A Novel Diffractive Backlight Concept for Mobile Displays

***Jyrki Kimmel* and Tapani Levola**

Nokia Research Center, Tampere, Finland

Pasi Saarikko

Nokia Research Center, Helsinki, Finland

Johan Bergquist

Nokia Technology Platforms, Tokyo, Japan

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Introduction

- **Mobile communication devices are becoming a mainstream means for accessing and creating multimedia content**
  - **Mobile phones are developing toward "multimedia computers"**
  - **Display resolution is moving from QVGA to WVGA and beyond**
  - **Pocketability is key – increasing pixel pitch squeezes light throughput**
- **Need for power saving technologies is increasing rapidly**
  - **The UI is estimated to consume about 1/3 of total power in a traditional mobile phone**
  - **The backlight is the major power drain in the display**
- **More efficient backlight structures are required**

- **<u>This study:</u>** ***a diffractive optical approach for energy efficient backlight unit design***
  - **Concept**
  - **Experimental study on a model grating structure**

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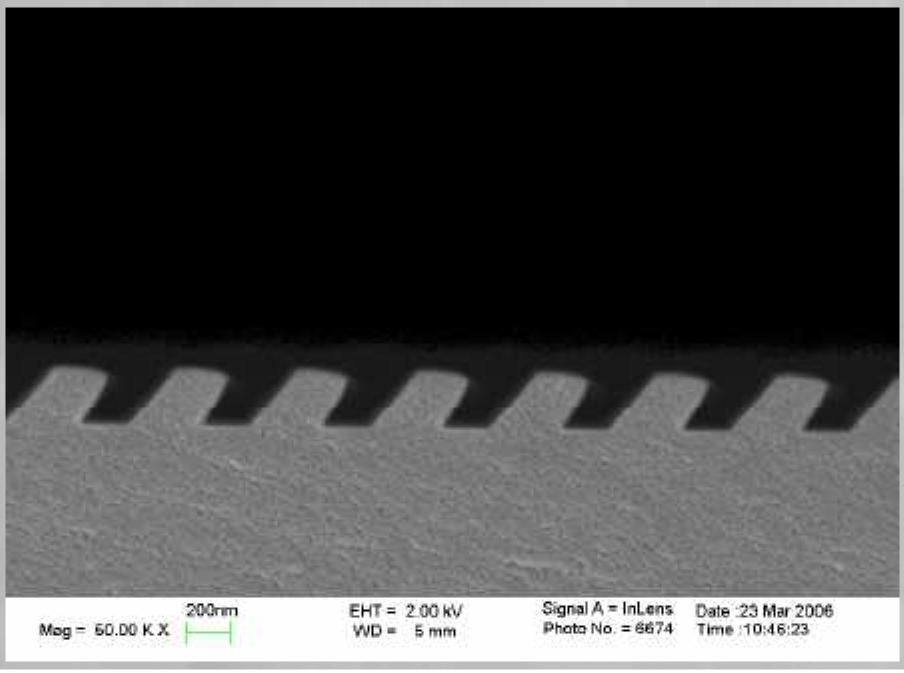
State-of-the-Art in Backlight Units

- **The backlight has evolved from a roughened plastic plate illuminated by green LEDs to a sophisticated, carefully engineered device aimed to efficiently direct light through the LCD**
  - **(“Pseudo”-) White LEDs**
  - **Geometric optics or statistically distributed scattering backplates**
  - **Brightness enhancing films and beam steering structures**
- **The white light is however for the most part (90 %) blocked by the color TFT LCD**
  - **Polarizers block 50 % of the light**
  - **Color filter blocks 2/3 of the spectrum at each RGB subpixel**
  - **The active aperture of a transflective pixel in transmissive mode can be 50 % or less**
- **Diffractive optics with uniformly designed gratings have been proposed***
  - **High spectral dependence**
  - **Unwanted diffraction orders need to be redirected**
  - **Microlenses are required to direct the light to the corresponding subpixels**

*D.R. Selviah and K. Wang, “Modeling of a Color-Separating Backlight with Internal Mirrors”, SID Symposium Digest, Vol. XXXV, Book I, pp. 487-489, 2004.

Advances in Diffractive Optics

- **Studies on near-to-eye optics have led to advanced grating structures by the adaptation of diffractive exit-pupil expanders (EPEs)***
- **The ability to direct light into selected diffraction orders by advanced grating design can be utilized in direct-view displays**
- **It has been demonstrated that the gratings are replicable****



*T. Levola, “Diffractive Optics for Virtual Reality Displays”, Proceedings of the Twenty-Fifth International Display Research Conference, pp. 542-545, 2005.

