Ensuring the next generation of LED Lighting is safe

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I have often stated that the future of LEDs look bright, however with the recent announcements made by Philips Lumileds and CREE regarding the technical specifications of their next generation LEDs developed within their Research & Development Labs the lighting industry can be assured that LEDs will only get brighter and brighter. Looking directly at any of the high powered LEDs in production today, they are so uncomfortably bright that even a momentary glimpse of the source can leave a strong afterimage on the retina persisting for several minutes in many cases.

However there appears to be very little awareness of the actual eye hazards posed by LEDs. The Solid-State Lighting Research Centre based at Aston Science Park is continually asked a multitude of questions on LED safety, however the following are some of the most common questions:
Q.1 How safe are LEDs to view or perhaps they are not?
Q.2 How long can an LED be viewed for?
Q.3 Does LED safety need to be formally assessed and measured? If so how should this be done?
Q.4 How should an LED product be labelled for the purposes of eye safety?
Q.5 Does the colour of an LED affect the safety of the eye differently?
These are all important questions, and for the answers we look towards the work of the national and international optical radiation safety committees that are attempting to tackle the LED safety measurement issue. Promisingly the foundation work in LED safety was put in place in 2001 however progress was sidelined due to the debate concerning whether or not an LED should be treated as either a 'lamp' or a 'laser' source. However, the debate has now been concluded and LEDs were dropped from the Laser safety standard and included under the lamp based safety analysis so 2008 should be the year when clear guidelines are issued which answer all of the above questions

LED technology advances – impact on safety
The next generation of LEDs will be available in less than two years and are set to significantly increase in brightness requiring fixture designers to take into account product safety in the future. For example, Philips Lumileds announced in February that a research white LED device with a chip of 1mm2 delivered 136 lumens at 350mA (115 lm/W) whilst at 2000mA it produces 502 lumens (61 lm/W). This record has recently been shattered by Cree who has developed a White LED that is

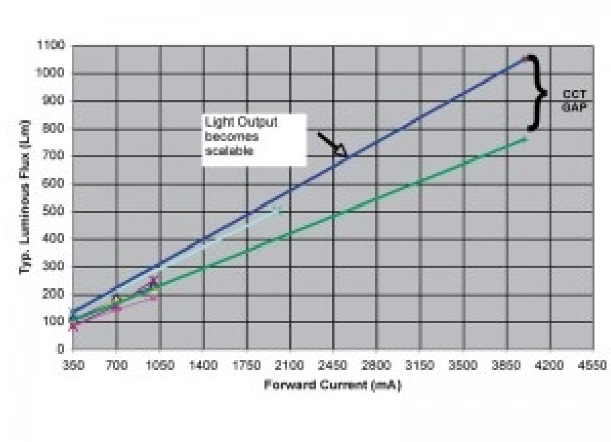

Figure 1: The typical light output from various single chip LED emitters

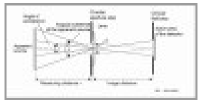

Figure 2: Diagram illustrating a system to make LED safety measurements

equation1

Figure 3: A simple system to make accurate LED safety measurements

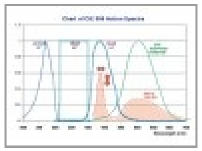

Figure 4: CIE 009 / IEC 62471 Lamp

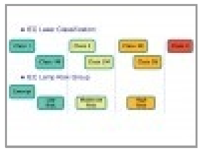

Figure 5: The labelling

capable of being driven at a forward current of up to 4 Amps from a single chip which is between 1-2mm2. This latest development device is capable of emitting over 1050 lumens at 4A or 14.6W providing an efficacy of 72 lumens per Watt whilst driving it at 350mA delivers 136 lumens yielding an impressive 129 lumens per watt efficacy.
To set these record breaking devices in context, figure 1 illustrates the significant leap in performance such devices would be compared to the current high powered white LEDs available on the market today.
The ability to produce scalable light at higher and higher forward currents is being achieved by new LED manufacturing processes which overcome inherent limitations with previous LED chips which traditionally make them more inefficient when operating at high forward currents.
Interestingly, figure 1 also identifies the gap in performance of cool and warm white LEDs due to the relevant differences in phosphor efficiency when converting the blue LED into white light. Warm white LEDs are generally safer than their counterpart cool white LEDs as more blue light is converted to other wavelengths thus giving a warmer appearance and reducing the Blue Light Hazard.
Other aspects of LED technology which are developing at pace to increase LED radiant intensity include:
a) The reduction in the size of the LED emitter
b) The use of exotic secondary optics for beam control purposes.
For example, the use of photonic crystals on the surface of LED chips will have a major impact on future safety as they enable highly collimated and very efficient light extraction without the need for secondary optics.

