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Development of novel UV LED technology using cathodoluminescence inspection

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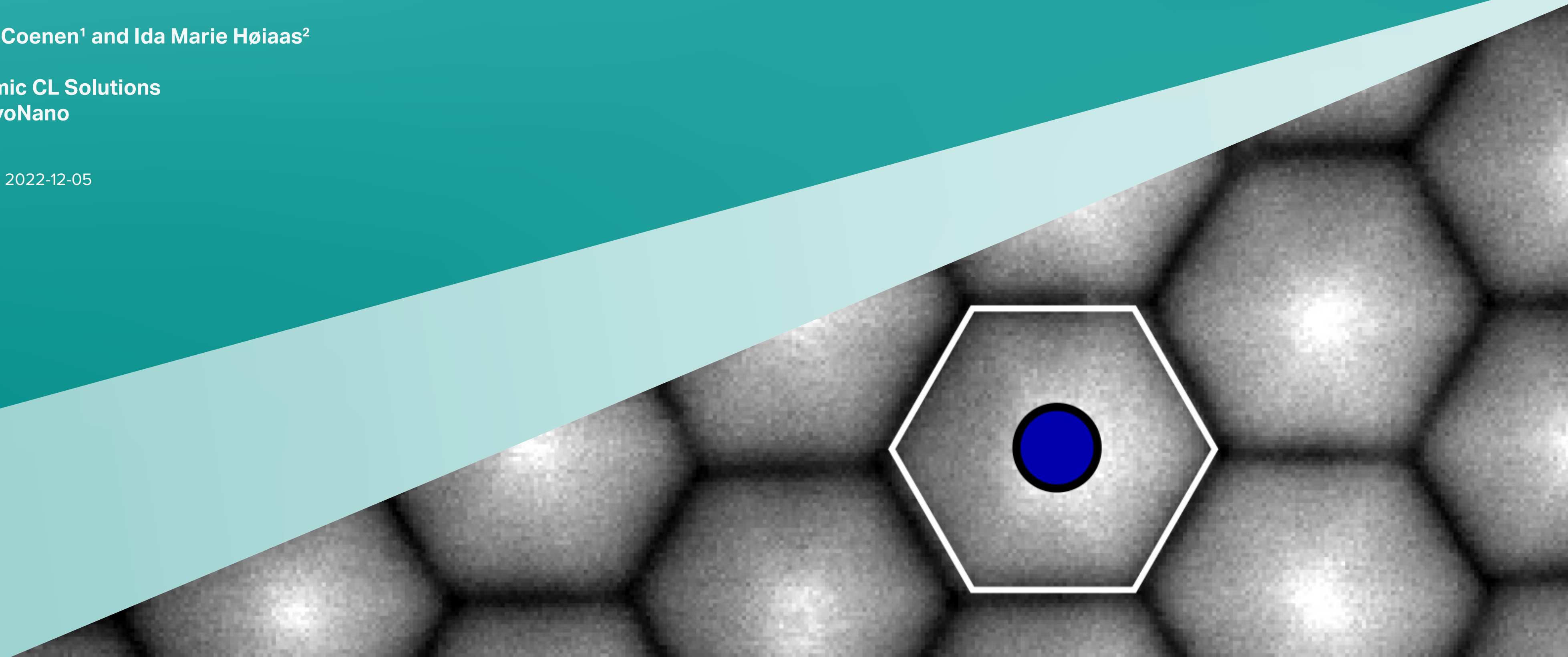

Development of novel UV LED technology using cathodoluminescence inspection

Light emitting diodes (LEDs) have developed into a mature and widely used technology over the last decades, finding applications in displays, ambient/car lighting, remote controls, optical switches and more. The active light emitting layer in LEDs is usually composed of compound III/V direct bandgap semiconductors such as (In)GaN for blue/visible LEDs and GaAs/InP for IR LEDs. Such devices can be made with high external quantum efficiencies (EQE > 70%) and good stability (over 30000 hrs operating time) while maintaining a low price point. The advancement of LED technology has effectively rendered older techniques such as tungsten filament light sources almost obsolete. More recently, there has been significant interest in pushing LED technology beyond the IR and visible spectral range into the ultraviolet (see **table** for definition of UV ranges).