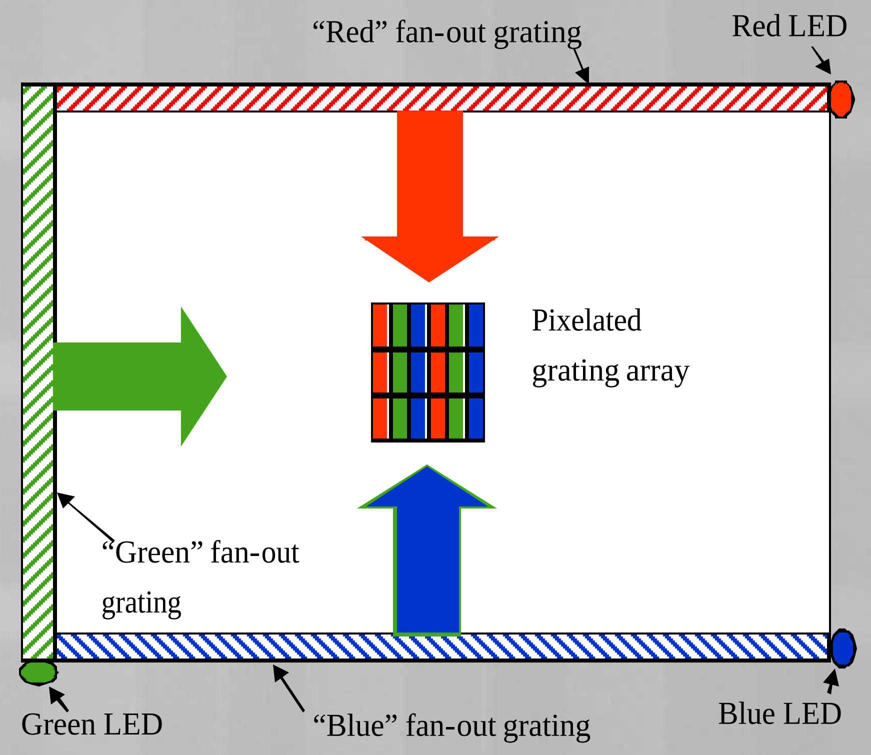
T. Levola, “Diffractive Optics for Virtual Reality Displays”, J. SID, Vol. 14, pp. 467-475, 2006.

← T. Levola, “Novel Diffractive Optical Components for Near to Eye Displays”, SID Symposium Digest, Vol. XXXVII, Book I, pp. 64-67, 2006.

**T. Levola, and P. Laakkonen: “Replicated Slanted Gratings with a High Refractive Index Material for In and Outcoupling of Light”, Optics Express, Vol. 15 no. 5, pp. 2067-2074, 2007.

New Diffractive Backlight Concept

- **Red, green, and blue LEDs are used as light sources**
- **Fan-out gratings for each primary light source spread the light out to form a collimated sheet of light for a each primary color**
- **A pixelated grating array is formed on the surface of the backlight**
  - **Each subpixel has a grating structure that corresponds to the direction and input spectrum of the light pertaining to the pixel**
- **The result is *an array of red, green, and blue beams of light, one for each subpixel***

