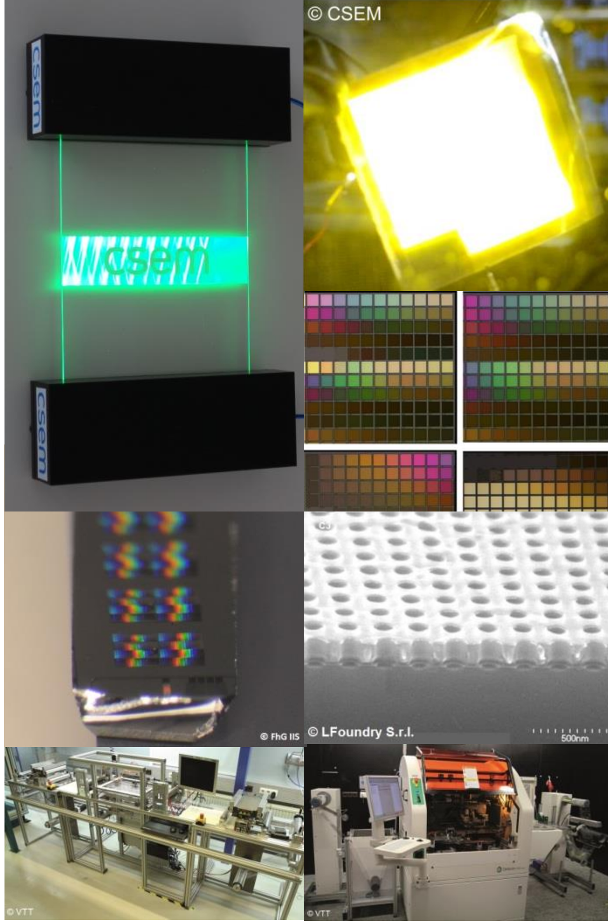
Large Area Solid State Intelligent Efficient luminaires

Rolando Ferrini

Muttenz, 30.10.2014



LASSIE-FP7

SEVENTH FRAMEWORK PROGRAMME

Heterogeneous Technology Alliance

SWISS PHOTONICS

BASF The Chemical Company

REGENT LIGHTING

VTT

Fraunhofer IISB

Fraunhofer IIS

LFoundry

GAIKER

AMIRES

1984•2014 30 YEARS

csem

Outline

- CSEM / HTA / Swissphotonics
- Large Area Solid State Intelligent Efficient luminaires (LASSIE-FP7)
  - A look into the past …
  - Objectives
  - LED-based polymer foils
  - Heat Management
  - Light Management
  - Multispectral colour sensors
  - Environmental & Cost assessment
- Conclusion