Ultraviolet LEDs have many interesting applications. UVA/UVB/UVC LEDs can act as compact and affordable pump light sources for various spectroscopy applications in lifescience, materials science, medicine, environmental monitoring, and sensing. Additionally, UVA LEDs are used for UV curing (resins, adhesives etc.), lithography, 3D printing and more; UVB LEDs are used in skin treatment, tanning, and plant lighting to name a few applications. UVC LEDs are employed for ultraviolet germicidal irradiation (UVGI) in which the UVC emission is used to kill or inactivate pathogens for disinfection of laboratory equipment, air, water, and/or food. As such it can be an effective weapon in battling infectious diseases [1]. Compared to low-and mid-pressure mercury based UV lamps, LED systems are more flexible, compact, have a faster on-off time, can handle more on-off cycles, and are environmentally more friendly as they do not contain mercury. In this note we will focus on UVC LED materials.

Name	Wavelength range (nm)
UVA	400-315
UVB	315-280
UVC	280-100

Table 1 The ultraviolet spectral range is often split in UVA, UVB and UVC ranges although other naming schemes exist as well

Currently, the main material of interest for UVC applications is AlGaN which is a tertiary III/V semiconductor. By varying the elemental concentrations of aluminium and gallium the optoelectronic properties can be tuned. The emission wavelength can be varied from 210 to 365 nm for instance. Despite the large potential of AlGaN UVC LEDs, the technology is less mature compared to the visible and IR technologies still. In particular, growing efficient bulk UV LEDs has proven to be rather challenging due the following reasons:

1. Crystal lattice mismatch with the growth substrate leads to large defect densities in the active semiconductor materials, resulting in a lower internal efficiency

2. Light outcoupling is inefficient due to absorbing layers and electrodes in devices

Together these issues can lead to poor overall performance and current reported EQE values are typically in the 1 – 10% range, significantly lower than what is currently achievable in visible/IR LEDs [1]. By switching from bulk to nanostructured LED systems these existing problems can be alleviated. Novel approaches such as van-der-Waals epitaxy on graphene, where graphene acts as growth substrate and electrical contacting layer at the same time are very promising. On the one hand, nano structuring allows growth of less defective materials and at the same time enables better light outcoupling, leading to more efficient devices.

However, in order to develop and produce efficient UV LED devices the nanoscale electrical and optical properties need to be understood and verified, which requires microscopy. Performing inspection with conventional optical microscopy techniques on such nano/microstructured LED concepts and devices is difficult because of the following reasons:

1. Spatial resolution of existing technologies is not high enough because they are limited by diffraction

2. It is difficult to properly excite the AlGaN material because UVC excitation sources are expensive and inefficient

3. Typical high-NA optical microscopy elements such as microscope objectives are not transparent for UVC light.

Alternatively, cathodoluminescence provides an ideal technique for studying UV LED devices as it does not suffer from any of these limitations. The technique has a high spatial resolution and because of the high electron energy (> 1 kV) used in scanning electron micrscopy (SEM) the Al(Ga)N material can easily be excited.

