

Multi-watt LED light engines offer challenges and opportunities

Multi-watt class LED array light engines are emerging as viable replacements for current light sources. As **Gareth Jones** of Enfis describes, this brings new opportunities for application developers, as well as challenges for systems designers.

Over the last few years there has emerged a new class of light emitter which is able to compete in terms of light output and efficiency with the more traditional light sources such as incandescent, halogen and arc lamp technologies. This new light source, commonly known as the high-power LED light engine, has been built upon the developments of a small number of LED chip companies such as Osram, UEC, Arima Optoelectronics and CREE – some of the larger industry players who provide access to their best LED chips.

In addition, a small number of companies such as Lumileds, Osram, Cree, Nichia, Optodiode, Epitex, Lamina Ceramics and Enfis have developed efficient LED packages which have enabled these chips to be driven at high power while also allowing the heat to dissipate effectively. This is also coupled with efficient thermal management techniques and high-efficiency, low-cost electronic driver technology to bring about the Multi-Watt (MW) LED light engine.

Scaling approaches

There are two main approaches for the generation of traditional lighting-scale lumen values from LEDs. One approach favored by companies such as Lumileds (and the far eastern clone companies now producing Luxeon look-alikes), Cree and Osram is to produce single power chip LED packages which can be attached to PCBs in tight clusters to produce reasonably high output powers. However, there is a sacrifice in the thermal management and the maximum radiative power density that may be available to such approaches.

The other approach utilizes the packaging of a large number of small or power LED chips onto thermally efficient tiles which provide a very high-power density and thermally efficient light-emitting arrays. An advantage of this approach is the ability to integrate multiple wavelengths (or colors) within the array to produce white light, for instance. This technology is favored by companies such as Optodiode, Lamina, Epitex and Enfis. The arrays can be monochromatic, or a combina-

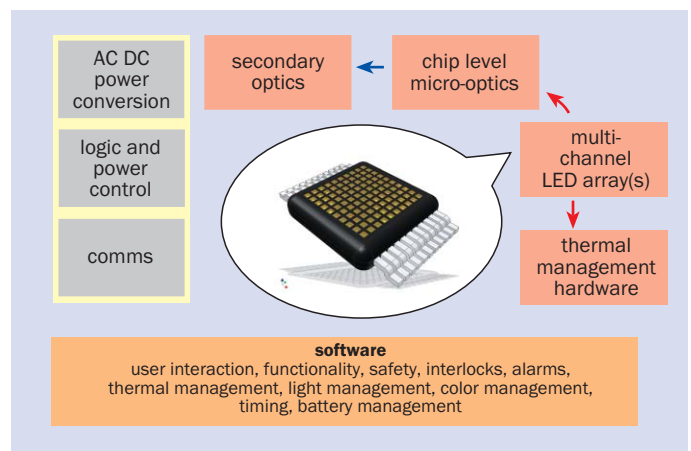


Fig. 1. Light engine component block diagram.

tion of colors such as red, green and blue or a combination of LED and phosphor for white light emission.

Enfis has invested considerable resource in the development of MW LED arrays and is able to achieve power density levels in excess of those on offer from the majority of “off-the-shelf” LED companies (see Table 1). The company believes that the integration of the light engine such as power conversion, optics, thermal management and the manufacture of the plug and play light engine into medium cost niche lighting applications will enable competitive LED based illumination products to become widespread.

Light engines

The array is not the whole show – indeed it cannot be used effectively without some other important light engine system components.

Table 1. High-power LEDs

Company name	Part no.	Size (cm)	Area (cm ²)	Light output	Radiant power density (mW/cm ²)	Thermal resistance (°C/W)
Lamina	BL-3000-red (λ _d ~ 618 nm)	27 × 32	8.6	6800 mW 1938 lm	790	<1
Lumileds	Luxeon III red (λ _d ~ 627 nm)	8 × 15	1.1	770 mW 140 lm	690	15
Enfis	MW-5x5-red (λ _d ~ 625 nm)	9 × 12	1.1	4000 mW 880 lm	3700	<1

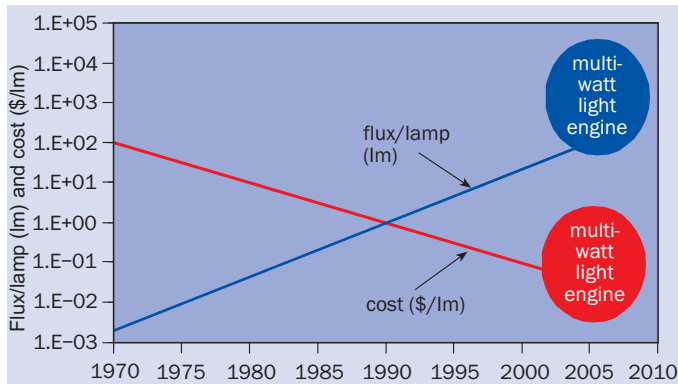


Fig. 2. Changes to the LED cost/performance landscape enabled through the development of MW-LED arrays.