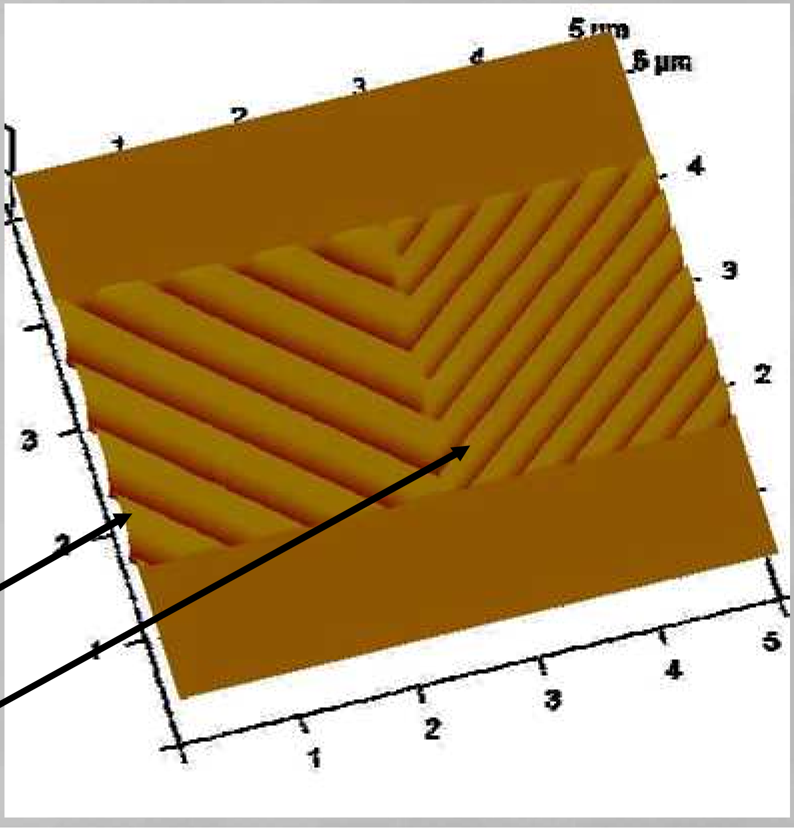


Proof-of-Concept Model Grating

- **A binary grating master was manufactured at Nanocomp Oy in Joensuu, Finland, on fused silica**
- **Replicas made on 1 mm thick PMMA (also made at Nanocomp Oy) were used in the experiments**
- **AFM image was taken at the Optoelectronics Research Centre of Tampere University of Technology**
    - **AFM tip size reduces the sharpness of the groove shape images**

Grating parameters

Primary	**Width (μm)**	**Depth (nm)**	**Grating period (nm)**
Red and blue	118	220	450
Green	59	220	300



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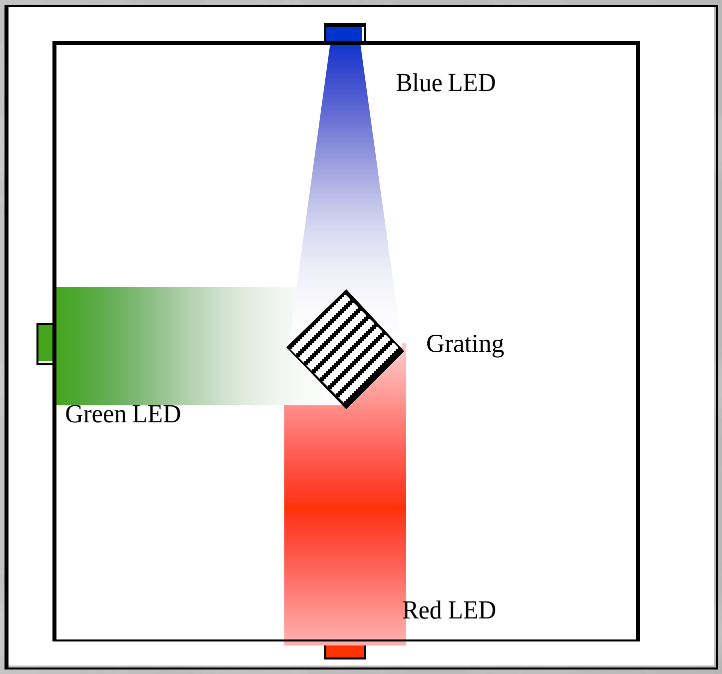
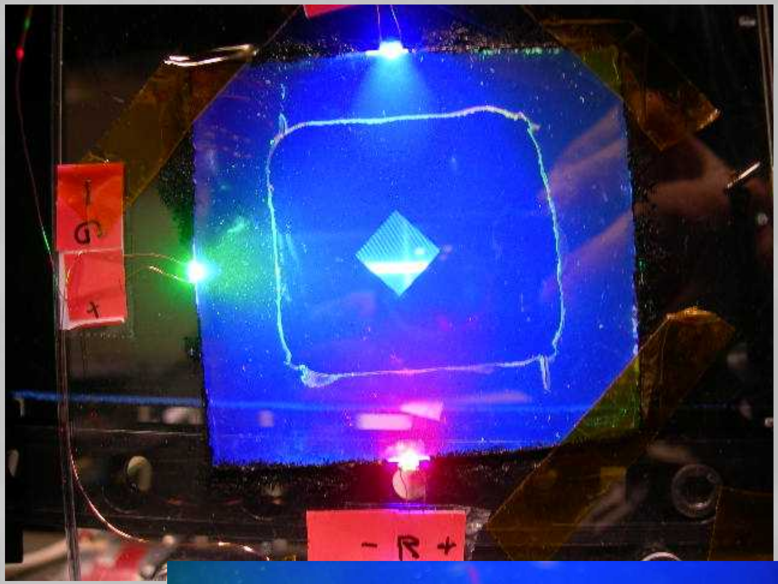
Model Grating Experiment

