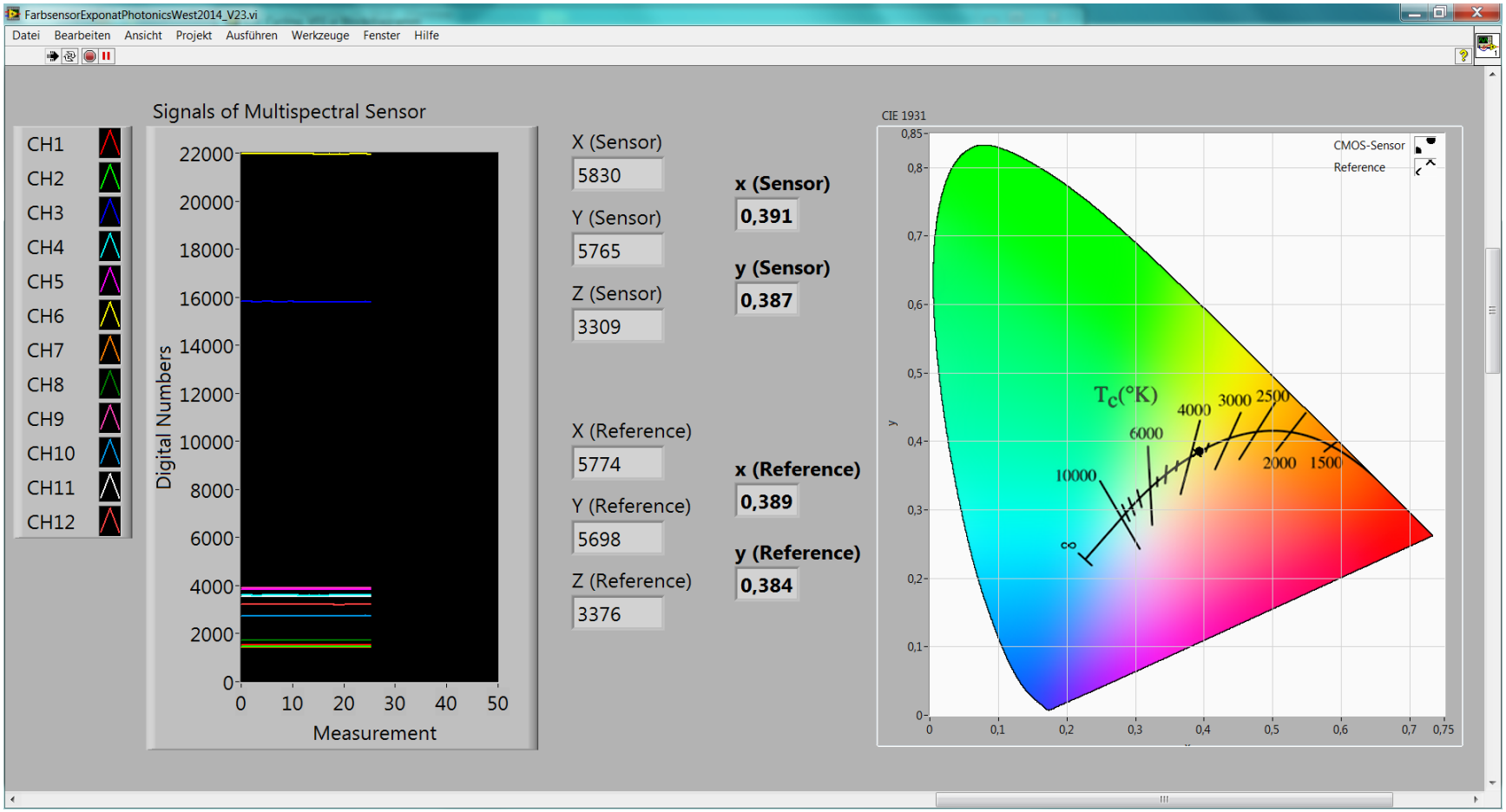
4. Application

Color feedback of a LED luminaire: »4000 K«