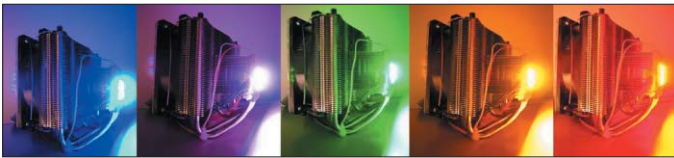


Fig. 3. Digital light: Enfis MW-LED light engines using RGB color mixing to generate instant color changing over a wide color range.

Around these arrays lie the thermal, electronic and optical management systems. Figure 1 (p35) shows a schematic block diagram of the typical components in a light engine.

The need to drive more power through these LED arrays whilst providing improved longevity, higher wall plug efficiency, lower cost and smaller form factor presents the light engine designer with a number of challenges with respect to the component blocks shown in figure 1 (p35).

Market predictions

Roland Haitz described a trend in the light output per lamp and cost per lumen according to the curves, shown in figure 2, in blue and red respectively. These predictions are similar in nature to predictions made by Gordon Moore, co-founder of Intel, in the 1960s, that the number of transistors per square inch on integrated circuits had doubled every year since the IC was invented. Moore predicted that this trend would continue for the foreseeable future. Both laws are based around similar types of processes relating to inorganic semiconductors, and show that both cost and packing density can be improved considerably over many decades and will be expected to improve for LEDs over the next 10–20 years.

Recent advances in multi-chip arrays have altered the slope of these curves dramatically, providing orders of magnitude changes in lumens/lamp and reduction in lumens/\$. This has brought more applications into the market space for MW-LED light engines.

Crucial to the adoption of MW-LED light engine technology by the wider general lighting market will be two key improvements: the luminous efficacy (lumens out to electrical watts in) and the cost per lumen.

Lighting is dominated by the various light source technologies which have the following luminous efficacies:

- Incandescent, 10–15 lm/W
- Halogen, 15–20 lm/W
- LEDs (2005), 20–25 lm/W
- Fluorescent, 50–95 lm/W

However, the luminous efficacy of LEDs is set to increase at a dramatic pace fuelled by key government investment particularly in the US and Japan. Recent laboratory results from Cree showed 70 lm/W for their XLamp single die package, and forecasts now indicate that around 150 lm/W will be achieved within the 3–5 years.

These improvements will have a profound effect on the size, cost and energy savings using LEDs for lighting applications. As an example, the power consumption equivalent for a standard 100 W incandescent light bulb would be reduced using LEDs to around 5–10 W in the coming years!

Niche market applications

Given the current luminous efficacy (lm/W) and cost (\$/lm) there exists a number of niche markets ready and willing to accept the MW-LED light engine.

These markets demand high power – from hundreds to tens of thousands of lumens – but are also able to take advantage of the unique characteristics of MW-LED light engines. These niche applications are accessible since they will pay a price suited to the current cost structure in the LED light engine industry. The technology is available and improving, while the price is just acceptable and improving. Some examples of niche illumination markets for MW-LED light engines are:

- medical and dental lighting
 - entertainment/stage and architectural lighting (figure 3 shows an Enfis MW-LED RGB light engine providing approx. 10,000 lm)
 - industrial task lighting
- In addition there exists a large number of other niche applications not usually associated with lighting such as:
- light based medical treatments – see facial treatment device as depicted in figure 4
 - non-destructive testing
 - curing of sealants and adhesives
 - automotive headlamps
 - large area LCD backlighting

Desired system characteristics

The next-generation light sources for medical, industrial and niche illumination applications will require certain key product design fea-

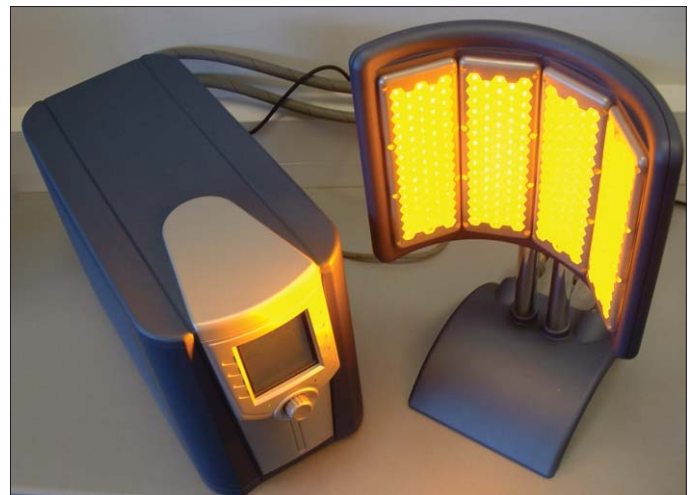


Fig. 4. Enfis medical MW-LED Light Engine system for skin treatments.

