Laser-phosphor illumination in projectors

White paper

1 A story

Once upon a time, there was a group of happy fireflies. They were all having the time of their lives, flying together high up in the sky. Suddenly, one little firefly felt a bit tired. He stopped flying and fell down. But as he was falling, he sent a spark to his friends in the sky to say goodbye. The spark hit another firefly, and when he got tired, he also sent a spark along to his friends. Now two sparks floated synchronously into the air and struck the next firefly. More and more fireflies started falling, and more and more sparks moved forward on a search for the next happy firefly.

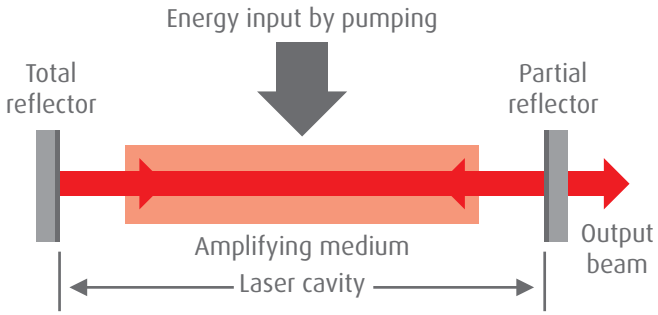
Suddenly, the group of sparks encountered a mirror. 'Mirror, mirror, on the wall, who is the brightest of them all?' 'You are not,' said the mirror, 'I can hardly see your light.' The sparks decided that they would be much brighter if they all came together later and gathered more friends. They turned away from the mirror and started a quest to find more friends by making any firefly they found on their way fall. After a long trip through the swarm of fireflies, they bumped into another mirror. 'Mirror, mirror, on the wall, who is the brightest of them all?' 'Together, you are,' said the mirror – and the sparks burst through the mirror, out into the open as the brightest light anyone had ever seen.

2 What is a laser?

Replace the word 'firefly' with 'electron' and 'spark' with 'photon', and the story above describes how a laser works.

LASER is an acronym that stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation:

- **Radiation:** You need the generation of light photons to produce light. And the photons are generated by pumping energy (an electrical current) through a gain medium. This energy excites electrons to jump to a higher energy level. After some time, or if they are stimulated by another photon, they drop down to their lowest energy state, which causes them to release a photon.
- **Stimulated emission:** The generated photons stimulate the excited electrons to drop to a lower energy level. By doing this, a new photon is generated with the same physical parameters – the same phase, frequency, polarization and direction – as the incident photon. In a Light Emitting Diode (LED), on the other hand, emission is spontaneous: at random intervals, excited electrons fall to a lower energy state, and random photons are generated that exit the structure in all directions.
- **Light Amplification:** The laser cavity, in which the photons are generated, amplifies the light so that you have multiple photons with the same physical parameters in that cavity. The amplification occurs because the photons that are bouncing back and forth against the mirrors of the laser cavity are stimulating other electrons to drop to a lower energy state and thus release a photon with the same physical parameters. One mirror reflects slightly less than the other, and, when a threshold of generated photons is reached (called population inversion), the photons exit the cavity as a laser beam.



3 Why is using a LASER in projectors a good idea?

Compared to a lamp, a laser has many advantages:

- A laser is a **solid-state source**. In this respect, it is similar to an electronic chip: there are no moving parts, it's very small, and production can be automated in a controlled environment. Furthermore, just like electronic chips, lasers can be produced inexpensively if the quantities are large. In contrast, the process of making projector lamps is much more labor intensive: manufacturing glass bulbs and inserting electrodes into them, which become very hot (over 300°C); making reflectors with the correct tolerances; aligning the bulbs in a reflector and fixing them all together...
- The laser has a **very narrow wavelength band**. This means that the colors are very saturated and remain stable over time, as long as you keep the temperature under control; whereas lamps have a very broad wavelength band and the spectral power distribution in this band even changes over time.
- Because a laser degrades very slowly over time, its **lifetime** is much longer than that of a lamp.
- As a laser is an **electronic device**, it can be very well controlled by electronics. It switches on instantly, and it can be dimmed from maximum to a very small light output (just like an LED). Lamps, on the other hand, cannot be dimmed to almost zero because in order to maintain the chemical process in the lamp, a certain amount of light and heat is required.