Optical Radiation Safety & ICNIRP
Any standardisation work on LED safety must first of all take into account known safe limits of human exposure to optical radiation for the various bands of the ultraviolet, visible and infrared regions of the spectrum. Since the early 1970’s, the International Commission on Non-Ionising Radiation Protection1 (ICNIRP) has published technical information on safe exposure limits to all kinds of non-ionising radiation. The various laser and lamp safety standards that currently exist have very likely based their limits on the ICNIRP data, and the same situation will be true for LED safety.

Optical Radiation Safety Measurement
In order to make safety measurements on LED based products a straightforward bench top system can be used as illustrated in Figure 2 with a typical practical configuration shown in Figure 3. Referring to figure 2, a light collection aperture (Circular field stop) coupled to an optical detector is placed in the beam at a given distance and the level of optical radiation (or light) is recorded. The collection aperture (circular aperture stop) is typically 7 mm in diameter with the measuring distance ranging from 100 mm to 200 mm depending on the standard, to mimic a fully dilated naked eye

Safety Limits	requirements of the two classification schemes

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viewing the source. An additional field stop is also placed over the source to create a well defined field of view as required for a radiance measurement. Figure 3 highlights a typical laboratory system used for LED safety measurements.
The various optical radiation standards define a minimum possible retinal spot size via the concept of the source subtense angle parameter (a); this parameter can be defined for a ‘bare’ LED chip emitter as shown in equation1, left.
For example, an LED chip which is 1 mm in diameter will, when viewed from a distance of 200 mm, have a corresponding source subtense angle of 5 mrads.
The source size for a standard LED is easy to determine as it is the LED die size. However it is more difficult to determine if an LED has optics attached or indeed there is an array of LEDs within close proximity to each other. Therefore, most standards adopt the term ‘apparent source’ as shown in figure 2. This is often used to denote that any primary and secondary optics placed in front of an LED can serve to alter both the observed size of the source, and its apparent location as perceived by the observer. Generally, an LED is used with secondary optics and this has the effect of making the LED chip appear larger than it actually is thus spreading the power emitted by the LED across the retina in the eye.
The impact of the apparent source can be to modify the safe exposure limit and required measurement distance. In all of the various standards and guidelines to be discussed, the above principle of measurement and source definition is applied.

Retinal Hazard Limits
There are several effects that can prove hazardous to the retina within the eye including:

- Photothermal Limit: This represents the maximum allowable heating power of the light beam;
- Photochemical Limit: This represents the chemical energy of the light beam;
- Blue Light Hazard: Long term exposure to blue light is hazardous and a possible cause for Macular Degeneration.

One or more of these hazards are usually referred to within all relevant safety standards.

Laser Safety & IEC
At the international level, laser safety standardisation work has tended to centre on the work of the International Electrotechnical Commission2 (IEC) who publish product and application based standards for electronic and electrical products.
For laser safety, the main IEC product safety standard is the landmark document IEC 60825-1 published in various incarnations over the last few decades. Additionally IEC also publish a range of applications based laser safety standards covering for example the medical, industrial and optical fibre communications fields. In respect of LED safety, the 2001 edition of the standard IEC 60825-1:2001 was noticeable in that LED sources were explicitly and unambiguously included within its

scope. Annex G of the standard was also very useful in defining the radiometric parameters of LED devices needed to assist with the hazard analysis. In 2007, the decision was made to remove LEDs from the scope of the IEC 60825-1:2007 standard and instead the harmonised standard IEC 62471:2006 (see next section) has been adopted by the IEC committee to include LEDs. Unfortunately, due to the way standards are adopted it is possible that at the national level, any legislative or regulatory requirements for product safety which either reference or are based directly upon the previous IEC 60825-1: 2001 standard will by definition still encompass LEDs within their scope of application. This situation will remain so until these calling standards are themselves revised and updated to reflect the recent changes occurring at IEC.