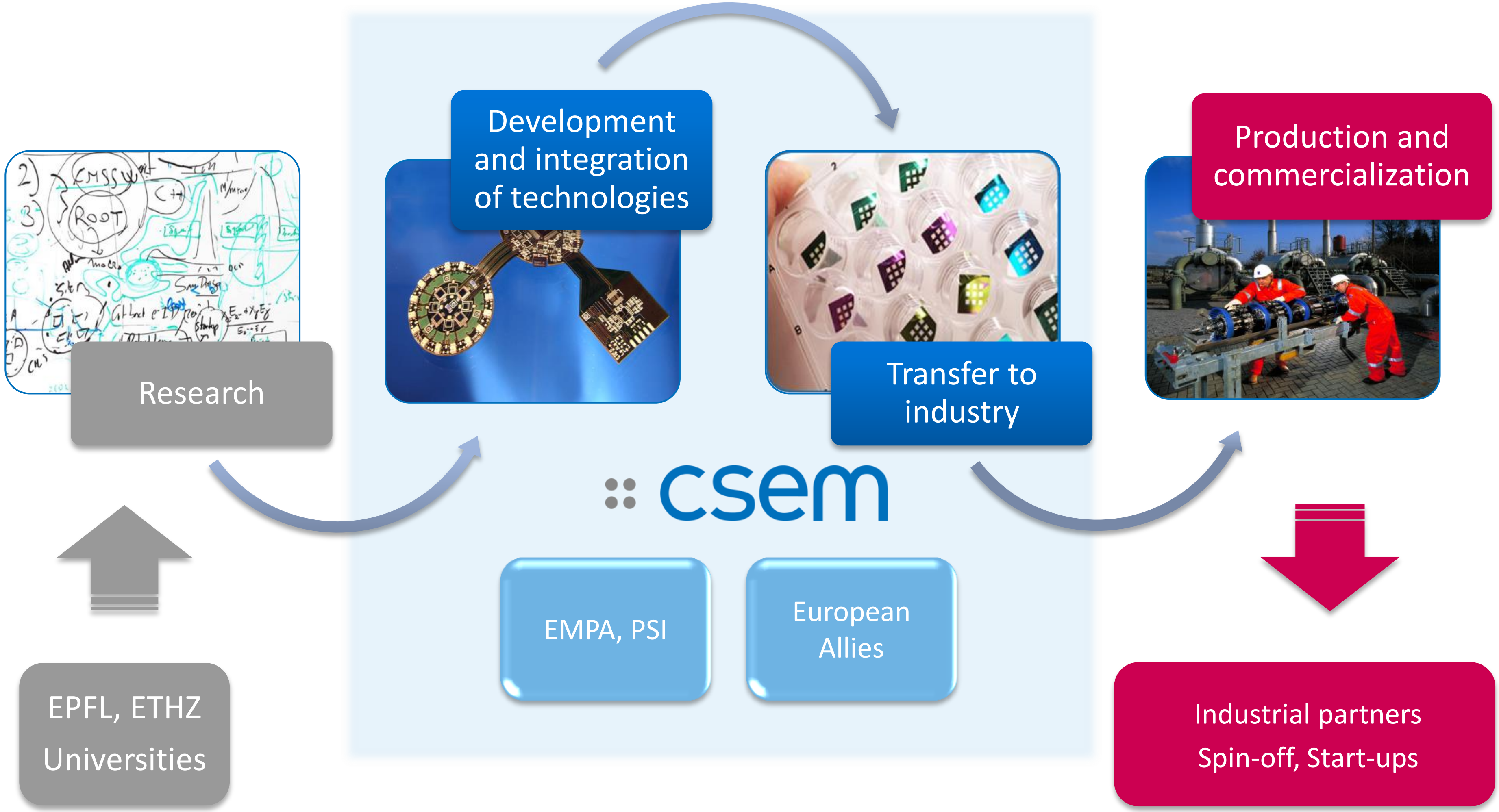
CSEM at a glance

Our mission

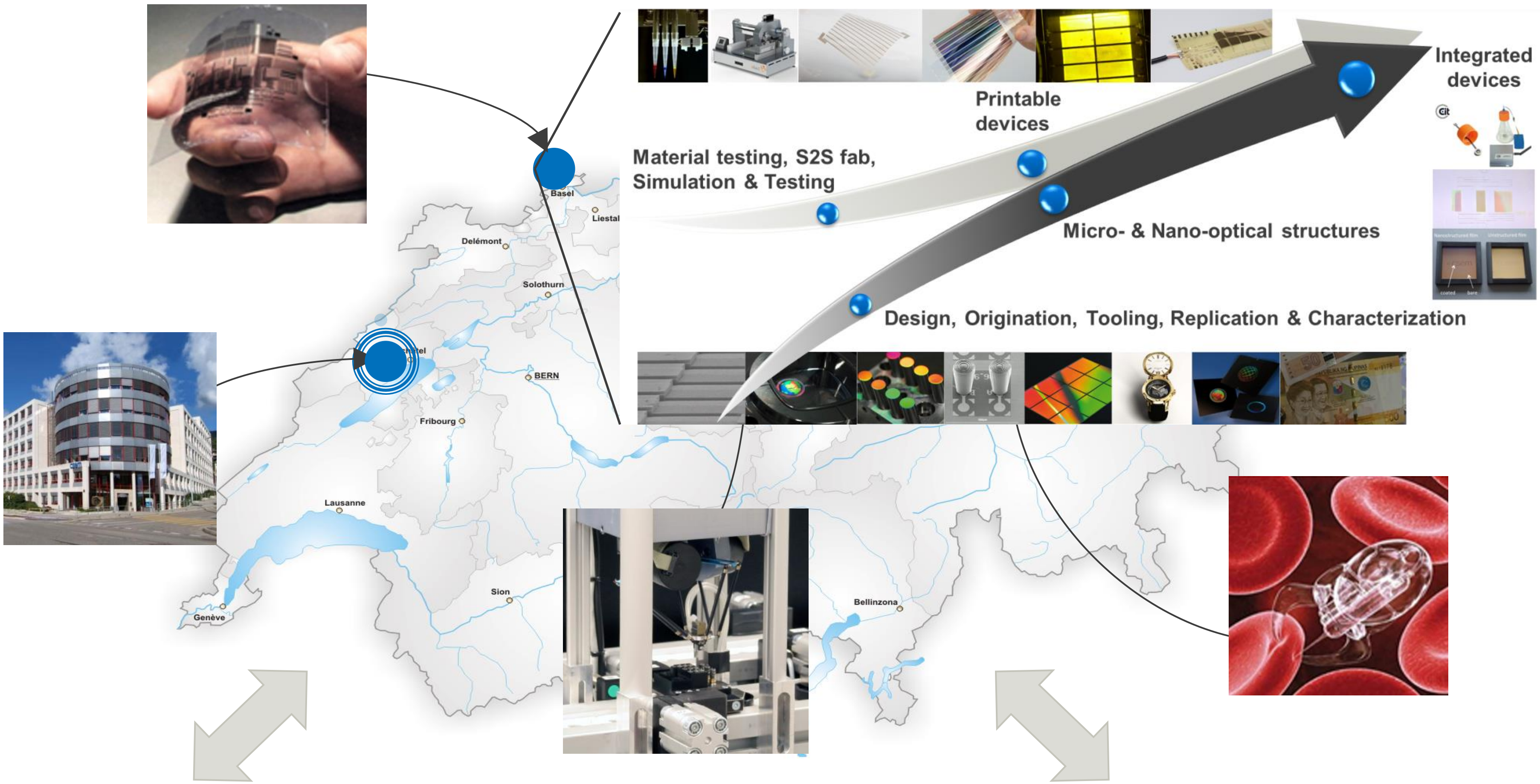
Development and transfer of microtechnologies to the industrial sector – in Switzerland, as a priority – in order to reinforce its competitive advantage

- Cooperation agreements with established companies
- Creation of start-ups

CSEM’s positioning



Closer to industry …



csem brasil

csem uae

Heterogeneous Technology Alliance

CSEM's European network

Division Recherche Technologique

Grenoble

Empl. 2'000

Turnover : 191 M€

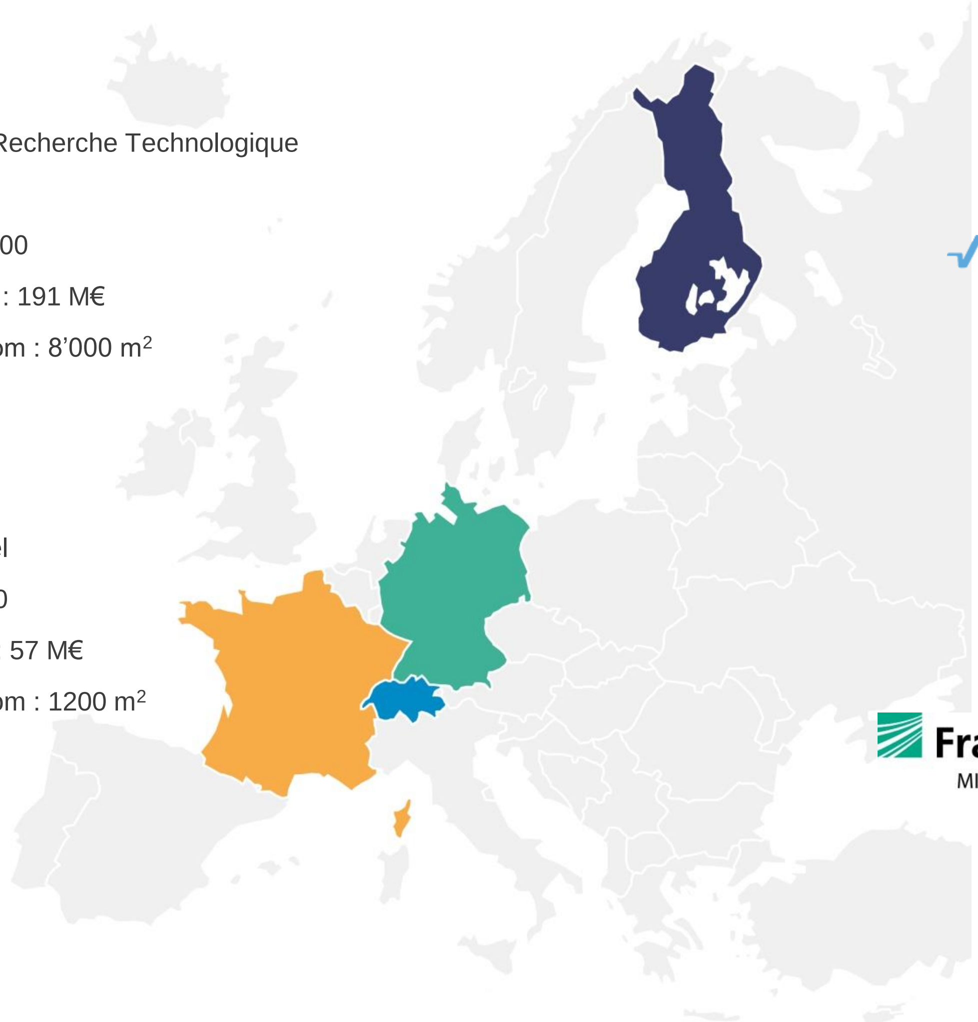
Clean room : 8'000 m^2

Neuchâtel

Empl. 400

Turnover: 57 M€

Clean room : 1200 m^2



Espoo, Oulu

Empl 2'800

Turnover : 278 M€

Clean room : 2450 m^2

Fraunhofer MIKROELEKTRONIK

Dresden, Berlin, München

Empl. 1'800

Turnover : 220 M€

Clean room : 8450 m^2

SWISS PHOTONICS
CTI – Start-up and Entrepreneurship, R&D Funding, KTT Support

Swiss National Laboratory for Solid State Lighting (SSSL)

- **Swissphotonics** is the Swiss national thematic network (NTN) for photonics, supported by the Swiss Innovation Promotion Agency (CTI).
  Mission: advocacy for photonics, national and international networking (e.g. Photonics 21, EPIC), workshops, partner and fund matching.

- **Swiss National Laboratory for Solid State Lighting (SSSL)** serves as a one-stop entrance point for requests of companies active in SSL.
  Mission:
  - Consulting and contract R&D services with focus on Swiss SMEs (but not only):
    - Feasibility and case studies
    - Supply of test components, characterization and metrology
    - Access to standard know-how and equipment in SSL
  - Building a national SSL cluster
  - Seminal talks and Workshops

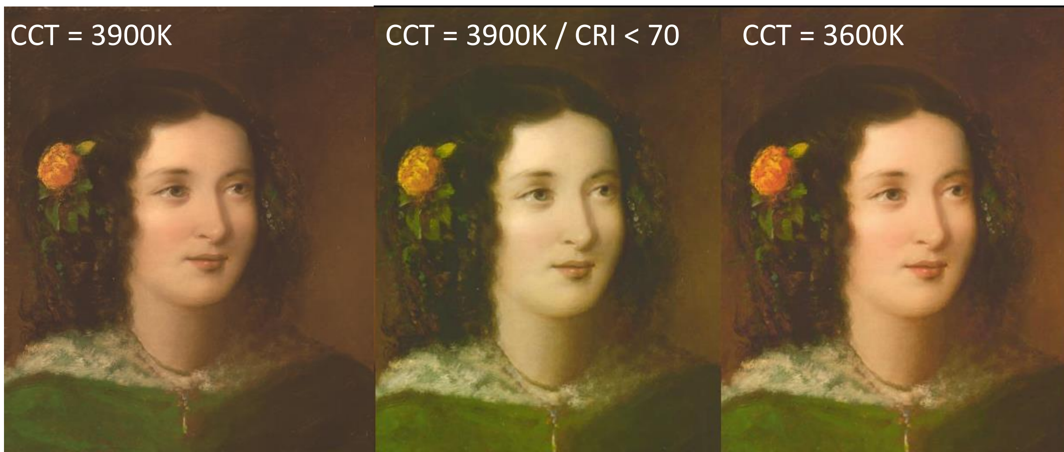
csem EMPA Materials Science & Technology EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE Zürcher Hochschule für Angewandte Wissenschaften zhaw