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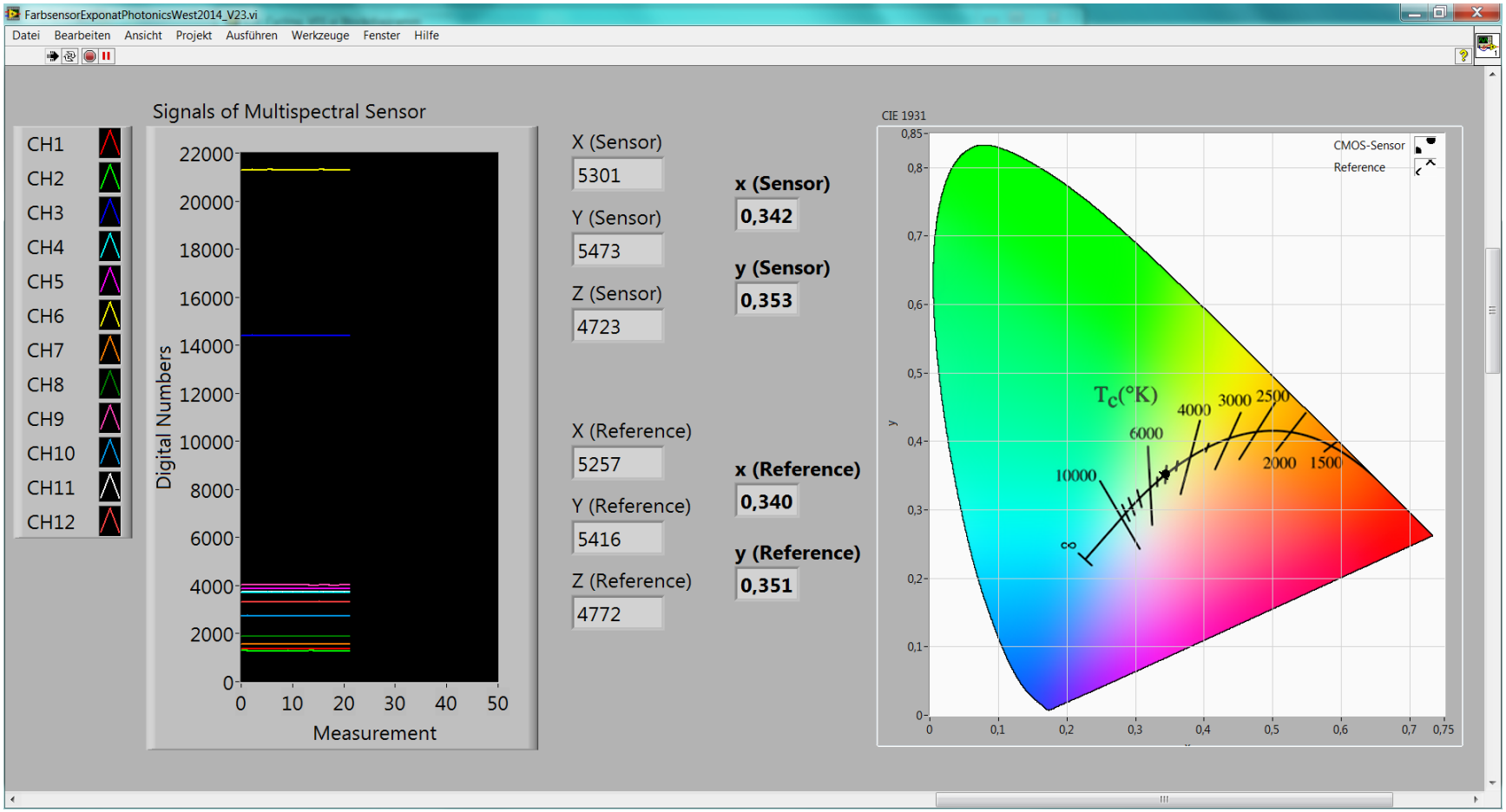
4. Application

