Micro-pixellated flip-chip InGaN and AlInGaN light-emitting diodes bonded to a CMOS driver backplane

Basic Technology Research Programme
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A 1000 micro-emitters per square millimetre

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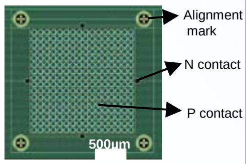
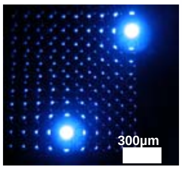
We report the development of micro-pixellated LEDs in a flip-chip format, with the transparent sapphire substrate forming a protective surface. The devices consist of a 16x16 array of elements which can be individually addressed, bonded to a Complimentary Metal Oxide Semiconductor (CMOS) control backplane. The devices have been fabricated in Blue (470nm) InGaN and UV (370nm) AlGaN based wafers, and performance characteristics are shown for bare and flip-chipped devices. These devices offer a promising basis for integration into a wide variety of optical and lab-on-a-chip microsystems.

Flip chip LED design

The flip-chip LED arrays comprise of 256 individually addressable micropixels in 16x16 array, each pixel having a diameter of 72µm on a 100µm pitch. Blue (470nm) and UV (370nm) devices have been fabricated from standard GaN wafers using an Inductively Coupled Plasma (ICP) etch process. The contacts were Ni/Au for the positive (p) contacts and Ti/Au for the ground (n) contacts, which filled the area between the LEDs. An Al layer patterned onto the p-contact serves as a light reflector.

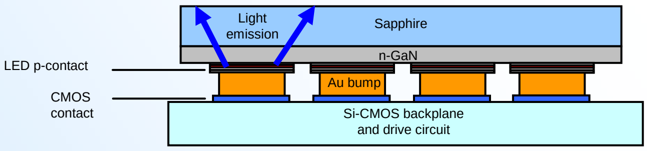


Flip-chip LED array design

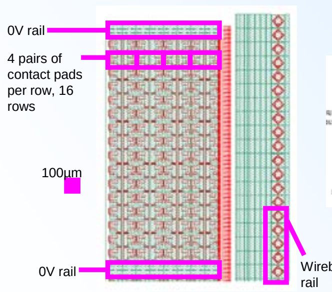


Bare device with two elements emitting through the sapphire substrate

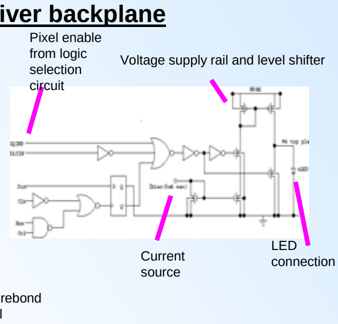
The LED arrays are flip-chip bonded with Au contacts onto a CMOS driver backplane. Heat, ultrasound an pressure provide the necessary stimulus to melt the Au contacts during the bonding process.



CMOS driver backplane

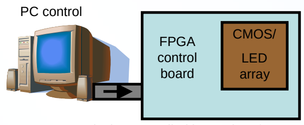


CMOS top layer pad design



CMOS pixel driver circuit

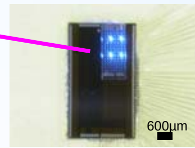
A CMOS driver device was available and a blue LED array was cut to a matching size. The driver consists of a 4x16 array of individually addressable contact pads with up to 50V and 5mA from each pad. It is capable of DC or pulsed operation at frequencies from a few kHz up to the MHz regime. The pads can be theoretically pulsed down to <1ns. In addition each CMOS pixel incorporates a Single Photon Avalanche photo Diode (SPAD), which has future potential for detecting fluorescence signals from samples placed on the LED array.



CMOS device controlled by PC interface and FPGA board

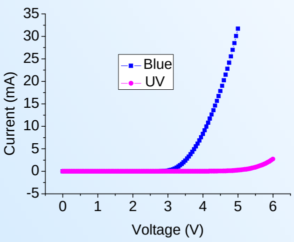
LED array sawn to size.

Flip-chip Bonding courtesy of Optocap Ltd, Livingston, UK.

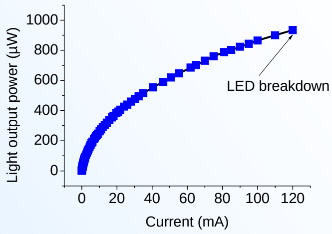


Bonded CMOS/LED array in operation

Bare Device performance

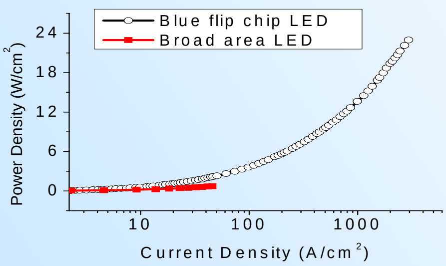


Blue turn-on V_t = 3.7V
UV turn-on V_t = 5.3V



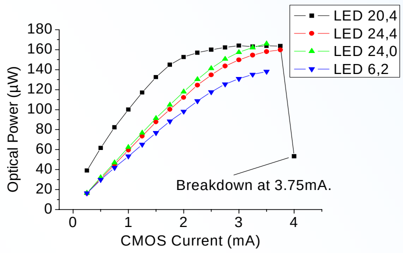
Blue device optical output power at breakdown- 934µW at 120mA

When compared against broad area device sized 408 x 540µm² made from same wafer, the blue flip chip device can reach a far higher power density output. This is likely due to enhanced light output through the sapphire substrate instead of a transparent contact. The small device size should also be a factor in allowing greater heat dissipation.



Output from LED/CMOS device

Increasing current through single LEDs from the CMOS device shows the output power levelling off around 160µW. This is due to the CMOS current source coming out of saturation. Breakdown is observed due to excessive gate voltage on the high-voltage drift MOS devices.



Current-Light output power of flip chip LED powered by CMOS

The pulsed output from the LED/CMOS device was measured using a Photomultiplier tube and 1GHz oscilloscope. At 1MHz, the minimum pulse width obtainable was 5ns. This is larger than the potential minimum of the CMOS device but is attributed to the device working outside its specification. Future plans include a custom-made CMOS device capable of driving a full 16x16 array.