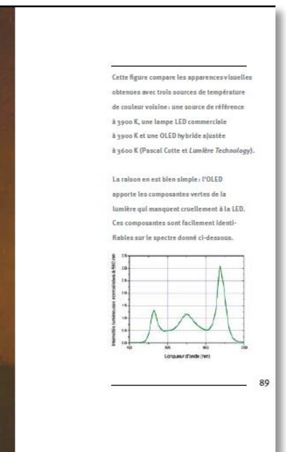
LASSIE-FP7

Introduction

A reflexion on « future » lighting and its quality

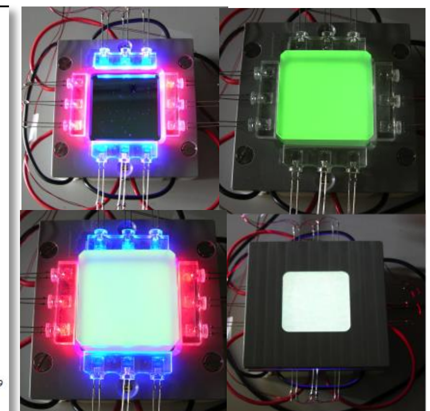
Black body | Philips NR63 | Hybrid OLED




Cette figure compare les apparences visuelles obtenues avec trois sources de température de couleur voisine : une source de référence à 3900 K, une lampe LED commerciale à 3900 K et une OLED hybride ajustée à 3600 K (Pascal Cotte et *Lumière Technology*).

La raison en est bien simple : l'OLED apporte les composantes vertes de la lumière qui manquent cruellement à la LED. Ces composantes sont facilement identifiables sur le spectre donné ci-dessous.

89



M. Schaer, P. Cotte, L.Zuppiroli (*Lumières du Futur*, PPUR, 2011)

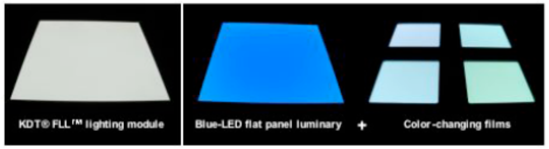
Colour changing films

CTI Project « New Color-changing films for lighting applications » (nr. 8184.1 EPRP-IW)

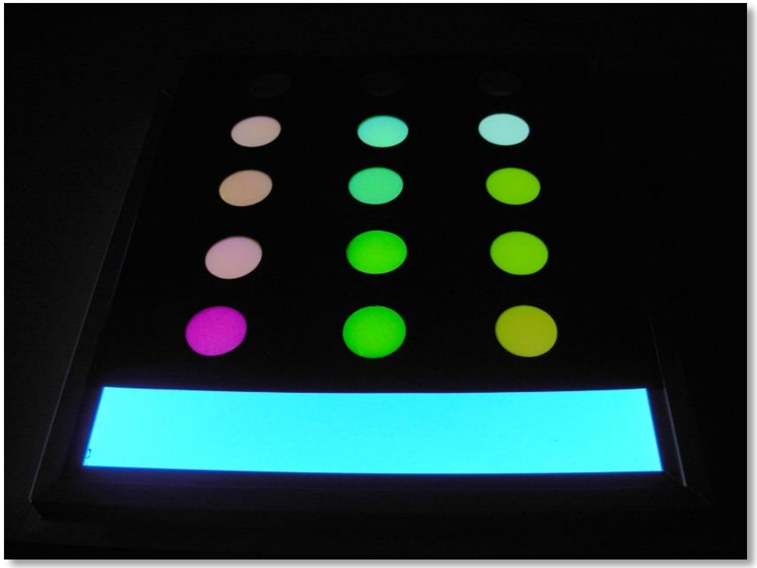
Summary of project and project results for publication on the KTI/CTI homepage or annual report

Initial cost and operating cost (*e.g.* efficiency and lifetime) are important factors for the success of a product in the illumination market. On one hand, the source efficiency is considered as one of the major differentiation elements. On the other hand, in lighting applications the human color perception is a fundamental factor. The spectrum of an illumination source should preferably be close to the daylight spectrum in order to be accepted as "pleasant". Therefore, the holy grail of the illumination industry is a light source that combines all the favorable characteristics of the existing technologies: cheap, efficient, with a "pleasant" spectral power distribution (color-rendering index) and a color temperature that can be easily tuned and adapted to the needs of the intended application. While light emitting diodes (LEDs) are the emerging technology for lighting systems because of their high efficiency and lifetime compared to traditional light sources (*e.g.* incandescent bulbs and halogen lamps), they do not meet the same standards of light and color quality. If the use of multiple LEDs emitting at different wavelengths yields the most efficient white LEDs, the color issue remains because LEDs are small band emitters and cover only very narrow spectral regions. Alternatively, white-light LEDs are realized using either a blue or a UV LED and one or more phosphors. With blue LEDs the phosphors absorb a portion of the blue light and fluoresce at longer wavelengths. The mixing of the blue light and the fluoresced wavelengths produces the white light. The drawback of this approach is a relatively poor color-rendering index and a poor color mixing. With UV LEDs three or more different colored phosphors are used and virtually all of the UV-LED emission is absorbed. However, the degradation of both the packaging material and the phosphor matrix due to the high flux of UV radiation is an important issue. In all of these applications, either inorganic or organic phosphors are used to enhance the color-rendering index. On one hand, most inorganic phosphors used in lighting applications were developed to convert the UV-light produced in fluorescent lamps. Therefore, these pigments are not well adapted to the efficient white light conversion of UV-LEDs and blue LEDs. Moreover, developments based on toxic materials will not have an important impact on the market. Developing new inorganic phosphors, which will be integrated in industrial products on a large scale, will not be an easy task. On the other hand, the big advantage of organic molecules compared to inorganic materials is the possibility of easily tailoring their optical properties by means of organic synthesis. Moreover, certain classes of organic fluorescent dyes are known to have very high absorption coefficients and excellent fluorescent quantum yields, both fundamental properties for efficient color conversion. However, even when incorporated into a polymer matrix in order to be integrated into the light source, the organic molecules have a low stability that limits their application to lighting systems.

In this project, a new approach was proposed to realize *new color-changing films* (CCFs) to improve the emission properties of LED-based lighting modules. In order to combine the advantages of organic molecules with an increased stability, organic fluorescent dyes were encapsulated into inorganic or organic hosts, thus obtaining highly doped color-changing nanopigments. These latter were dispersed into polymer films that were eventually combined with nanopourous hybrid polymer layers providing both optical isolation from the substrate and light out-coupling, thus obtaining color-changing multi-layers with optimized optical characteristics. We highlight that these films are well adapted to the ILFORD coating technology that is characterized by being intrinsically large surface, high volume, and low cost. Preliminary stability measurements showed a loss of 50% in absorption/emission after a 300 hours-exposure. With standard and well-known solutions the film stability can be improved to obtain a CCF lifetime in the order of 1000's hours. The CCFs were applied to a blue-LED-based flat panel luminary and their performances for white-light generation were measured and assessed against commercial KDT® FLL™ lighting modules (see the picture below). The measured low efficiency (10 lm/W) is due to emission/absorption losses. Optimizing the optical design will allow us to increase absorption/emission and light out-coupling, thus obtaining efficiency values in the order of those of the KDT® FLL™ modules. Moreover, a better choice of fluorescent dyes and/or the fine tuning of their absorption/emission spectra will enable us to enlarge the color temperature (CCT = 6000-9000 K) and rendering index (CRI = 70-80) performances.



