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Photonic Quasicrystal patterned LEDs offer a brighter future.

mesophotonics

Key Words

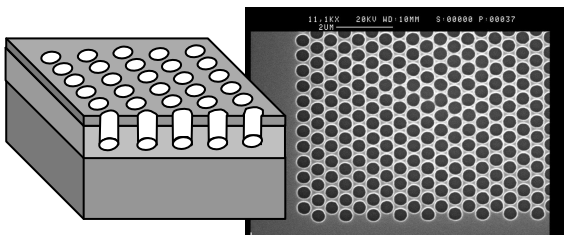
- Photonic Crystal LED
- Photonic crystal design services
- Tailored light emission profile
- Increased efficiency
- Photonic Quasi-crystals
- Reduced packaging costs
- Technology licensing

Introduction

The market and applications for Light Emitting Diodes (LEDs) has grown significantly over the last few decades as the efficiency has improved and the packaging technology has advanced. Applications for high brightness LEDs range from mobile phones to automotive and display lighting. In 2004 this market was valued at $3.7Bn (Strategies Unlimited 2005). The overall market for LEDs is expected to grow dramatically as the wall plug efficiency and the total optical output of LEDs approaches that of fluorescent lighting. This will allow the LED to be used in more applications in the vast general illumination market. LED lighting provides many benefits over other lighting technologies such as compact size (millimetres square), robustness (similar to semiconductor electronics) and extremely long lifetimes. This will allow LEDs to be a 'fit-and-forget' solution. The cost of LEDs are currently too high for many applications mostly due to packaging costs associated with managing the heat due to poor wall plug efficiency and the modification of the light emission profile to suit the application.

Photonic Crystals and LEDs

One of the ways in which light extraction efficiency can be increased from a surface emitting LED is by the use of periodic surface patterning. Early Photonic Crystal patterned LED structures have been shown to increase the light extraction efficiency by several times [1]. By exploiting the Purcell effect, Photonic Crystals in close proximity to the light emitting region promise orders of magnitude increase in light extraction [2].



A Photonic Crystal designed for controlling visible light emission is illustrated on the left. The associated scanning electron microscope image of a fabricated device is shown alongside. Typical features are 100's nm in size.

Photonic Quasicrystals and LEDs

Extra benefits such as modifying the emission profile of the LED can be found through the use of Photonic Quasicrystal structures. Quasicrystal structures use a pattern on the surface that although precisely defined

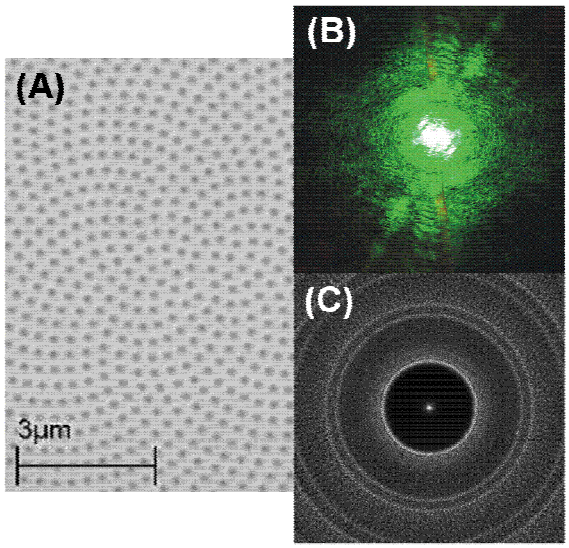
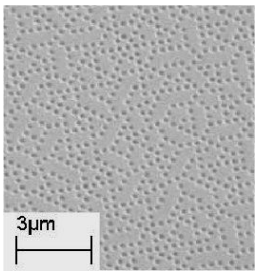


Illustration of a proprietary Sunflower Photonic Quasicrystal designed for far-field emission in the green. (A) SEM of the proposed design (B) Out-of-plane far field emission highlighting the narrow cone light projection (C) Diffraction pattern of the quasicrystal indicating the circular Bragg peaks.

using what are known as tiling rules, these patterns can appear to lack order when examined in less detail as shown below. By employing the high symmetry nature of quasicrystals many Bragg peaks can be merged to form tailored far-field emission patterns ranging from uniform illumination to cone shaped emission, thus eliminating any artifacts due to the regularity of photonic crystals [3].