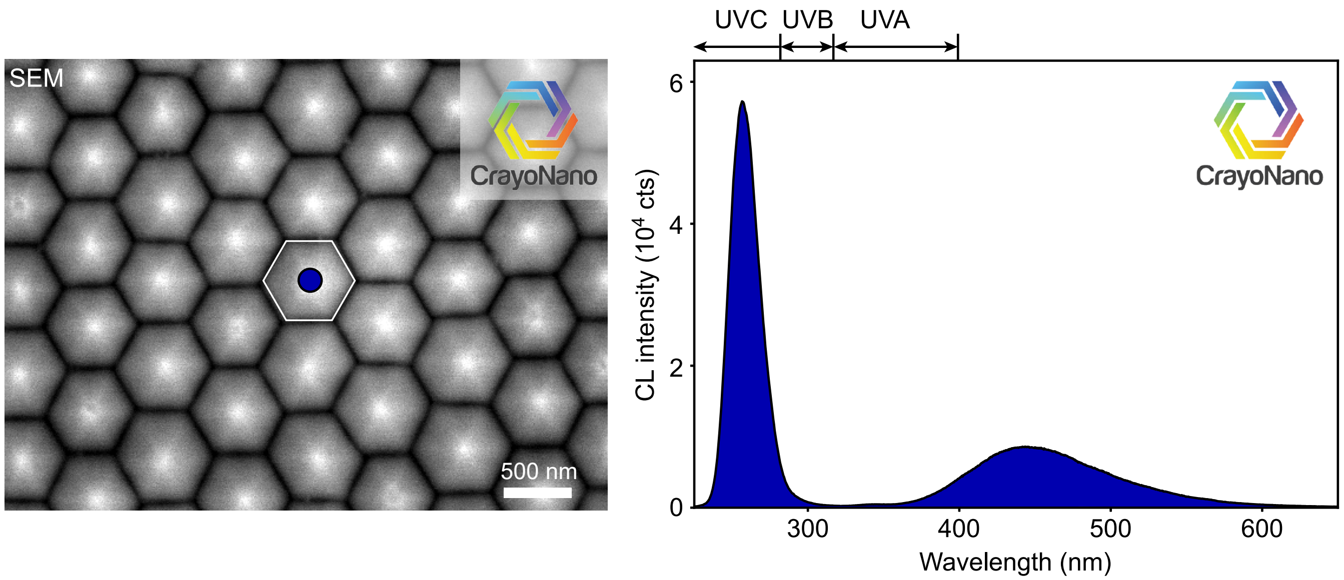

Figure 1 SEM image showing a nanorod UVC LED. The white hexagon indicates an individual nanowire On the right side a CL spectrum acquired with the beam placed on a single rod as indicated by the blue dot. For reference the different UV regions are indicated on top of the spectrum. This spectrum was acquired using 5 kV acceleration voltage and a 1s dwell time. The measurement was acquired using a Hitachi SU5000 SFEG SEM equipped with a SPARC spectral system tailored for measurements in the UV spectral range. Measurement courtesy of CrayoNano.

Figure 1 shows a scanning electron micrograph and hyperspectral CL measurement of a nanorod based AlGaN LED device (images courtesy of CrayoNano). This device was grown using metalorganic chemical vapor deposition (MOCVD). The CL spectrum shows two emission bands. The main UVC emission band at 257 nm corresponds to band edge emission from the AlGaN material in the device. The second band centered around 445 nm corresponds to deep-level defect emission. The peak shapes/width, center wavelength, overall ratio between quantum well emission and defect bands, and the overall intensity of the UV peak can be used to assess the LED quality and to understand its optoelectronic properties. By scanning the electron beam across the structure fine spatial details can be revealed similar to other semiconductor materials (see application notes on GaN, perovskite, and CIGS for example).

UV CL imaging can also be used for bulk Al(Ga)N geometries or other UV emitting materials such as SiC, hBN, AlBGaN, ZnO, Diamond and more. We anticipate that CL imaging and analysis will play an important role in the development of next-generation UV LED devices.

Reference

1. H. Amano *et al.*, The 2020 UV Emitter Roadmap, *J. Phys. D: Appl. Phys.* (2020)

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About

Delmic is a passionate high-tech company based in Delft, the Netherlands that develops powerful and user-friendly solutions for light and electron microscopy. Our systems are used by researchers and companies all over the world in fields ranging from life sciences, geology, material sciences to nanophotonics.

The SPARC Spectral system is a unique cathodoluminescense (CL) solution which allows you to acquire high-quality CL data in a fast and simple manner. The system is flexible, modular and can be customized according to your research needs.

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