2006-2008



Patents

- EP08164280.3 & US 2010/0102251
- US 13/114.558 & PCT/IB2012/052577

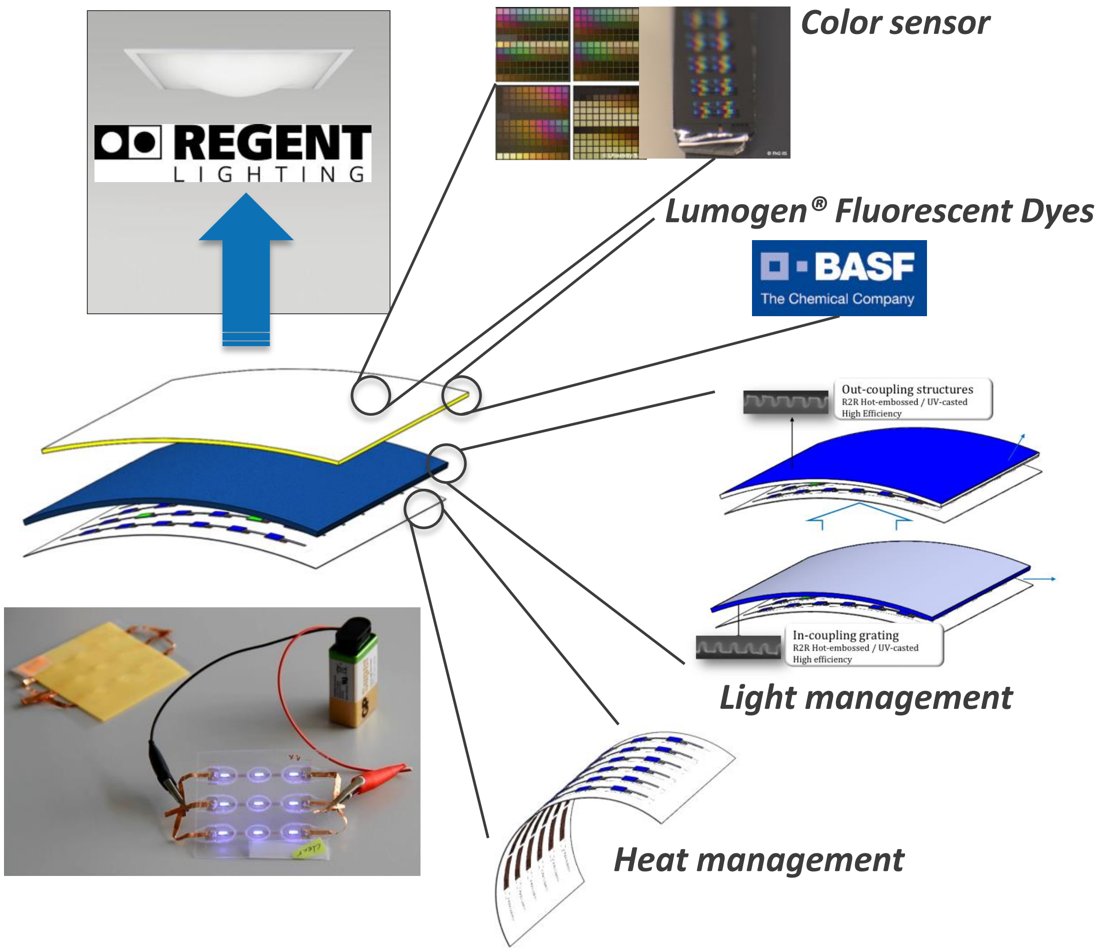
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

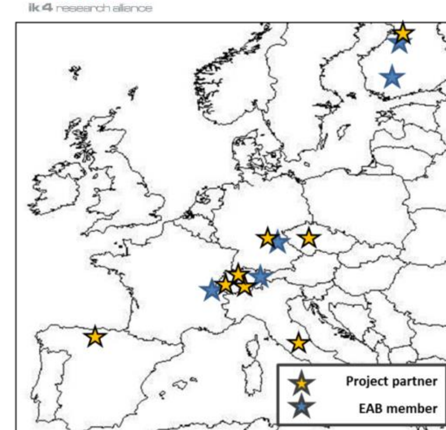
LOMM

LOTFI

ILFORD

Large Area Solid State Intelligent Efficient luminaires





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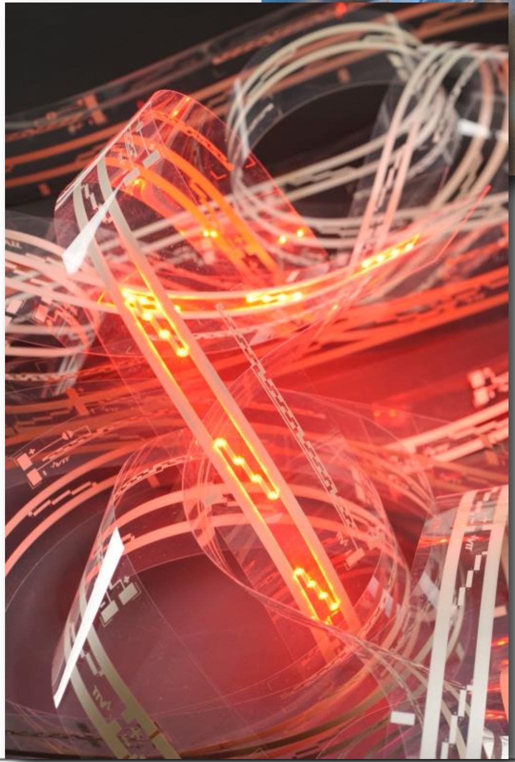
LED-based foils

LED-based polymer foils

Opportunities

- LED-based polymer foils ➔ Flexible lighting modules
- Printing and assembly with R2R processes
- Improved performance:
  - Optimized electronics layout
  - Traditional electronic SMD components
  - Bare LEDs with no on-chip optics



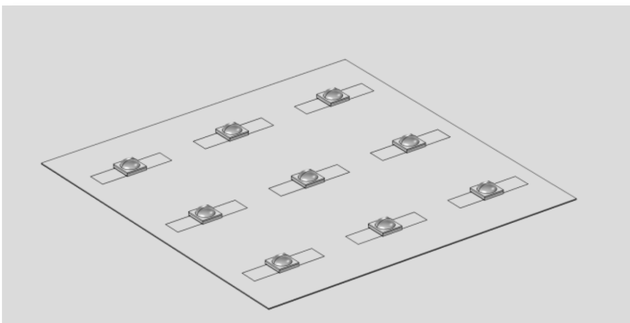
Challenges

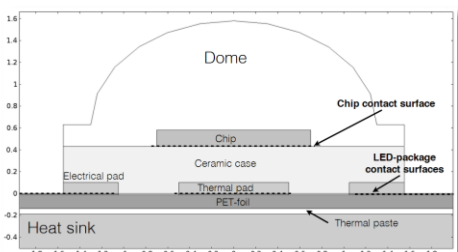
- Heat management
  - Poor thermal conductivity of the polymer foils

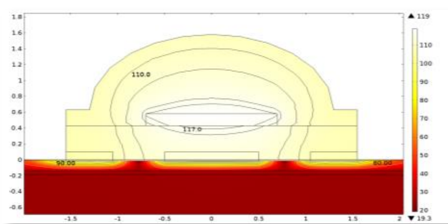
Heat management: Simulation & Test

Simulation

Thermal model
(Comsol / FEM)



