Innovative Thin-film Optics for Solid-state Lighting

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The point-like nature of the LEDs imposes the use of either inefficient and bulky light scattering sheets or of costly short-pitch LED arrays to achieve the spatial luminance uniformity required by large-area luminaires for professional lighting. Here we present an innovative thin form-factor light management (LM) system comprising a highly engineered combination of diffractive, refractive micro and nano-optical elements. The developed solution is compatible with large-area, low-cost roll-to-roll manufacturing.

The presence of light emitting diodes (LEDs) in the lighting domain is expected to reach a penetration rate of 56% by 2016 [1]. This rapid shift towards LED technology brings enormous business opportunities since LED-based light sources can still benefit from a significant amount of R&D efforts in different aspects.

One of these aspects is the design and realization of planar large-area panels used in e.g. the Professional Lighting domain, where the light emitted by the LEDs needs to be spatially homogenized over the entire emitting area not only efficiently but also maintaining a thin form factor of the module.

Commercial products of this kind today use either edge-lit or backlit configuration and both approaches have severe disadvantages. The former is compatible with thin profiles but requires a rather high density of LEDs to achieve the required light output and the luminance uniformity is typically rather low. On the other hand, back-lit configuration is compatible with high luminance uniformity and acceptable efficacy levels only if the diffuser is set away from the LED a distance larger than the LED pitch.

In the framework of the LASSIE-FP7 project CSEM is developing a light management concept which is a hybrid of the two above. The LASSIE-FP7 concept is based on light in-coupling and subsequent out-coupling into and from a thin-film waveguide using a backlit configuration.

In LASSIE-FP7 LM system, the light emitted by a collection of blue LEDs is coupled into a thin-film (0.5 mm), flexible transparent waveguide through diffractive in-coupling pixels (3x3 mm^2) replicated on the surface of the former. The LED board is in a backlit configuration with respect to the waveguide and both in close proximity (~0.2 mm).

Similarly to the edge-lit approach, the in-coupled light travels inside the waveguide based on total internal reflection (TIR), until it is disrupted by the presence of out-coupling structures and escapes.

With the waveguide at close distance from the LED board and the in-coupling pixels aligned to the LEDs, a substantial amount of the light is in-coupled inside the waveguide (Figure 1). In addition, each in-coupling pixel contains large number of sub-pixels (0.1 to 0.1 mm^2) positioned in a chessboard arrangement (Figure 2) which ensures in-plane light in-coupling.

Out-coupling pixels are, for instance, replicated in-between adjacent in-couplers, allowing the effective emissive area to increase (see Figure 3).

Before leaving the lighting module, blue light is down-converted into a high-quality white light using a thin-film) (50-500 µm think) color changing foil (CCF) also in close proximity to the waveguide. The CCF, produced and supplied by BASF, comprises a series of proprietary (Lumogen®) organic dyes. These are extruded into a polymer matrix in a finely tuned concentration according to the color target.

The presented LM system is compatible with large-area, cost-effective, roll-to-roll manufacturing.

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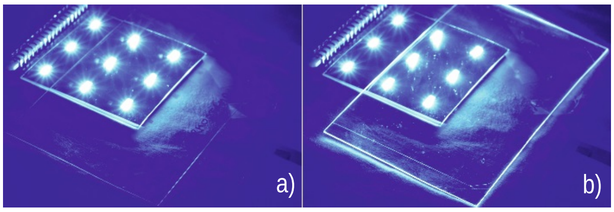

Figure 1: a) 0.5 mm thickness PC foil sitting on top of a 3x3 LED board (VTT); b) 0.5 mm thickness PC foil with replicated in-coupling pixels on the same LED board; the glowing edges in indicative of the in-plane light in-coupling.

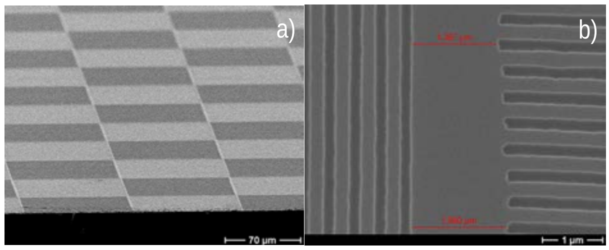

Figure 2: a) SEM picture of an in-coupling pixel showing a number of sub-pixels; b) Close-up SEM picture of two adjacent sub-pixels with mutually perpendicular grove orientation and nearly perfect overlap.

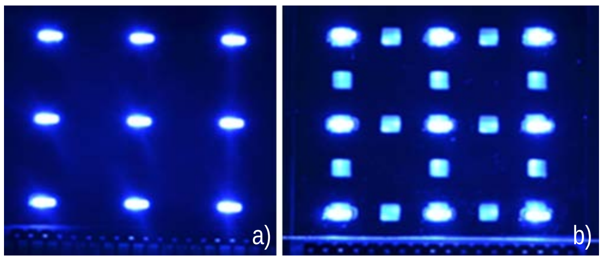

Figure 3: a) picture of the LED board; b) picture of the same LED board with CSEM light management foil on its top surface.

[1] Prasad, A. 2015 Year of (LED) Light. LED professional 47, pp. 32-36 (2015)