LEDs & Lamp Safety

The decision by the IEC committee to remove LEDs from the scope of the IEC 60825-1: 2007 laser safety standard was in fact an acknowledgement of an existing standard CIE S 009: 2002 which addresses the photobiological safety of lamps and lamp systems, including LED sources. This standard was prepared by the International Commission on Illumination3 (CIE), an independent organisation devoted to the worldwide dissemination of knowledge and information pertaining to the science of light and lighting. It is worth pointing out though that the CIE standard is itself drawn extensively from the work of the Illuminating Engineering Society of North America4 (IESNA) that publishes several standards in this field. The safe exposure limits in the CIE lamp safety standard are, like those in the IEC laser safety standard, based upon the underpinning ICNIRP safety data and guidelines. Also, the measurement methods in CIE S 009: 2002 are similar in format to those contained in the IEC laser safety standard. Unfortunately, the CIE standard does not provide detailed information on how to measure a source configured within an array, nor does it include the hazards posed by aided optical viewing, and there is also no information on product safety labelling requirements.

Furthermore, the exposure measurement is undertaken at a fixed distance of 200 mm from the (apparent) source location and this approach may not be universally applicable to the evaluation of LED and LED array sources. The standard does however provide a clear delineation of the various ocular hazard bands as shown in figure 4 and its methodology is directly applicable to broadband sources (such as a white HB-LED).

To accommodate the removal of LED sources from IEC 60825-1, the IEC published in 2006 a lamp and LED standard (IEC 62471:2006) that was harmonised with (and indeed directly based upon) the CIE S 009: 2002 lamp safety standard. This relatively new IEC standard is already undergoing revision to better reflect the needs of LED source hazard assessment and labelling, and the updated version is forecast for release in 2008. Whilst there is no specific information on labelling requirements, the lamp safety standard does contain its own risk classification scheme for potentially hazardous lamps namely: Exempt; Low Risk; Moderate Risk & High Risk which follows a similar reasoning to the IEC laser product classification. Unfortunately, it would be better for the LED industry to have one harmonised (risk based) classification scheme for the hazards posed by lasers, lamps and LED sources rather than the two schemes which now exist. Figure 5 compares the two classification schemes.

In summary, for the purposes of international trade of LED products, manufacturers and vendors of LED products should consider IEC 62471:2006 to be the currently applicable product standard for LED safety. Again this is notwithstanding any specific national regulatory requirements or directives which refer to an alternative standard or assessment method such as the IEC 60825-1:2001 laser (and LED) safety standard.

Also, as noted above, caution needs to be advised at this stage that a fixed assessment distance of 200 mm may not be sufficient to fully ascertain the maximum optical radiation hazard posed by the source and consideration might also need to be given to the effect of aided viewing (e.g. magnifiers, telescopes) upon the hazard assessment.

LED Safety & the EU

Having considered the situation concerning LED safety at the international level we now turn our attention to the European standards. The European Union has a clearly established process by which safety standards are prepared and adopted. For electrical and electronic goods such as lasers and LED light sources, responsibility for standards ratification lies with the European Committee for Electrotechnical

Standardisation5 (CENELEC). Once CENELEC issue a European normative standard member states will usually adopt that standard adding a national prefix (eg BS for the UK, DIN for German etc.). Currently in the EU, the relevant normative safety standard for the trade of laser and LED products is EN 60825-1:2001 and it should be noted that this standard is still based on the corresponding IEC laser safety standard IEC 60825-1:2001 which includes LEDs within its scope. As it cannot presently be assumed that CENELEC will necessarily follow the recent changes implemented at IEC, it may be some time (e.g. mid 2008 at the earliest) before the European Union standard is revised and updated to presumably remove LEDs from its scope. Furthermore, there are certain EU product regulatory requirements such as CE marking, and compliance with the low voltage directive (LVD) and General Product Safety Directive (GPSD) which specifically stipulate the use of standard EN 60825:1 and accordingly, LEDs are thus encompassed by these product safety based requirements and regulations.