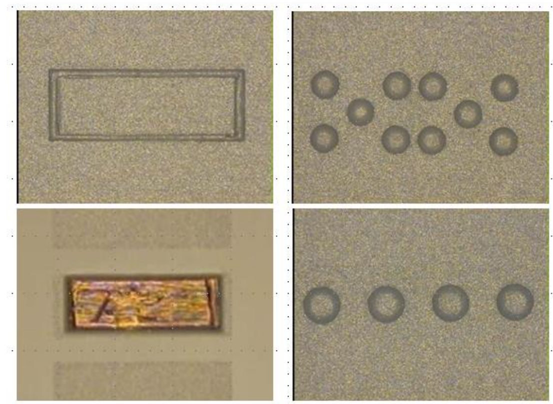


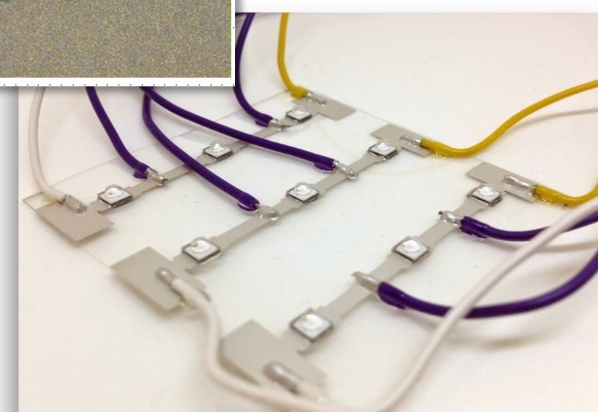


- The model was set-up to represent the test structures

Test structures

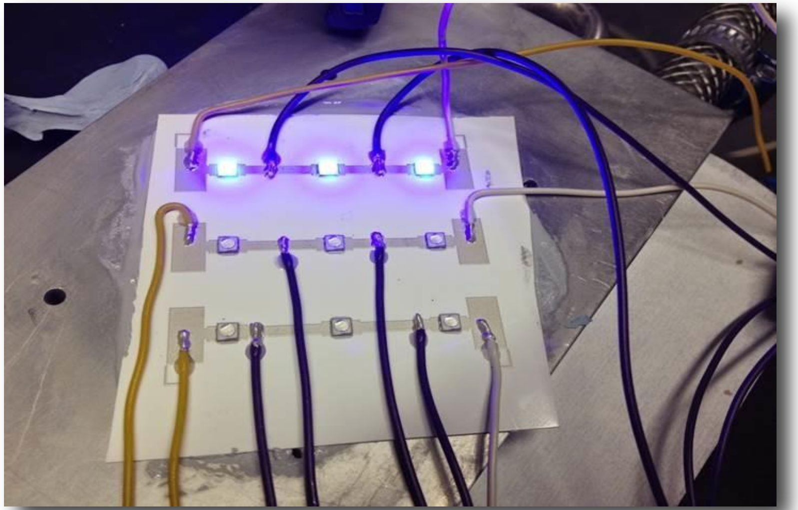
Processing





- Test structures: circuits with vias & slugs

Heat management: Measurements



Thermal transient tests

Modelling

Sensitive to the thermal conductivity of the PET foil

Measurement

Forward voltage ↔ LED temperature

Identifier	Simulated T, degC	Measured T, degC	Std	Deviation wrt Sim.	Min Meas. T, degC	Deviation wrt Sim.
No-vias	117	97	10	-20	87	-30
Small vias (10)	99	75	4	-24	69	-30
(18)	89	69	3	-20	64	-25
Large vias (4)	104	83	6	-21	77	-27
(7)	94	74	8	-20	65	-29
Slug	59	59	3	0	55	-4

- **Vias** work well but requires further development
- **Slugs** provide the best thermal performance

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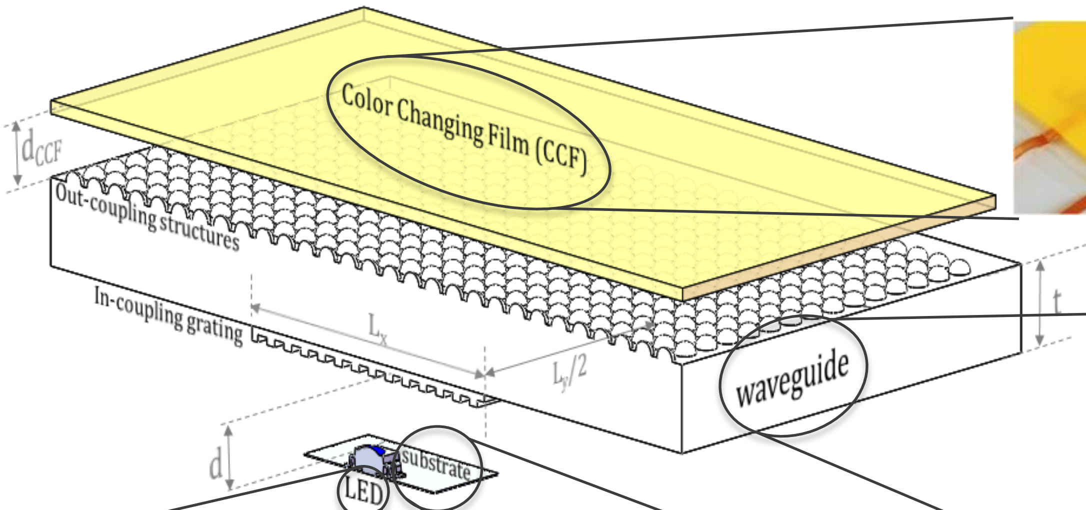
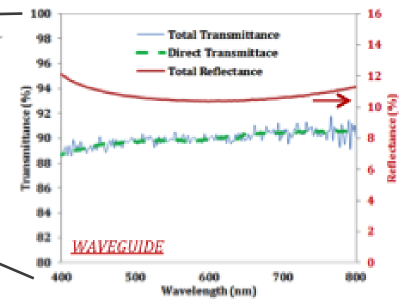
Light Management

Light Management: Concept

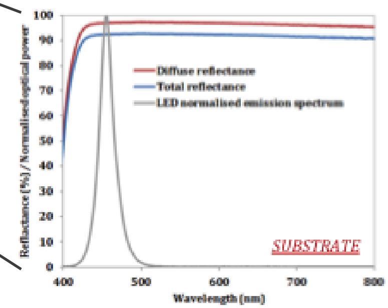


Color Changing Films (CCFs)
✧ Flexible & R2R compatible
✧ Organic fluorescent materials
- Broad spectrum
- High color rendering



Commercial PC foil (0.5mm)
✧ High transmittance
✧ Low optical absorption

Compact blue LEDs
✧ λ_{max}: 470nm / FWHM: 20nm
✧ Angular aperture: ±60º

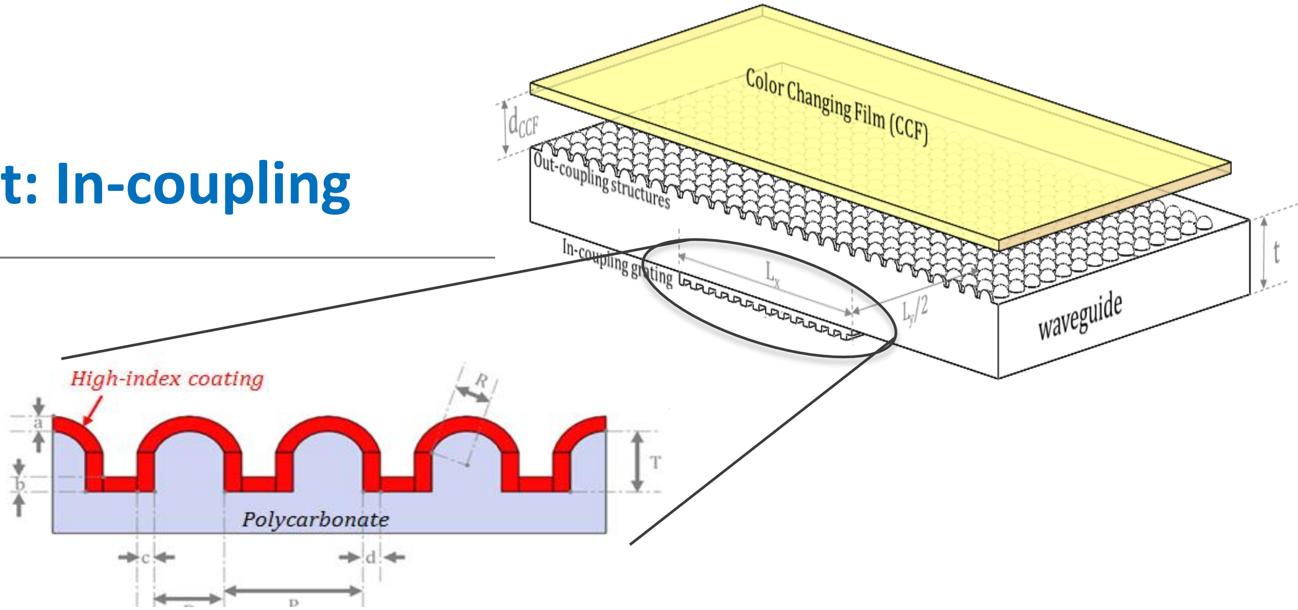


High reflectance substrate
✧ Good adhesion / LED bonding
✧ Highly resistant to scratches

- **Parameters optimized for max. efficiency**
  - < 5mm total module thickness
  - Compatible with R2R integration

Patent pending

Light Management: In-coupling



Grating parameters optimized for

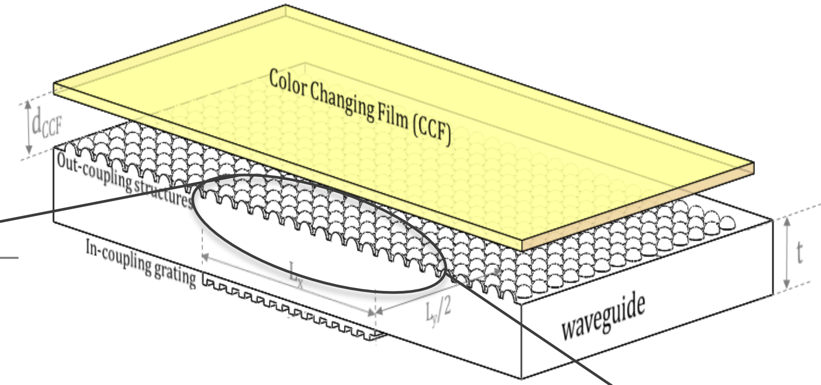
- Maximum efficiency
- Compatibility with manufacturability limits