When we use a laser as a light source in a projector, the above advantages translate into the following clear benefits:



Simplicity
- With lasers, you never have to change light bulbs – so, the light source no longer requires maintenance
- You can start up your projector more quickly, as the laser light source doesn't need to warm up
- If the cooling allows it, laser illumination enables 360° projector orientation which gives you ease of installation
- There's no mercury involved, so lasers are more environmentally-friendly



Lower Total Cost of Ownership
- No replacement lamps: so, they don't need to be ordered and stored; and no technical personnel are needed to monitor the projector's brightness and install a new lamp periodically
- If the optical system is properly sealed, filters are no longer needed, so the projector's maintenance hours drop significantly



Higher reliability
- Laser projectors have higher redundancy. If a laser diode fails, your image is still guaranteed
- Lasers have a longer lifetime than lamps, and they generate a more constant light output during their lifetime
- Repeatedly starting up or shutting down your projector doesn't impact its lifetime



Better image quality
- Depending on the optical design choices, there's a possibility to have wide color gamut
- No color break-up thanks to a laser's high switching speed

Although there are so many advantages to using lasers as a light source, there are still some disadvantages:

- Lasers have the potential to be cheaper than lamps. However, current production volumes are not big enough to make lasers cheap. As blue lasers are used more often in the industry, for instance in Blu-ray players, and because of the used materials, they are less expensive than red or green lasers.
- Lasers are much smaller than lamps, and so they generate heat in a small area; and although a laser is certainly much more efficient than a lamp, the heat it generates must still be dissipated. Because the heat is generated on such a small area, liquid cooling is the preferred cooling method, while lamps can be more easily cooled directly with fans. Secondly, the temperature needs to be quite low compared to a lamp. That's why the required radiator surface needs to be bigger to get the heat out.

4 Types of solid-state illumination

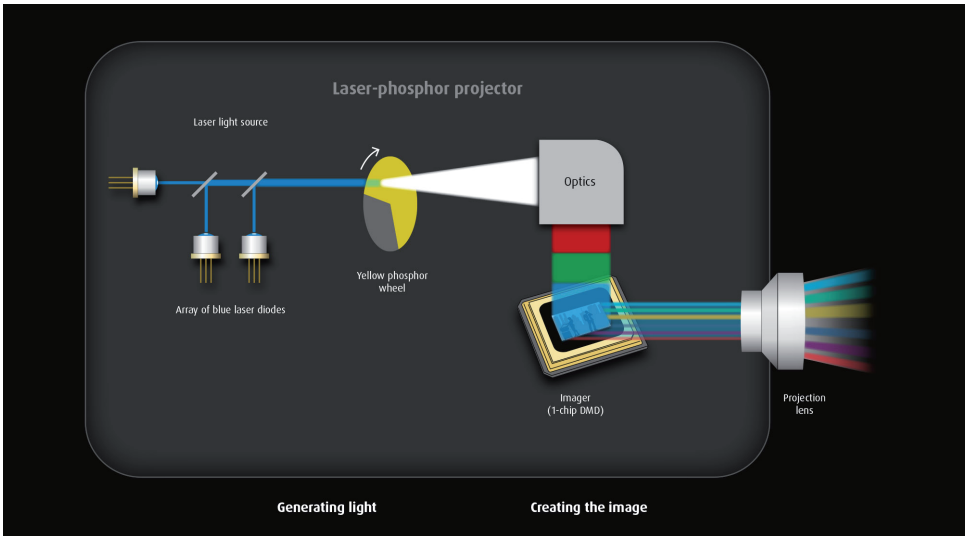
In a **direct laser source**, the red, green and blue primaries are generated by using red, green and blue lasers. Barco uses this method in its Digital Cinema projectors, with a brightness of up to 60,000 lm. As red and green lasers are still very expensive, it makes sense to use these in the high brightness projectors for 3 reasons:

- One 60,000 lm laser projector replaces two stacked 33,000 lm Xenon illuminated projectors, which avoids alignment and stability issues.
- The Xenon lamps that produce 33,000 lm have a lifetime of only 500 hours, so these 6.5 kW - 7 kW lamps are very expensive and they need to be replaced very regularly. For example: in a dual stacked solution that is used +/- 4000 hours a year, 120 lamps need to be replaced over its lifetime.
- By using the red, green and blue discrete laser wavelengths, you can create a 3D image at a high brightness, while some other 3D technologies create a brightness that is only a fraction of the maximum brightness. The technique of 3D is to create the left eye image with certain red, green and blue wavelengths and the right eye image with other red, green and blue wavelengths. This technique is called Six Primary 3D (6p 3D).

In a **laser-phosphor light source**, only the (less expensive) blue lasers are used. The red and green light is generated by illuminating a phosphor surface with blue lasers. The blue light excites the phosphor, which emits a broadband yellow light. This broadband yellow light is captured and is split into red and green light with a color filter. As this method uses only the less expensive blue lasers, the light source can be made more cost-effective, and you see this illumination technology appearing in the lower lumen range. However, as this is a new technology, the price is currently still higher than that of a lamp-based projector, so this method makes economic sense from about 4,000 lm and higher. Below that lumen range, lamp illumination and LED illumination are still the better choice today.

In conclusion, a laser-phosphor projector is a projector that uses only blue lasers and a phosphor wheel to create all colors.

