Color sensors for smart lighting applications

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Overview

1. **Introduction:**
   Why color sensors for smart lighting?

2. **Methodology:**
   Nanostructures as color filters

3. **EU-funded project »LASSIE-FP7«:**
   Realization of color sensors
   Application in a color feedback system

4. **Conclusions**
1. Introduction
Why color sensors for smart lighting?

»Mixing« of light required for color tuning (»tuneable white«)

High-quality lighting requires precise color matching over time and from luminaire to luminaire

Wavelength of LEDs changes with temperature and due to aging

⇒ How to keep the color of a luminaire constant?
1. Introduction
Why color sensors for smart lighting?

- Color-sensing feedback is more reliable than binning and modeling temperature and aging effects of LEDs

⇒ Cost-effective color sensors are needed for high-volume illumination applications
1. Introduction

Technologies for color sensors

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

- Are there other approaches ...
  - ... feasible using CMOS semiconductor technology?
  - ... enabling highly integrated sensors at low cost?
2. Methodology
Nanostructures in nature
2. Methodology
Nanostructures in art and science
2. Methodology

Surface plasmon resonances

- Perforated metal films (»hole arrays«) ⇒ resonances of oscillating electrons, »enhanced transmission« (Ebbesen 1998)

- Color and multispectral sensors feasible

- Resonance wavelength can be tailored by geometry at constant layer thickness ⇒ ideal for CMOS!
2. Methodology

Nanostructures as spectral filters

Conventional CMOS photodiode

Photodiode with added metal layers as on-chip optical filters
3. **EU-funded project »LASSIE-FP7«**

Large Area Solid State Intelligent Efficient luminaires

- **Color sensor**
- **Lumogen® Fluorescent Dyes**
- **Light management**
- **Heat management**

*Property of the LASSIE-FP7 Consortium*
3. »LASSIE-FP7«
CMOS nanostructures as color filter

- 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
 Simulation of metallic nanostructures

Simulation: green filter (band pass)

Spectral transmission of a hole array (period 280 nm)

Simulation: blue filter (low pass)

Spectral transmission of an island array (period 320 nm)
3. »LASSIE-FP7«

Simulation of metallic nanostructures

- Example for a filter set of color/multispectral sensor
- Typically, 8-16 spectral channels are used
- More robust than color sensors with 3 channels, more spectral information

Spectral filters covering the wavelength range from 400 – 600 nm
3. »LASSIE-FP7«

Fabrication of CMOS color sensor

LFoundry chip

Optical images from MPW

SEM image of nanostructure
3. »LASSIE-FP7«

Color tuning concept

- Colour conversion film optimised for 4000 K (main application)
- Red + green + blue LED for colour tuning
- Target tuning range: CCT 2700 – 6500 K
- Feedback control algorithm tunes from actual to nominal colour point iteratively
3. »LASSIE-FP7«

Color feedback demo
3. »LASSIE-FP7«
Color feedback demo
3. »LASSIE-FP7«

Color feedback demo
3. »LASSIE-FP7«
Color sensor demo at the LASSIE booth

- Multispectral sensor
- Microcontroller board for sensor configuration and data acquisition
- Live sensor data at different colored illumination conditions
4. Conclusions

- High-quality LED lighting systems benefit from color feedback sensors
- Photodiodes with on-chip colour and multispectral filters can be fabricated in high volume at low cost using a CMOS process
- Implementation of color feedback loop in order to stabilize the chromaticity point of LED luminaires demonstrated in »LASSIE-FP7«