Optimized grating design

- 50% in-coupling efficiency
- 25% transmittance
- 25% reflectance (recycled by substrate)

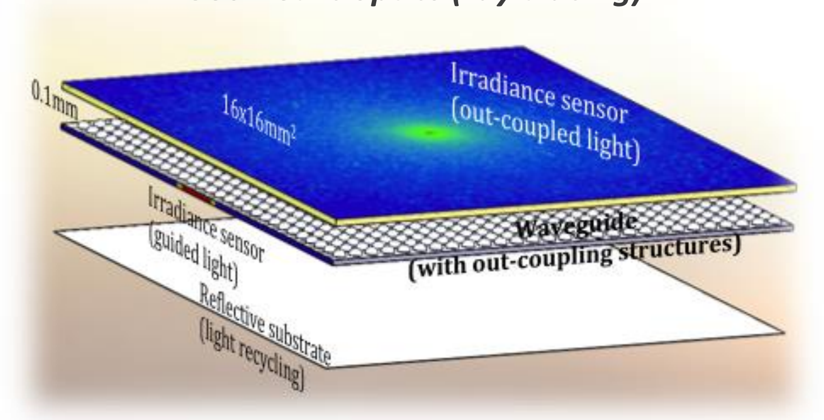
Patent pending

Light Management: Out-coupling



Refractive microstructures

Geometric optics (ray tracing)

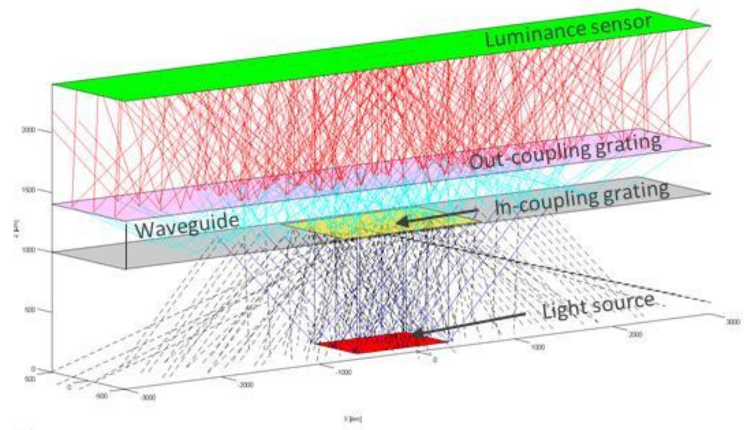


RCWA ➔ ZEMAX

- RCWA-calc. in-coupled light ➔ZEMAX source
- Profiting from ZEMAX built-in features:
  - CAD design (no design limitations)
  - Integrated number of sensors

Diffractive nanostructures

Wave optics (RCWA)



RCWA + Ray tracing

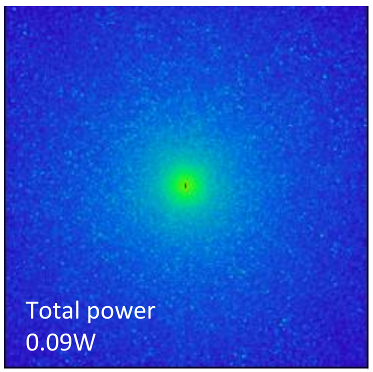
- MATLAB® code: RCWA + Ray tracing modules
- Multiples in- & out-coupling gratings
- Light recycling by the substrate

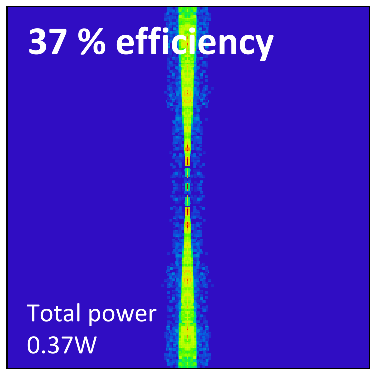
Patent pending

Light Out-coupling: 1D microstructures

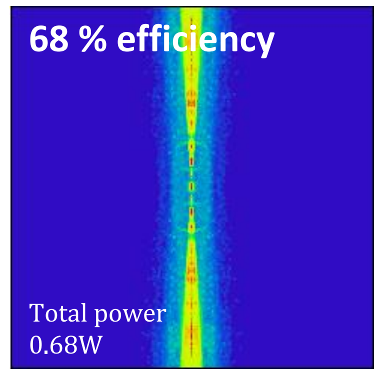
Total optical power: 1W

WAVEGUIDE ONLY	ENGINEERED 1D OUT-COUPLING MICROSTRUCTURES			Irradiance (W/cm²)

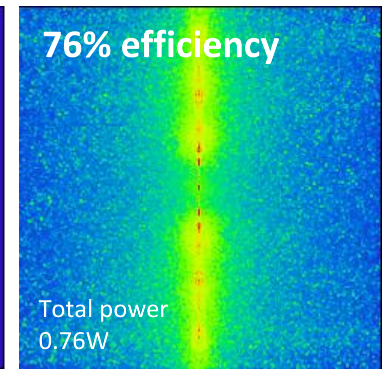




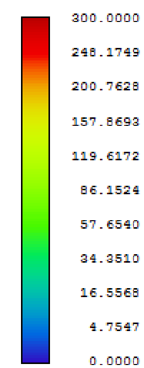
No Light recycling



Specular
Light recycling

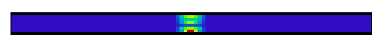


Diffused
Light recycling



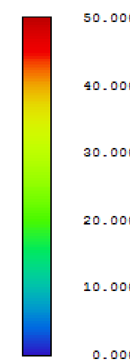
Total power
0.45W

Total power
0.043W



Total power
0.068W

Total power
0.053W

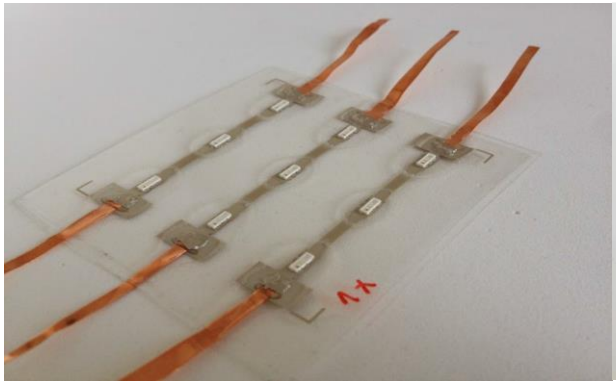


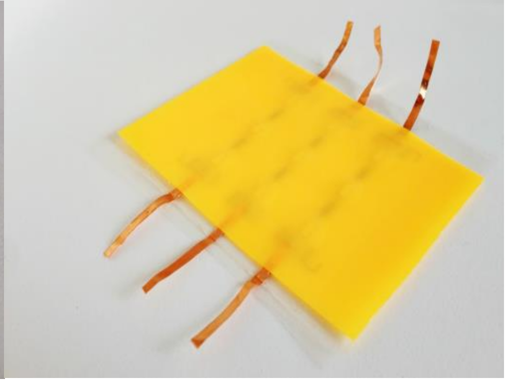
Property of the LASSIE-FP7 Consortium

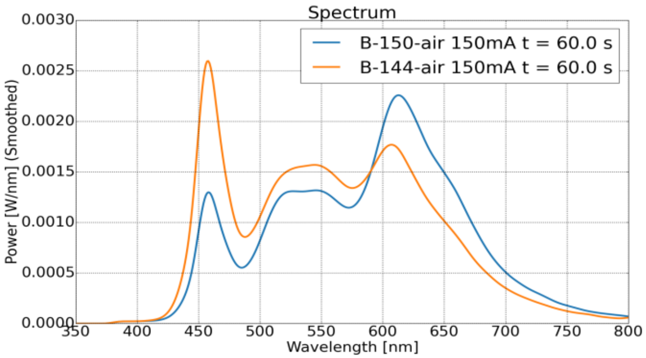
Patent pending

Test modules: Preliminary results (no optimization)

With no optimization and specific light management …







	Power W	*Lum. Flux lm*	*Rad. Power W*	*Efficacy lm/W*	*CCT K*	*CRIa*	*CRI9*
LED foil	1.257	-	0.5649	-			
LED foil + CCF	1.247	105.9	0.3489	85	3101	93	78
	1.248	112.5	0.3615	90	4748	93	59