The following illustration shows how a laser-phosphor projector (in this case, a single-chip projector) works:



LED projectors are another type of solid-state illumination device. The Light Emitting Diodes (LEDs) are electronic components, like lasers, but there is no gain medium and there are no mirrors to create a stimulated emission, so you only have spontaneous emission. However, because light is generated in all directions and the area where light is generated is bigger, it's difficult to capture all of the generated light in the optical system. As a consequence, it's not possible to create a higher brightness projector with LEDs. LEDs are used as a light source only in lower brightness projectors (up to a few thousand lumens).

A last type of solid-state illumination is **hybrid illumination**, which is any combination of the technologies discussed above. An example: an LED projector sometimes uses blue lasers with green phosphors (instead of green LEDs) because of the better performance/cost ratio.

5 Lasers and the environment

We've now explained in detail how a laser works. There are two additional laser properties that still need to be discussed. The first is laser coherence – linked to a phenomenon called 'speckle' – and the second is radiance which is related to laser safety.

5.1 Coherence and speckle

Coherence means that all the photons vibrate with the same frequency, in phase and in the same direction. As one of the big advantages of a laser this makes it easy to use a lot of lasers in a projector. However, coherence means that laser light will easily interfere with a screen surface, creating sparkles of brighter and darker spots that are called '**speckle**'. For example, when you look at the spot on the wall created by a laser pointer, it looks grainy. This speckle is something you want to avoid in a projected image.

There are several ways to decrease this effect. The first is to use a multitude of wavelengths, resulting in a **wide spectral bandwidth** – which is possible but more difficult for direct laser technology. With laser phosphor technology, de-speckling becomes really natural because of the wide wavelength distribution or spectral bandwidth that comes from the phosphor. Another way is to use **angular diversity** – where light is mixed in as many directions as possible – to fully fill the light cone that's transmitted through the lens, in the same way as it would be with a lamp.

5.2 Radiance and laser safety



The second important laser property is **high optical radiance** which is a result of generating light from a very small area. The high radiance makes it potentially dangerous to look directly into the beam of a native laser source – just like with a laser pointer or the laser scanned beams used at large laser light shows.

International standards divided laser into four classes – ranging from lasers that cause no harm to the eye or the skin (Class 1), to the lasers that are used for cutting and welding metal (Class 4). More info on laser classification can be found in the IEC 60825-1:2014.

When lasers are combined as a light source for projection, projector manufacturers exert a lot of effort to diffuse the laser light in order to fill the aperture of the projection lens and thus create a lower radiance. So, when the light comes out of the projector, it still has the **native laser wavelengths** – in the case of a laser phosphor projector the spectral bandwidth is "broadened" – but in all other respects the light is the same light that's emitted by a lamp projector, given the same output power. By the way, it's also inadvisable to look into a beam coming from a lamp projector. That's why laser projectors and lamp projectors are now evaluated by the same standard IEC 62471-5:2015. This IEC standard divides projectors into more appropriate Risk Groups instead of laser classes.

For more information, go to:
www.barco.com/en/News/Post/2014/5/27/LIPA-applauds-the-IECs-update-to-international-laser-standards
www.barco.com/en/News/Post/2015/10/12/LIPA-annual-meeting-read-the-chairmans-report

6 UHP-type lamps contain mercury

In the home lighting industry in Europe, there is an EU directive to phase out incandescent light bulbs. This is possible because there is another product available on the market that is a form, fit, function replacement and is commercially viable: LED.

In the projection industry, UHP-type lamps contain mercury to build up pressure inside the lamps. The European Union's RoHS (Restriction of Hazardous Substances) directive 2002/95/EC, adopted in February 2003, restricts the use of certain hazardous substances in electrical and electronic equipment.

Certain substances (including lead and mercury) are banned if a technical and economical replacement solution is available. If such a solution is not available, manufacturers can request an exemption. An exemption needs to be renewed every 5 or 7 years.

The UHP-type lamps category (4(f)) has been exempted until 2018, but a request for renewal is underway. The deadline for the approval of extension applications was January 2015. After that, the European Commission communicated that it would take between 18 - 24 months to decide on these applications.

See the EU communication on this: http://ec.europa.eu/environment/waste/rohs_eee/adaptation_en.htm

In conclusion, the renewal of the exemption for UHP-type lamps has been requested, and we will know by the second half of 2016 if this renewal is accepted or not. Some people are speculating that the renewal will not be accepted, but nobody knows what the decision will be until the decision has been made.

7 The future of solid-state illumination

The decision concerning the RoHS exemption can have a major impact on the projection industry. We are seeing that a lot of manufacturers – including Barco – are investing heavily in laser-based products because of the clear benefits for our customers: more brightness, truer colors, more uniformity, longer lifetime, and greater ease of use and peace of mind.

Lamps are still the dominant light source, but almost all new developments in the professional markets use laser sources, usually laser-phosphor sources. As lamps still have a price advantage at the time of purchase, we see that lamps still have their place in the market for low-cost products, although lamps are under pressure from the LED sources.

Barco expects laser costs to drop significantly in the next few years, and manufacturers will be able to shrink the size of the laser-phosphor projectors to that of today's lamp-based projectors.