MicroLEDs emit light in programmable patterns

Arrays of microLEDs can be used in imaging optics, biophotonics and other fields. Simon Andrews explains to **Tim Hayes** what the impact of this enabling technology could be.

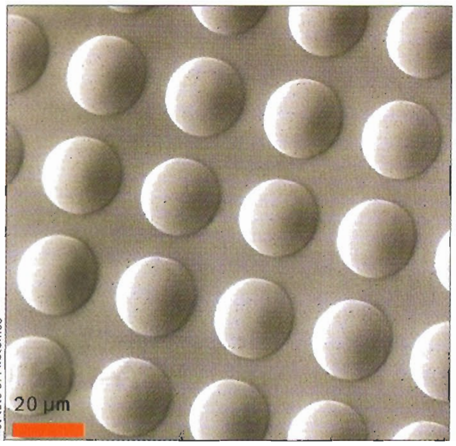
Micro-pixellated LEDs, or microLEDs, are light-emitting arrays where the emitting area consists of thousands or even tens of thousands of micron scale elements. The Institute of Photonics, an industry-focused research unit based at the University of Strathclyde, UK, is at the forefront of this emerging technology, and has developed what it believes are the highest performance microarrays yet demonstrated.

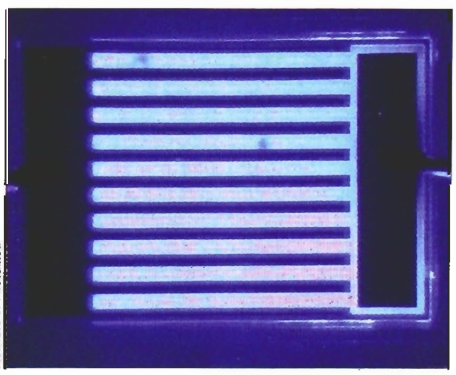
"We have developed a range of microLEDs in various formats, based on the light-emitting capabilities of gallium nitride (GaN) semiconductor materials," explained Simon Andrews, business development manager of the Institute of Photonics. "This allows us to generate what is in essence a programmable pattern of light."

The technology involves taking wafers of GaN or similar materials and microstructuring them to give individually addressable LEDs on a microscale. "We have achieved 1000 LEDs per square millimetre," said Andrews. "This was the goal of a recently completed EPSRC basic technology programme called BT1000, in which the institute was the lead partner and Martin Dawson was principal investigator."

In a microLED array, each LED element is typically 20 µm in diameter on a 30 µm pitch, but this is not a hard and fast limit. The arrays can be extremely small. For example the 64 × 64 array is about 2.3 × 2.3 mm square. "We consider 64 × 64 elements to be a typical size for ease of handling, but even that provides 4096 individually switchable LEDs in an area of only a couple of square millimetres," noted Andrews. "We have now gone well beyond that, with emitters of 4 µm in diameter and arrays of 128 × 96 elements."

This compares with conventional GaN LED devices, which have an active area approximately 350 µm in diameter and, according to Andrews, have a number of drawbacks that the microLED device seeks to overcome. "MicroLEDs are more compact, have better efficiency and beam quality, and allow faster switching speeds than their macro counterparts," he commented. "The overall device could be made small enough to be carried on the person, opening up the possibility of having personal units capable of detecting a range of different chemicals and biological targets."





Top: Microlenses aligned with each microLED allow each beam to be focused by its own microlens. Bottom: Arrays of LEDs in other formats have been produced, such as micro-stripes and micro-rings.

Quantum dots

In addition to different array formats, devices at various output wavelengths have been produced. "We typically make arrays that emit ultraviolet, blue or green light," said Andrews. "Red light is also possible, but for that you need to start with a different material system."

The emission wavelength is determined by the structure designer and semiconductor crystal grower. GaN and the family of similar alloys currently allows wafers to be readily grown for efficient light emission from around 370 to 550 nm, covering near-ultraviolet, violet, blue and green light. Extension deeper into ultraviolet, down to approximately 250 nm, has recently been demonstrated, covering the UVA and UVB regions of the spectrum and beginning to enter the UVC region.

