Pyramidal MicroLEDs in the Same Material System Delivering RGB

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Abstract

An innovative microLED technology based on a novel bottom-up growth technique is demonstrated. The novel technology allows for overcoming main fundamental limitations hindering further development of microLEDs. The technology allows for RGB emission within a single materials system (InGaN/GaN). Blue and green emissions have earlier been demonstrated, but now also a red emission peaking at 635nm is realized. The technology is suited for hybridization with extremely high accuracy, using a cold-bonding flip-chip method. MicroLED technology based on the pyramidal architecture is promising for manufacturing of micro displays for applications such as Head-Mounted-Displays (HMDs) and Head-Up-Displays (HUDs).

Objective and Background

MicroLEDs are emerging as a promising Display technology. Important for any emerging technology is to deliver high-impact improvements, either by replacing incumbents or enabling completely new applications. MicroLEDs are promising to revolutionize Head-Mounted-Displays, unlocking spatial computing in professional and consumer applications and next-generation human-vehicle interfaces through Head-Up-Displays to enhance safety and functionality.

However, fundamental challenges remain to improve the performance of microLEDs as well as challenges to successfully integrate with Silicon CMOS technology.

Today, the predominant technique to fabricate microLEDs is based on a top-down approach, where microLED manufacturing is based on an etching process of planar LED wafers in which die sizes desired for specific applications can be selected. However, the etching process will result in surface and sidewall damages, which is devastating for the optical performance due to an increased rate of non-radiative recombinations. This effect becomes increasingly pronounced as the size of the microLEDs decreases and the sidewall-to-volume ratio increases. A correlation between microLED die size and external quantum efficiency (EQE) has been reported for top-down etched blue-emitting InGaN/GaN microLEDs and shows a decrease of EQE by a factor 3 or more as the diameter of the microLED die is reduced from 10 μm to 1μm (1).

Also, many approaches take shortcuts to overcome the limited performance of RGB emitters but neglect the resulting increase in complexity of CMOS integration.

RGB in the same materials system is particularly important because integrating different material systems in a single display technology will result in an added complexity of the driving architecture, sometimes requiring separate micro drivers. This is due to the inherently different opto-electrical properties of material systems commonly used for RGB, such as InGaN and InGaP.

To build displays based on microLEDs, each pixel must be individually addressed. This requires integration with a Silicon CMOS backplane. To hybridize substrates of different materials is particularly challenging due to their different thermal expansion coefficients. Also, a high-precision bonding alignment is required due to the fine pitch required for high resolution microDisplays.

To properly approach both the challenge of performance and integration, it is firstly a matter of choosing a suitable microLED architecture.

Results

In this work, Polar Light Technologies' bottom-up approach is presented. These microLEDs have a particular pyramidal 3D shape. This unique approach has been used for microLEDs down to μm or even sub-μm dimensions, avoiding the inherent surface and side wall damages originating from etching in top-down procedures.

Bottom-Up Growth of Pyramidal MicroLEDs

Selective area growth of InGaN/GaN pyramidal microLEDs is performed on a SiN-masked GaN/SiC template by Metal Organic Chemical Vapor Deposition (MOCVD). The microLEDs are composed of an n-GaN core, a multi quantum well (MQW) structure, and a p-GaN capping (2,3). The resulting structures have close to perfect surfaces, as shown in Figure 1.

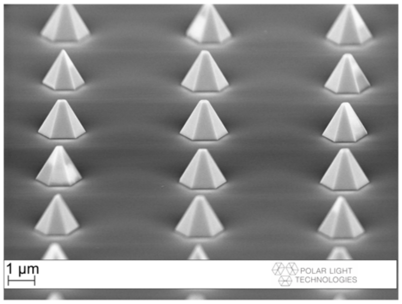

Figure 1. SEM image of μm-sized pyramidal microLEDs grown by MOCVD showing excellent surfaces.

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The pyramidal concept also offers an important advantage in terms of a narrow, sub-Lambertian light lobe. Angular-dependent power measurements show that 58% of the light emission will be within a light cone of +/- 20 degrees. This is of utmost importance for in-coupling into optics components such as waveguides or optical combiners. Figure 2 shows the measured angle-dependent optical output power of a 2x2 array of pyramidal microLEDs. The black line represents the normalized measured data, while the red dashed line represents a Lambertian emitter.

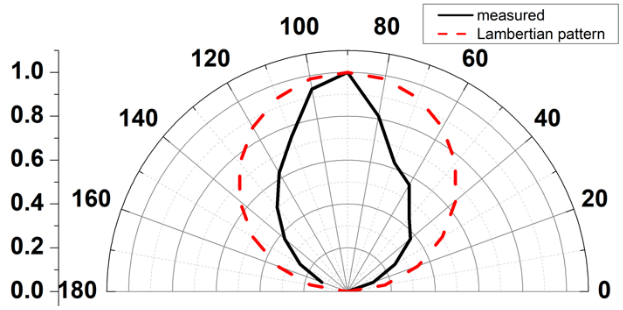

Figure 2. Light Lobe measured on pyramidal microLED emitters showing sub-Lambertian emission pattern.