- The experiment was laid out on a support that allowed adjusting the placement of three LEDs freely on the sides of the PMMA plate
- The green LED was placed orthogonally to the red and blue LEDs which were placed opposite each other
- 20 mA nominal current was used for the measurements
- The grating stripes were at 45º and 135º orientation with respect to the LED beam centers
  - Grating orientation inside the stripes was orthogonal to the direction of the beam center



Model Grating Experiment

- **Osram LEDs were used to illuminate the display**
  - **LED packages were 0.6 mm thick for efficient incoupling**
  - **Normal butt-coupling was used**
- **Since there was no way to spread the light on the entire area of the grating, there uniformity was poor**

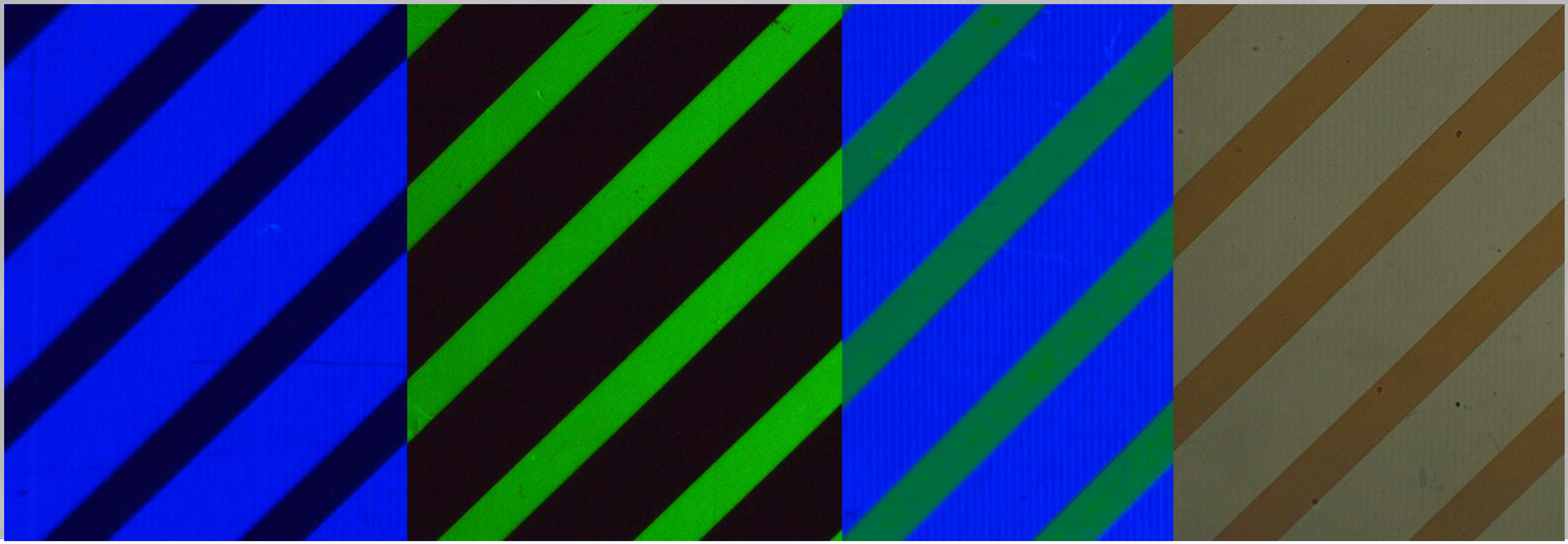


LED parameters

Primary	Dominant wavelength (nm)	FWHM* (nm)	Luminous intensity at 20 mA (mcd)	Luminous efficiency (lm/W) (Typical)
Red	625	19	180…900	43
Green	528	33	560…1800	36
Blue	460	25	90…280	11