Table 2. Wish-list of features for MW-LEDs

High power output (kilolumen level) for illumination applications
 High power output density i.e. high radiant intensity provides for compact optical solution and small mechanical form factor.
 Compact efficient thermal management to remove heat
 Small size – low weight
 Long lifetime – low maintenance
 Intelligent light source smart operation – feedback temperature, color etc
 End of lamp life indication prior to lamp failure
 Networked communications enabled (such as DMX, DALI etc to allow designer to use these light engines as plug and play component)
 Plug and play mains 110 V or 240 V, low voltage 12/24 V or battery operable
 Color selection – ability to vary color temperature and keep high CRI. (In some instances to provide enhanced CRI through the use of other colors in addition to RGB)
 Digital light control – selection color or light level and system will maintain these levels to the end of life through closed loop feedback
 Maximise CRI through the use of multiple emitters or broad phosphor emission
 Controlled linear dimming features

Table 3. Key design factors for MW-LED arrays

Use LED chips with high reliability – the lifetime of the chip is the dominant initial parameter
 Use LED chips with high efficiency to reduce heat
 Use LED chips which allow lowest thermal resistance path from the active region to the base of the chip
 Ensure LED chips are attached to the package with low thermal resistance
 Avoid moisture and other contamination near the chip and during the packaging process
 Provide low stress encapsulation scheme or dry gas sealing (especially for UV)
 Keep LED chip junction temperature as low as possible
 Use high thermal conductivity packaging
 Ensure match of thermal expansion coefficients between LED chips and package
 Provide efficient thermal management to remove heat from the back of the package
 Ensure that the wire bond is safely rated
 Avoid fusing through transients in testing, handling or in the system
 Minimize temperature cycling
 Ensure good electrical circuit design and connections from array

tures so that they may compete and add value to these markets where more traditional light sources and laser light sources dominate. Some of these “wish-list” design features are shown in Table 2.

Of course, to compete in all of these markets still requires the system to be competitive on price. This price point then sets a number of challenges for system designers to include as many features as they can whilst still providing a competitive product in fierce global markets.

The combined features above lead to the formation of a new light source: the MW-LED light engine with digital light network enabled functionality. Enfis is working closely with customers and suppliers to meet the needs of the niche illumination markets so that the right price can be offered with the right feature sets. A number of design challenges do exist to achieve real market penetration in the multi-watt range with cost being one of the biggest barriers to wide-scale adoption.

Design challenges

New higher power niche applications for MW-LED light engines are providing LEDs with applications in less cost sensitive markets compared with the traditional indicator lamp markets. However, in most cases there is already an entrenched competing light source which is better either in terms of efficiency, or cost, or power density; these values need to be surpassed for the LED product to gain market share. MW-LED light engines can offer strong additional benefits such as color mixing, dimming and reliability, but they must also be able to compete in the more mainstream areas such as cost, luminous efficiency and overall system size.

MW-LED arrays

Most MW-LEDs consist of a large number of LED chips on a thermally efficient base package. There are a variety of design choices with no standardization yet taking place. A lack of standardization provides challenges for system integrators and tends to “lock in” certain systems manufacturers to use particular suppliers, which can lead to a lack of competition and higher costs.

When electrical power is applied to an LED chip, between 70–95% of this power is dissipated as thermal energy (i.e. heat). This must be conducted away from the chip effectively to prevent catastrophic thermal failure of the LEDs and surrounding materials such as encapsulation. Thus, control of the temperature within the LED array is hugely important and is a large contributing design factor affecting the reliability of the system.

Some of the key design factors which enable high reliability MW-LED arrays are shown in Table 3.

There are two approaches which one can take regarding the reliable use of MW-LED array technology and consistent operation at higher powers:

- ensure LED chips reliably and efficiently operate at higher temperatures – requires packaging and encapsulation innovation, but does not require bulky thermal management systems
- remove heat from LED array/package to maintain low LED chip temperature – integrated thermal solutions requiring less array process development but ultimately resulting in larger system footprint

Both of these directions are important to enabling the use of MW-LED array light engines in general lighting applications.