Property of the LASSIE-FP7 Consortium

Patent pending

LASSIE-FP7

Intelligence

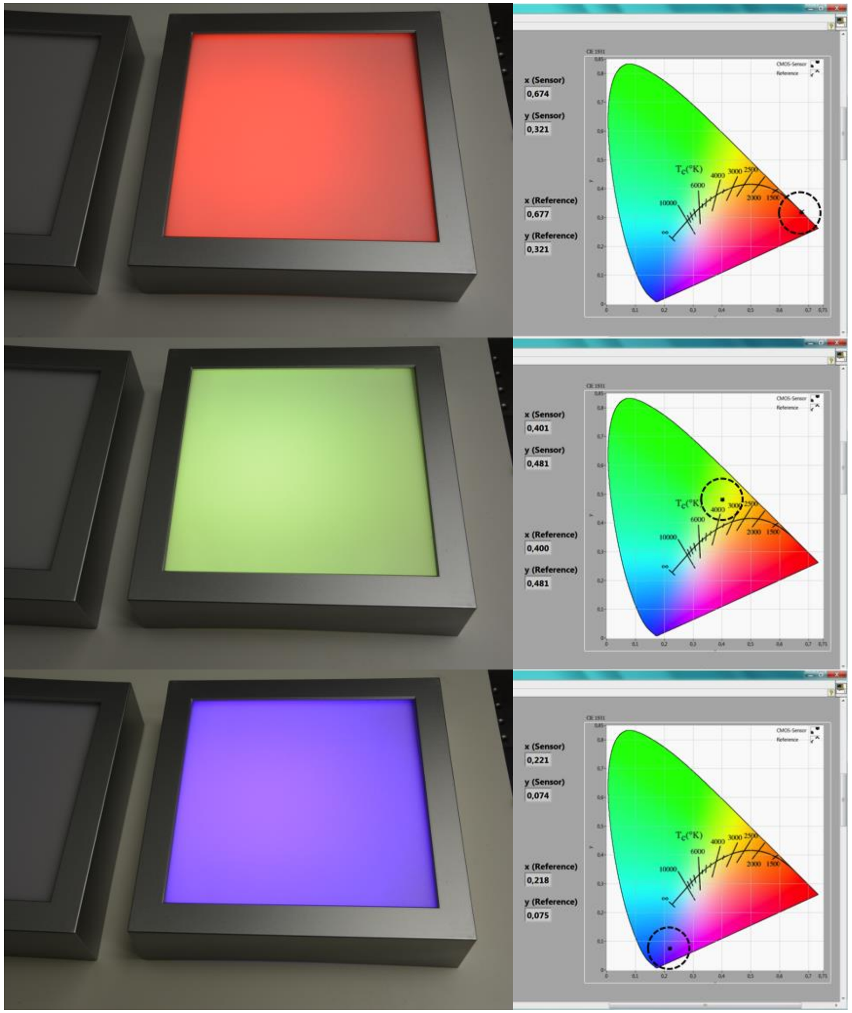
Intelligence: Colour feed-back

Intelligent luminaires require colour feed-back

- Accurate colour-sensing feedback
- Cost-effective colour multispectral sensors

Targeted solutions

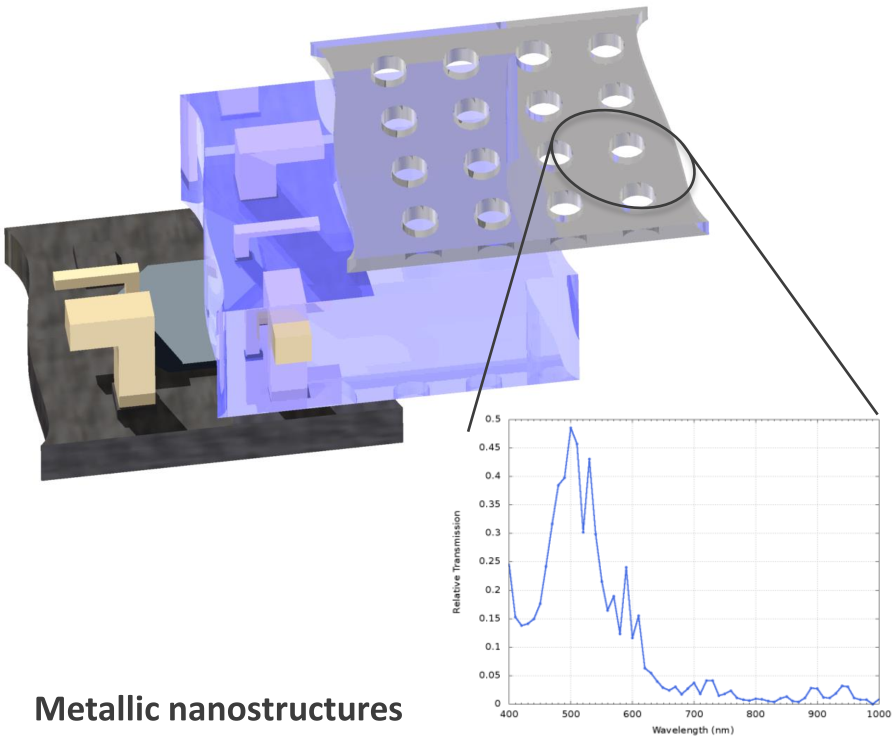
- ✧ 16 CMOS photodiodes with different filters
- ✧ Up to 16 spectral channels



Courtesy of FhG IIS

Multispectral CMOS sensor for colour feed-back

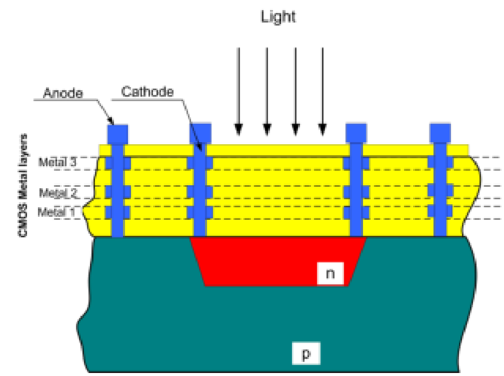
Spectral filters



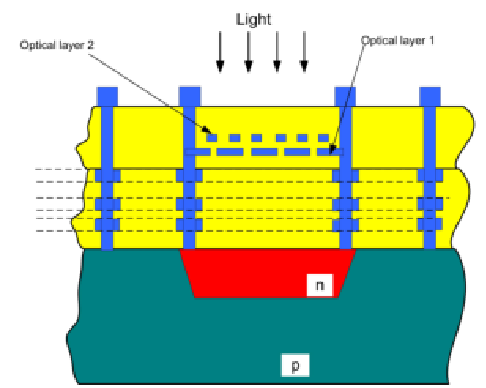
Metallic nanostructures

- Hole arrays (period ≈ 200 – 400 nm)
- Enhanced transmission due to plasmon resonances
- Filter wavelength is tailored by varying the geometry

CMOS integration



Conventional CMOS photodiode



CMOS photodiode with integrated metallic nanostructures as on-chip optical filters

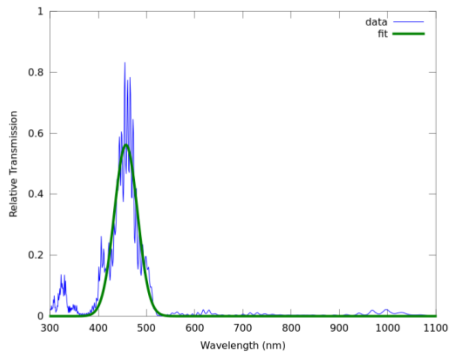
Colour filters: Metallic nanostructures

Simulation

Blue filter (460 nm)

Two nanostructured metal layers

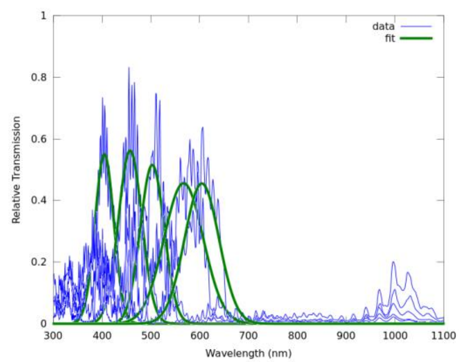
- Peak wavelength = 460 nm
- Peak transmission = 55 %
- FWHM = 55 nm