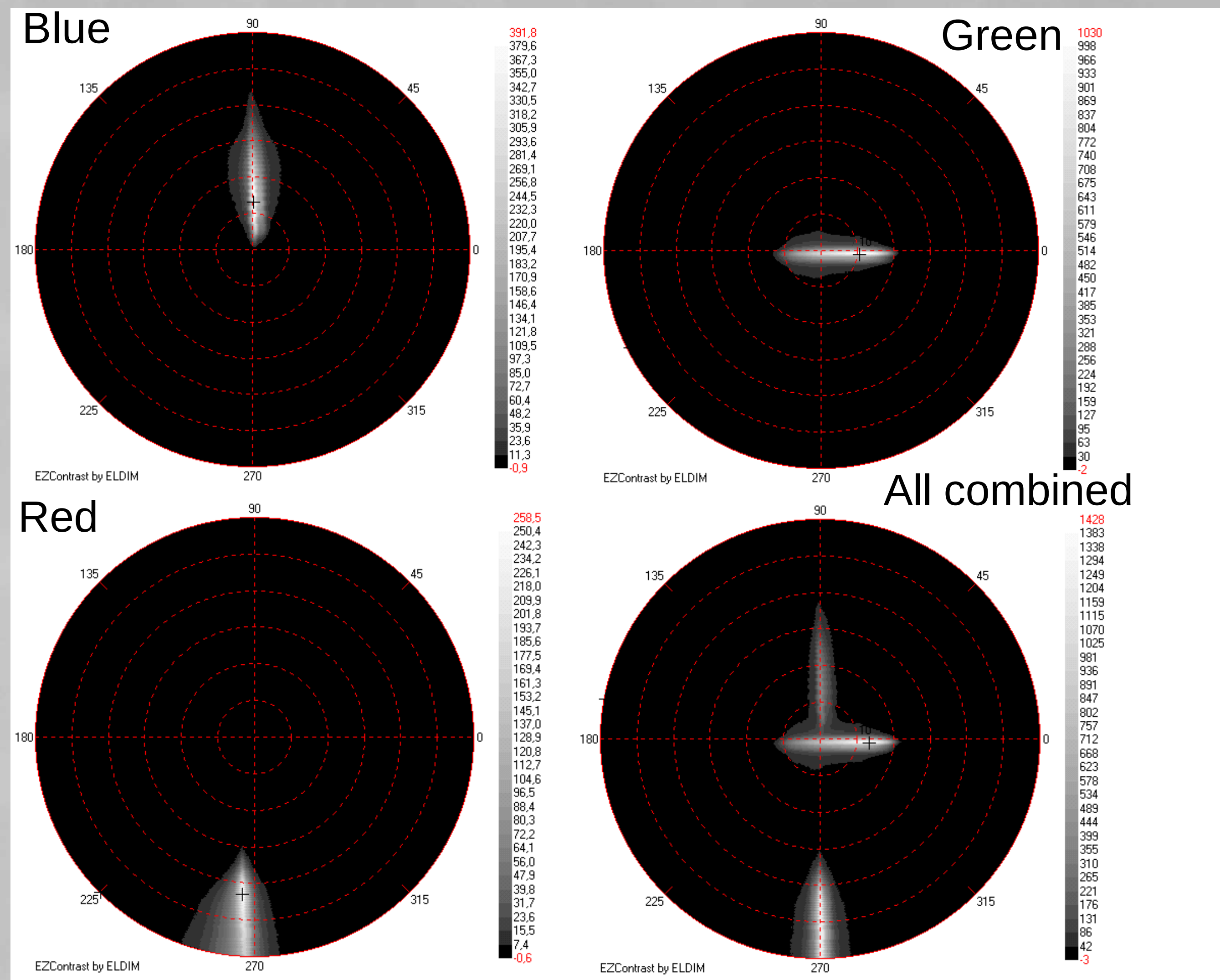
Results

- **Spectrum-specific outcoupling was clearly observed with excellent blue-green separation**
  - **Red light was coupled outside the NA of the microscope**



Results

- ELDIM R 120 Conoscope plots show efficient and directional outcoupling



Angles about the zenith of the outcoupling maxima in the model grating experiment.

Primary	Angle of maximum outcoupling (°)
Blue	15.0
Green	10.5
Red	58.0

Conclusions

- **A new diffractive optics based backlight concept was presented**
- **The results show the feasibility of the concept and that the gratings worked according to the initial design**
- **Good color separation was achieved by the use of dual grating strips, but red/blue separation needs a third grating**
- **Future work:**
  - **Next step is to make a pixelated grating array**
  - **Increasing the size to a real 2.8” QVGA size follows**
  - **Demonstrator for the fan-out grating is needed**
  - **Studies in conjunction with display panels will finalize the concept verification**
- ***There is a good possibility to create a new paradigm for energy efficient backlight design by diffractive optics***
  - **A real possibility to direct light in a spectrum-specific fashion to where it actually can be utilized by the LCD pixel**
  - **This study is the first step in this direction**

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