RGB in Same Materials System

To reach longer wavelengths, more indium must be incorporated in the InGaN QW. This leads to increasingly challenging strain conditions vs the surrounding GaN barriers. This strain caused by lattice mismatch has potential to destroy the quantum wells in the growth process, decomposing or generating a very defect dense structure. By utilizing the geometry and design of the pyramidal bottom-up concept, the increasing strain could be handled and an emission peaking at 635 nm could be demonstrated. The electrically excited emission spectrum was collected from a single pyramidal microLED and showed a FWHM of ~50 nm, as shown in Figure 3.

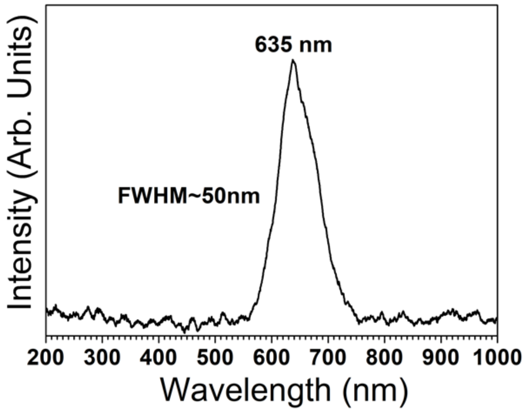

Figure 3. Spectrum of an electrically excited single pyramid with a peak emission of 635 nm and a FWHM of 50 nm.

An array of pyramids is photographed and shown in Figure 4, clearly producing a rich red emission color.

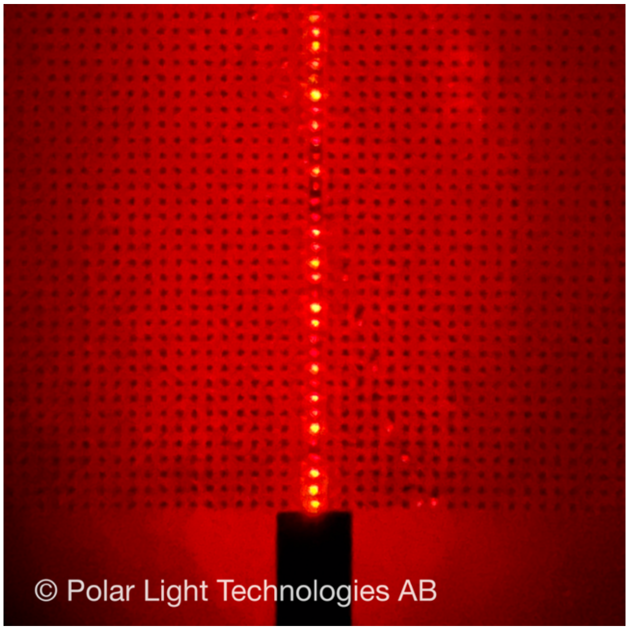

Figure 4. First proof-of concept for red microLEDs based on Polar Light Technologies' pyramidal concept.

MicroLED and Si-CMOS Integration

GaN/InGaN LEDs are typically grown on Sapphire or SiC substrates due to better matching lattice constants. GaN/InGaN LEDs grown on Silicon substrates usually require significant strain engineering or intricate buffer layers to accommodate the mismatch between the Si and GaN lattice parameters. Using SiC as the microLED substrate presents a difficulty in alignment due to different thermal expansion coefficients between SiC and Silicon.

Therefore, hybridization of the Silicon CMOS and GaN/SiC microLEDs is performed using a cold-bonding approach. The chip-to-wafer flip-chip process can be performed with extremely high accuracy and relies on Indium Bump Interconnect technology (4,5). This allows for avoiding thermal miss-alignment. Indium bumping of the CMOS wafer is performed and metallization of the individual pyramidal microLEDs constitute the metal-to-metal interface. The microLEDs are mechanically aligned with high precision and pressed together to form a strong electrical and mechanical bond. Figure 5 illustrates the configuration of the CMOS backplane and microLED chip that are part of the hybridization process.

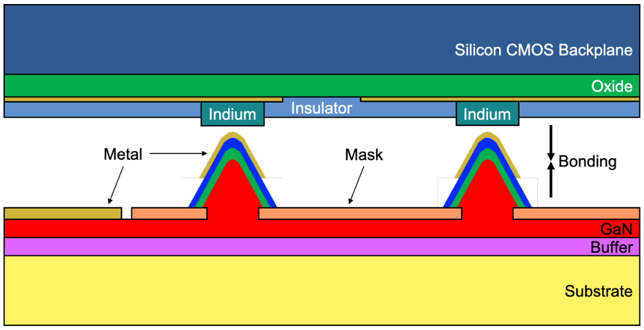

Figure 5. The pyramidal microLED and Silicon CMOS integration scheme.

Conclusions & Impact

The pyramidal microLED architecture presented here is suitable to overcome fundamental challenges in LED performance and manufacturing of micro displays. The novel bottom-up approach allows significant advancements such as RGB in the same materials system, as well as a technology suitable for integration with Silicon CMOS, enabling manufacturing of micro displays.

Micro displays based on this microLED architecture are promising for building state-of-the-art HMD applications as well as HUD applications. Enabling these novel applications is necessary for microLED to create impact.

Acknowledgements

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