Color feedback of a LED luminaire: »5000 K«



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4. Further applications
Spectral estimation and color rendering index

- Spectral estimation of the continuous spectral emission of light sources
- E. g. using 12 sensor channels
  - for the estimation of the spectrum at e. g. 100 wavelengths
  - using side conditions when solving the underdetermined equations
- Once the spectrum is known:
  - Tristimulus values (XYZ)
  - Chromaticity coordinates (xy)
  - Color rendering index (CRI)
  - Color quality scale (CQS)

  can be calculated easily

5. Conclusions

- High-quality LED systems benefit from color feedback sensors
- Photodiodes with on-chip color filters can be fabricated in high volume at low cost using a CMOS process
- Multichannel sensor response can be mapped to CIE tristimulus values X, Y and Z, providing chromaticity xy (CIE 1931)

Outlook:

- Quantification of sensor accuracy (MacAdam ellipses etc.)
- Implementation of LED control to stabilize chromaticity point of the LED luminaire demonstration system
- Algorithms for spectral estimation and measurement of color rendering index (CRI)

Acknowledgements

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Introducing EU project »LASSIE-FP7«
Objectives

- Project addresses all the limitations of today´s **solid-state lighting** (SSL) modules
- **Improvements** in terms of size (area and thickness), flexibility, efficiency, lighting quality, beam-shaping, lifetime, added intelligence production and production/installation costs
- Large-area, roll-to-roll (R2R) processes on thin **rigid to flexible** plastic substrates
- Hybrid approach combining **inorganic LEDs and organic materials**
- **Alternative to the OLED** technology

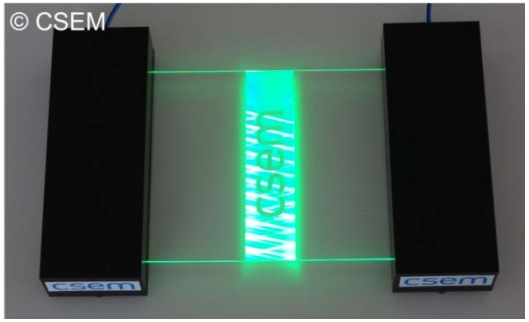
- Expected outcome: innovative large-area, high-performance, reliable, intelligent, and low-cost **LED-based module for professional and architectural lighting** (**20x20 cm²**, possible up-scaling to **60x60 cm²**)

Introducing EU project »LASSIE-FP7«

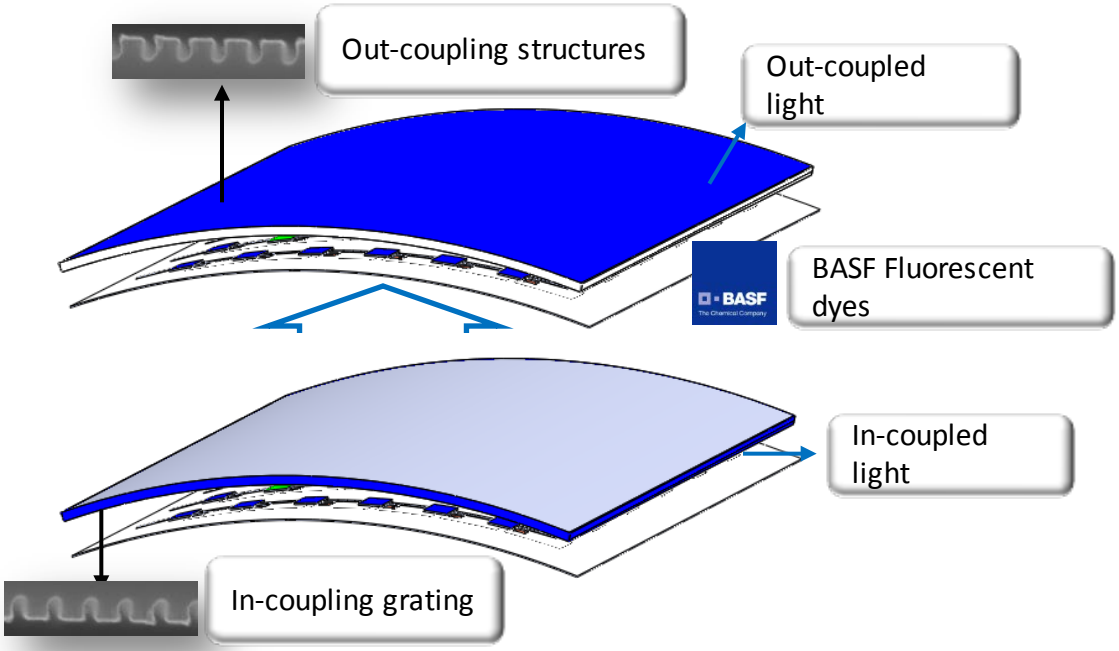
Building block: Light management solutions