In addition to any standard developments on laser and LED safety, it is worth noting that EU member states have just begun the implementation of the recent 2006 European Union Directive on Artificial Optical Radiation (EU OARD). Similar to concerns with electromagnetic compatibly, and acoustic noise hazards, the EU OARD is aimed at ensuring that all workers within the EU are protected from sources of potentially harmful (artificial) optical radiation: the term artificial denotes that the Sun is not included, being covering by existing health and safety legislation. Work undertaken towards this new EU directive is expected to extend and modify the picture with regards to LED product safety in the EU in forthcoming years; especially as it endorses a risk assessment

based approach to the optical radiation hazard assessment that may be required to go beyond the recommendations and limits of any particular optical radiation standard.
In summary for the EU, product safety compliance requirements for LED and laser sources indicate a need presently to follow the safety standard EN 60825-1:2001 which is a laser based product safety standard wherein LEDs are included in the scope. This situation will likely remain unchanged until as such time that the EN standard is revised and updated and may even be overtaken by any preliminary findings towards implementing the EU OARD.

Current issues with measurement standards for Optical Radiation Safety
Regardless as to which approach is taken towards addressing the EU Directive on optical radiation, from the perspective of lasers and high brightness LEDs critical concerns still remain from the measurement point of view:

• How to measure the apparent source size, apparent source location and subtense angle;
• How to calibrate broadband optical radiation safety measurement equipment (e.g. for measurement of LED power spectral density in watts per nm.);
• What is the most appropriate position (i.e. viewing distance) at which to measure the hazard posed by the source;
• Whether or not optically aided viewing is to be included in the assessment;
• How the hazard from LED arrays is to be measured and assessed.

It must be noted that all of the above items require further investigation by the standards bodies, regardless of whether an LED is to be treated as a 'laser' or a 'lamp'.

Conclusions
It is clear that the issue of LED product safety standardisation has been in a state of flux for a number of years whilst the issue of a 'lamp' versus a 'laser' assessment has been discussed. To some extent this matter can now be considered resolved in favour of the 'lamp' based assessment by the publication of IEC 62471:2006, and the removal of LEDs from the scope of IEC 60825-1:2007. Unfortunately, this is not necessarily the end of the matter as the unique nature of LED devices and product applications will likely pose hazards that exist beyond the limitations of the present standards and these require a thorough investigation to be made over the next few years. The immediate advantage of most standards is that the equipment required to make safety measurements of LED based products is relatively straight forward to construct. However, once the measurements have been collected the difficulty comes when attempting to classify the LED product as many of the safety standards in Europe still refer to the laser safety standard IEC 60825-1:2001 and therefore LED products may currently need to make reference to the IEC Laser Classification as well as the IEC 62471:2006 Lamp standard.

In order to assist the LED community in assessing the hazards posed by LED sources, the Solid-State Lighting Research Centre at Aston Science Park has developed a LED Safety Workshop course which reviews the contents of the standards along with a “hands-on” practical session which allows practical measurement of LED products.
Unfortunately, the development of standards is nowhere near the pace of LEDs and it may take several years for standards to fully catch up with the technology. Therefore, it is advisable that all lighting manufacturers assess their LED products and provide clear notification of their classification (which ever standard is used) to all.
www.photonicscluster-uk.org

Reference

1) International Commission on Non-Ionising Radiation Protection (ICNIRP) - www.icnirp.de
2) International Electrotechnical Commission (IEC) - www.iec.ch
3) International Commission on Illumination (CIE) - www.cie.co.at
4) Illuminating Engineering Society of North America (IESNA) www.iesna.org
5) European Committee for Electrotechnical Standardisation (CENELEC) - www.cenelec.org

Dr. Geoff Archenhold is Director of Business Development at Aston Science Park and member of the Government’s Photonics Leadership Group.

garchenhold@blueyonder.co.uk