SEM micrograph of a high order symmetry Pinwheel Photonic Quasicrystal structure defined using a selection of tiling rules showing the complex non-periodic orientation of the pattern .

By custom designing the quasicrystal structure for a desired cone emission profile the photonic crystal patterning reduces the need for beam shaping in the packaging. This greatly simplifies the overall LED design increasing efficiency and reducing cost.

The proprietary quasicrystal approach can be used to define other custom light emission profiles such as company logos, symbols or potentially even words to be emitted directly from the LED.

The use of photonic quasicrystals in LED structures has also recently been gaining interest [4] in the

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Molecular Imprints produces imprint lithography systems capable of reproducibly mass-producing sub 50nm features on a range of substrates and materials.

literature for the generation of identical light scattering independent of direction of emission. This is extremely useful in applications such as backlighting of displays that require very uniform illumination.

Defining the patterns

For visible LEDs the big challenge has been lithographically defining the tiny patterns required to generate high efficiency quasicrystals which are of the order of 50nm to 300nm in size. This is beyond the capabilities of most traditional optical lithography methods used in the semiconductor industry. Whilst for regular photonic crystal patterns low cost holography techniques have been demonstrated [5], until recently the only way to make the quasicrystal patterns for LEDs has been using slow and expensive e-beam techniques. Recently nano-imprint lithography techniques have become commercially available from Molecular Imprints Inc to allow these patterns to be cost effectively manufactured in large volume.

Impact on manufacturing costs

By increasing the light extraction efficiency and consequently the overall electrical to optical efficiency (lm/W) of the LED die, significantly more light can be generated from the same electrical input. This reduces the number of LEDS required to provide a given light level reducing costs, as well as significantly reducing the total heat generated further reducing packaging costs.

Tailoring the emission profile to the desired application also leads to additional cost savings by eliminating the need for costly and unreliable beam shaping optics currently used in LED manufacture.

Mesophotonics offering

The Mesophotonics team has over 10 yrs experience in modelling, designing and fabricating quasicrystal structures in a variety of material systems and is now offering design services to LED manufacturers wishing to incorporate the benefits of quasicrystal designs into their own LED structures.

Mesophotonics has a comprehensive patent portfolio [6] which it will licence to device manufacturers on attractive commercial terms. Mesophotonics believes that incorporating these structures into surface emitting LEDs will allow device manufacturers to achieve beyond 85% overall efficiency opening up a wide range of new potential markets.

References

[1] Erchak, A. A. et al. *"Enhanced coupling to vertical radiation using a 2D Photonic Crystal in a semiconductor LED"*, Appl. Phys. Lett. 78, no. 5, **2001**, Pg 563.

[2] Purcell, E. M. *"Spontaneous emission probabilities at radio frequencies"*. Phys. Rev. **69,** 1946, Pg 681

[3] Zoorob, M. E. et al., *"Complete and absolute photonic bandgaps in highly symmetric photonic Quasicrystals embedded in low refractive index materials"*, Nature, vol. 404, **2000**, Pg 740

[4] Zhang, B. *"Effects of the artificial GaN/air periodic nanostructures on current injected GaN-based LEDs",* Phys. Stat. Sol. (c) 2, no. 7, **2005**, Pg 2858.

[5] Kim, D-H et al., *"Enhanced light extraction from GaN based LEDs with holographically generated 2D Photonic Crystal patterns",* Appl. Phys. Lett. 87, **2005**, Pg 203508.

[6] Portfolio of Granted Patents in the US. US6640034, US6901194, US6778746, US6888994, US6775448, US6959127.

mesophotonics

Tel: +44 23 8076 3752
Email: info@mesophotonics.com
Web: www.mesophotonics.com