Integration of:

- Light in-coupling, guiding and out-coupling optical micro/nano structures
- Color conversion solutions



Large area LED-based SSL



LASSIE-FP7

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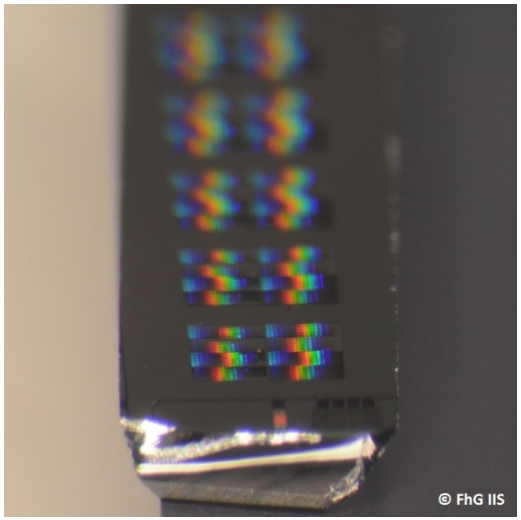
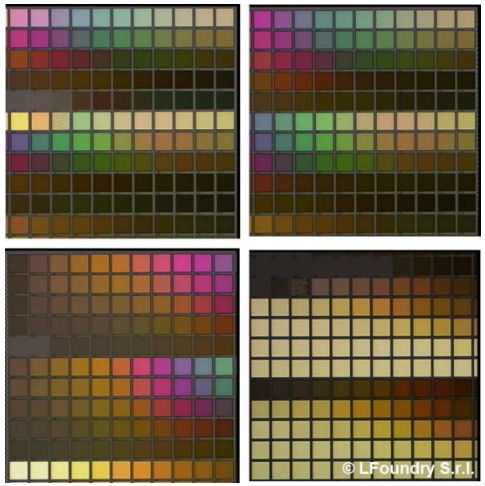
Introducing EU project »LASSIE-FP7«
Building block: Sensor device

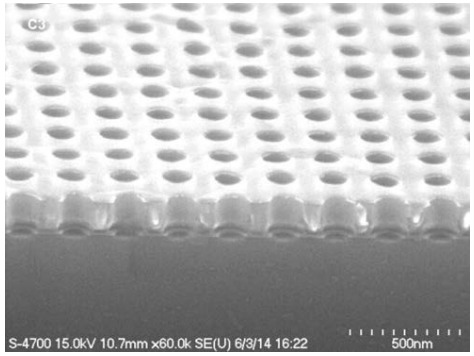
- A sensor device development
- Monolithic integration of the sensor in CMOS technology with color feedback



LFoundry chip



Optical images from MPW



SEM image of nanostructure

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Thank you for your attention

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