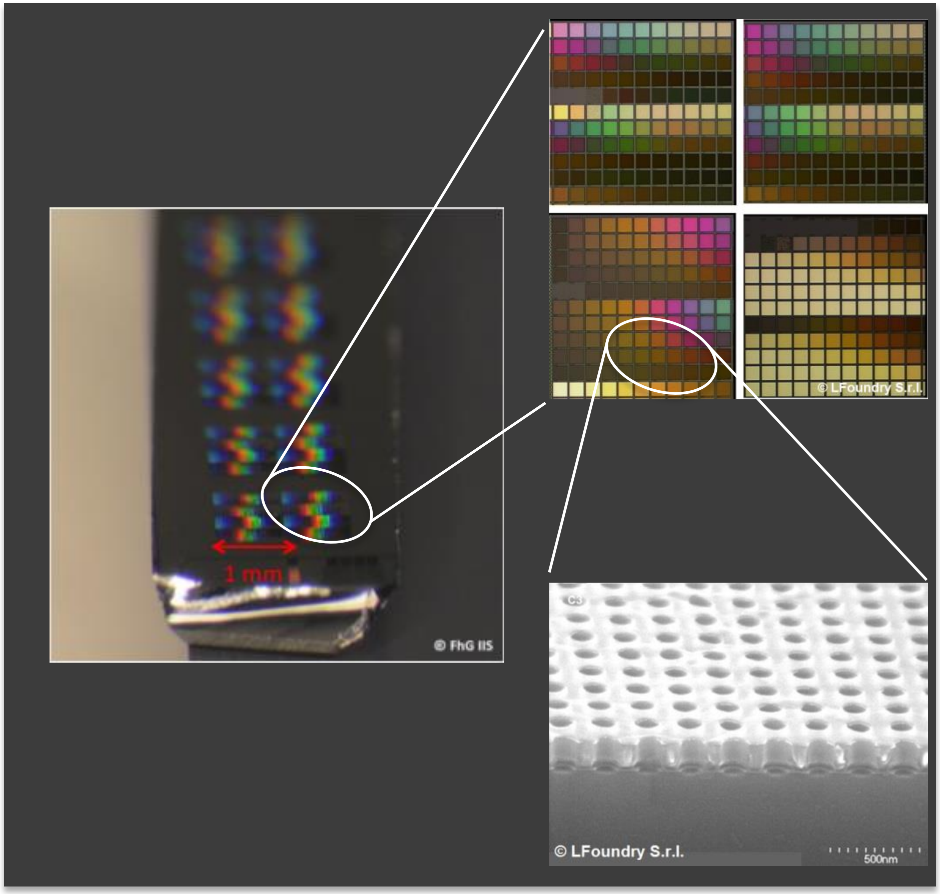
Filter set for the the multispectral sensor (example)

Multispectral sensor

- 5 filters
- Range = 400 – 600 nm



Fabrication



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LASSIE-FP7

Environmental analysis

Environmental & Cost assessment

Environmental & Cost assessment at early stage of design

- *Advantages* : reduce the environmental load / flexibility
- *Limitations*: new materials / processes / products, evolving development

- **Fulfilment of environmental specifications**

  To identify environmental requirements or limitations and identify sustainability priorities

  - Technical requirements: legal (e.g. directives on ecodesign) & best practices (e.g. ecolabelling)
  - Recyclability and recovery goals (valorisation, reuse & recycling targets)
  - Potentially hazardous substances (e.g. REACH regulation / RoHS directives)

- **Environmental Life Cycle assessment (LCA)**

  To analyse the contribution to different environmental impacts of processes, materials and energy resources used during the life cycle of the lighting module.

Sustainability evaluation

Defined profile

- High efficiency
- Low CO_2 emissions during use phase
- Exclusion of many "conventional" hazardous materials

Life cycle perspective

Necessity to weight environmental advantages and constraints of the new lighting module:

Obtaining Raw Materials → Production → Use → End of life

Hot spots identified and under analysis

- Valuable metals
- Potential Toxicity/ecotoxicity of materials
- Material yield (e.g. deposition processes)
- Solvent emission

Conclusion

Large area
- 20x20 up to 60x60 cm^2
- < 5 mm rigid to flexible

Low cost
- > 100 lm/EUR

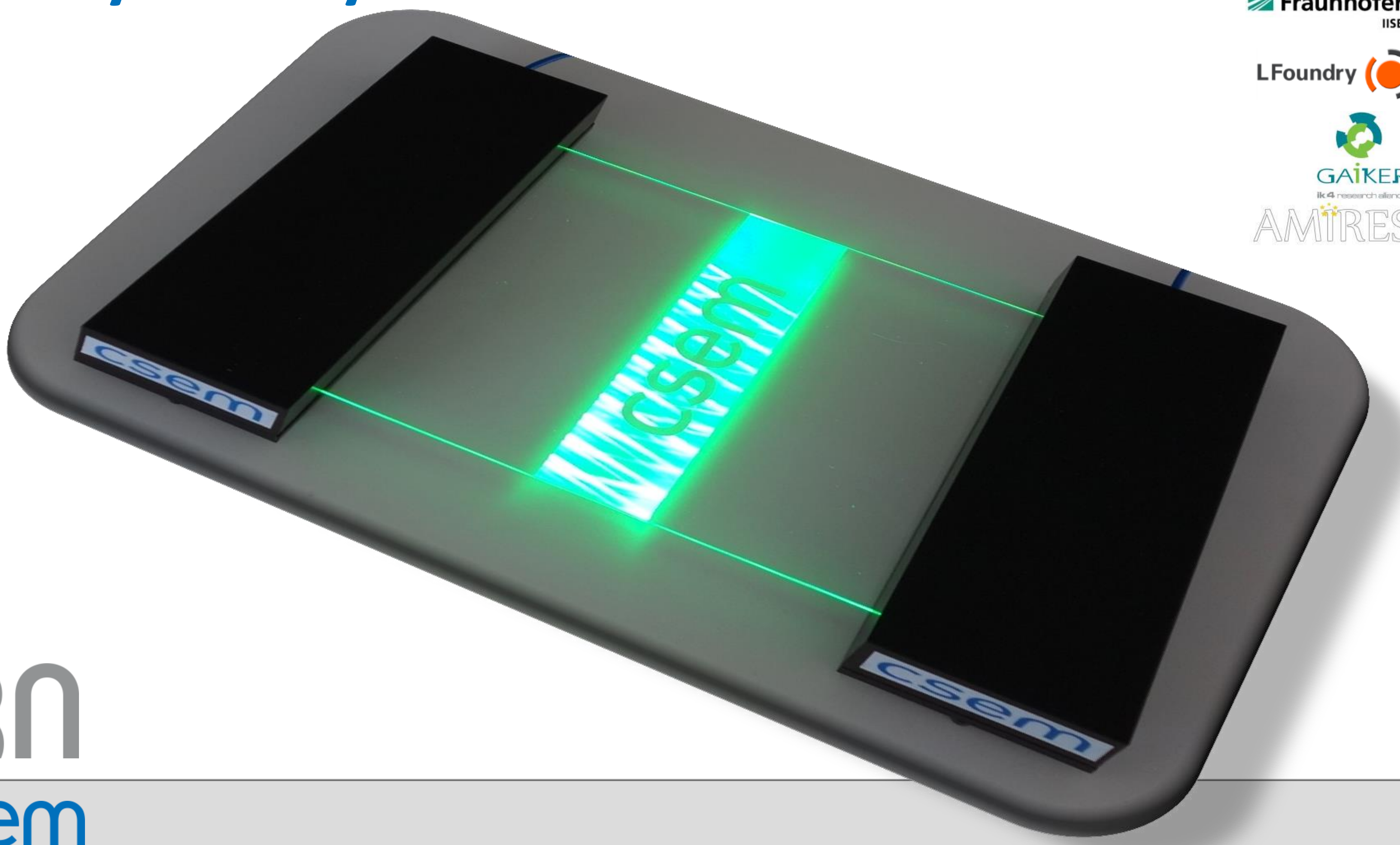
Intelligent
- Self-adaptive / -healing / -learning
- Health monitoring / Ambient-interacting
- Dimmable / Colour tunable

High efficiency
- > 150 lm/W ; > 50’000 lm/m^2
- > 50’000 hours

High quality
- CRI > 90 (spectral coverage> 90%)
- Lambertian & Non-lambertian

Environmental
- LCA & LCC

Thank you for your attention!



SEVENTH FRAMEWORK PROGRAMME

BASF The Chemical Company

REGENT LIGHTING

VTT

Fraunhofer IIS

Fraunhofer IISB

LFoundry

GAIKER ik4 research alliance

AMIRES

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