The electroluminescence from these materials is generally single-peaked with a relatively narrow linewidth, which allows spectrally selective excitation in a range of biophotonic applications.

"We are working on ways to vary the wavelengths of light that can be emitted by the arrays," explained Andrews. "Our chemistry colleagues at Strathclyde, led by Richard Pethrick, have developed UV transmissive polymers, which increase the transmission of UV light well below 300 nm and down towards 200 nm, to match the wavelengths possible from the GaN alloys. We have blended in different light-emitting polymers to colour-convert UV light into red, green or blue light. In addition, we have blended in quantum dots that can colour-convert UV light into practically any colour that you wish, depending on the size of the dot. As quantum dot technology is becoming easier to source all of the time, this is a significant development."

Programmed patterns

The size and shape of the individual emitting pixels can be controlled by the lithographic processing. Disk-like pixels ranging from 4 to 20 µm have been made, and other shapes produced include micro-rings and micro-stripes.

A matrix-addressing scheme allows the emitters to be addressed individually, and in this format they have produced a power output of tens of microwatts per element. In addition, the sapphire substrate can be etched so that microlenses are produced, aligned with each microLED emitter, so that the beam from each emitter can be focused by its own microlens.

With a suitable device layout and addressing scheme, the emission from each of the pixels in the array can be controlled separately. This allows the devices to function as microdisplays that are pattern-programmable via a computer interface. Suitable addressing schemes that are being explored include matrix-addressing from an electrode grid. Direct addressing of individual pixels via a CMOS-based silicon backplane has been demonstrated, working with Robert Henderson at the University of Edinburgh.

The emission characteristics of these sources make them suitable for a range of different applications. "The first and most obvious application was in near-eye displays, but the relatively high brightness of the arrays meant that they were not ideal for this. Pico-projection now looks more attractive as an application in consumer devices," commented Andrews. "But we are also developing a whole range of other potential uses in several markets."

The wavelength range and power density available from the arrays makes them suitable for inducing physico-chemical changes in a range of materials. Luminescence or fluorescence down-conversion and photo-polymerization can be achieved in organic materials such as light-emitting polymers, organic dyes and fluorescent biomarkers. The team has grown DNA strands on top of the UV LEDs, using light-activated tags to control the amino acid sequence.

"In addition, the UV-emitting microLED can produce enough energy to process photoresists," said Andrews. "That opens up the manufacturing of printed circuit boards without having to make a separate mask first, which would mean faster and cheaper development."

Other potential applications will open up as the technology is developed further, according to Andrews. "One area of study is the development of seamless drivers that would sit in the same footprint as the LEDs themselves," he said. "Another is incorporating single-photon avalanche diodes, which would enable both the light source and the detector to sit in a tiny footprint. This has been demonstrated recently."

New project

The success of the development has led directly to a new EPSRC-funded research programme that is getting under way. Entitled "Hybrid organic semiconductor/gallium nitride/CMOS smart pixel arrays", the £4 m (€4.7 m) award includes partners at the University of St Andrews, the University of Edinburgh and Imperial College London. "It is an ambitious programme, again led by Dawson, but that is testament to the robustness and potential of the technology itself," Andrews commented. The diverse project will look at integrating the technology all the way from the CMOS drivers, through the microLEDs themselves and on into polymer lasers and polymer waveguides.

"These microLEDs are not a solution looking for a problem," Andrews stressed. "This is an enabling technology for a variety of different applications. The questions that remain are about which of the many opportunities has the greatest economic return. We have some very specific and strong uses in mind where there are significant advantages, and the challenge will be to see which ones give a good return in these economically challenging times."

The Institute of Photonics welcomes contact from organizations or individuals interested in developing, licensing or exploiting this technology with a view to commercialization. Visit www.photonics.ac.uk to find out more information. □