Thermal management

If the heat cannot get away from the base of the package then the array will heat up and this will quickly result in poor system performance and reliability. Therefore providing efficient, low-cost, low-power consumption and small size heat dissipation systems to remove heat from the base of the array is a key technical challenge.

Figure 5 (p38) shows the difference in the thermal challenge between LEDs and incandescent light sources. LED systems are required to conduct the heat away from the chips and radiate no significant heat; whereas the majority of the heat generated within an incandescent naturally escapes into the environment through radiation.

There are generally three major stages in the removal of heat from a MW-LED array: →

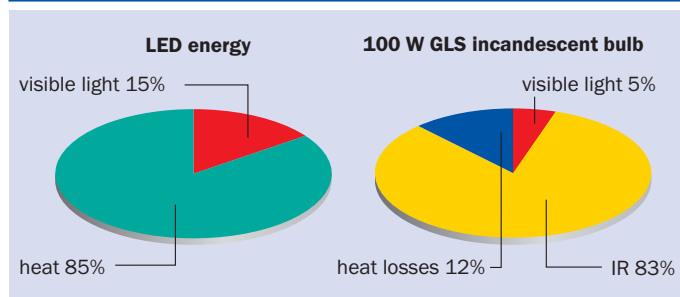


Fig. 5. The comparison between the energy conversion of an LED and an incandescent light bulb showing the difference in the type of energy generated.

- Primary thermal transfer from the LED chip to the base of the array is usually conduction. The chip must be in good thermal contact with the package and the package must be in good thermal contact with the conductive heat exchange system. In addition, the package itself must have low thermal resistance
- Secondary thermal transfer transports the heat from the base of the array efficiently and then spreads the heat out so that it can be removed via convection
- Thirdly, convective processes such as fans and fins can be used to transport the heat into the surrounding air

Each of these processes requires careful design and usually computational modeling to ensure that the transfer processes are optimized in terms of size, choice of materials etc. This must take into account the structural requirements of the overall system i.e. the shape and size constraints.

The above three phases are relevant for the more traditional heat exchange systems i.e. forced air cooling or fluidic cooling systems. Other highly-efficient technologies are now being developed that have the potential to reduce the size of existing systems but are beyond the scope of this article.

Optical management

MW-LED arrays are not point sources of light but are generally classed as extended sources with multiple elements and highly divergent emission. This can be an advantage where the spread of light is useful but in general, where one wishes to have control over the distribution of light, it creates problems with the efficient collection of light. This leads to the requirements for a complex optical solution.

Novel optical approaches are necessary to keep efficiency high

whilst retaining compact size which can lead to high costs for new optics and tooling. Many companies are developing a wide-range of optical solutions for MW-LED arrays using traditional lenses, reflectors, total internal reflection in plastic optics, and micro-lens arrays, as well as combinations of these. However, due to the lack of standardization in the design of the arrays there is no standardization in the optical solutions yet.

Electronics and power management

LEDs are generally DC-driven although some companies have been working on direct drive from AC supplies. The power conversion process from AC to DC introduces inefficiencies into the system, and this in turn introduces extra cost and also increases the size of the system. Also, there are important issues such as EMC and safety requirements which must be met.

Once the power conversion process has been performed the electronics are then required to control the current through the LED. This can be an issue when variations exist between the electrical characteristics of individual LED chips and therefore LED arrays. Such variations are widely referred to as “binning” issues and must be taken into account in the design process if reproducible systems are to be manufactured.

As the systems are driven smaller and produced at lower cost, each constraint reduces the available design space with traditional PCB design. New technology approaches are necessary such as integration of the electronics and optoelectronics into compact, thermally efficient packages. These take in AC power and provide all the necessary power conversion, control and intelligence within a small number of compact chips.

Conclusions

Multi-watt class LED array light engines have emerged and are creating new opportunities to replace current light sources for illumination. These MW-LEDs bring new opportunities for application developers, as well as challenges for systems designers.

Moving forward, there is a requirement to move towards standardization of arrays, connectors, optics, thermal management systems and electronic designs in order to reduce costs. There is also a requirement to move towards integration of electronics and optoelectronics in order to improve thermal efficiency, footprint and cost. ●

About the author

Gareth Jones is chief technology officer of Enfis Ltd, UK (www.enfis.com).

The next issue of LEDs Magazine Review will be published in December

Contact the editor, Tim Whitaker (editor@leds.iop.org), with news, product information and ideas for technical articles.

The deadline for contributions and advertising orders is 8 December.

Can't wait until December?

Our website is updated every day