Volume 2
Issue 3

Laser Lessons News Letter


Photo: James Pryatel

This issue:

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Introduction

As completion of the second volume of *Laser Lessons Learned* nears, we should review the purpose of this newsletter. It is actually two-fold:

1. Provide an easy to read and digestible style of laser safety information including lessons learned on recent near miss and accident events.
2. Provide a means of laser safety refresher training.

The second is actually a work in progress where the intent is to make HS5200-W *Laser Safety Training* a one-time only course with this newsletter being part of a refresher requirement. In order to accomplish this, the newsletter must cover the core requirements of HS5200-W. These are:

Laser Fundamentals
✓Laser Accidents
✓Bio-effects
✓Non-Beam Hazards
✓Laser Safety Tools
✓Administrative Controls
✓Personal Protective Equipment
✓Fiber Optics
Laser Safety Program
Regulations

As indicated above by the checkmarks, most all topics have been covered in the past two newsletter volumes. We are left with just three more topics to cover in this and the next issue. This issue will review “Laser Fundamentals.”

Don’t miss the important “Lessons Learned” on the last page!!!

Laser Fundamentals

Laser Fundamentals is the most basic of the topics that we have covered, but no less important. **L**ight **A**mplification by the **S**timulated **E**mission of **R**adiation is the foundation of our profession. From a simple laser pointer to the National Ignition Facility, all lasers operate by this same mechanism.

Light

Light is energy in the form of electromagnetic waves. The portion of the spectrum that deals with lasers is considered to be about 100 nanometers (nm) to 1 millimeter (mm).

- Ultraviolet (UV) – 100-400nm
- Visible – 400-700nm
- Infrared (IR) – 700nm-1mm

There are three properties of laser radiation that differentiate it from normal light. Laser radiation is ***monochromatic,*** meaning that it is of a single wavelength or color. Super continuum white light source devices make life difficult for the laser safety world. Operated uncontained, these sources present a significant Laser Protective Eyewear (LPE) problem.

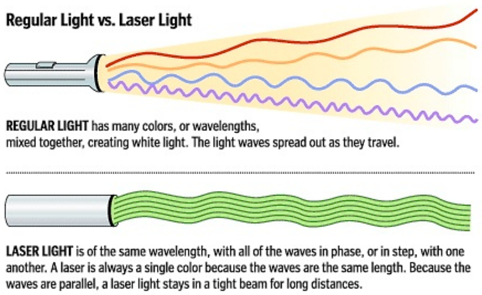
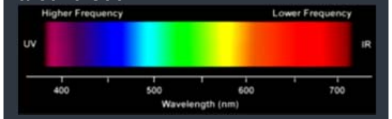


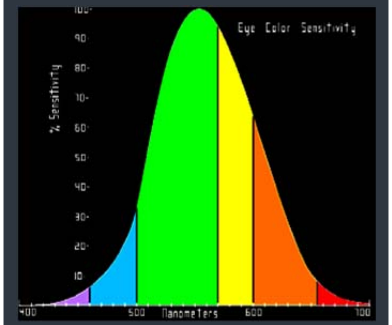
Figure 1: Laser light compared to ordinary light

Perception to Color:

The human eye has the ability to detect only a small portion of the electromagnetic spectrum. For most people, this lies between 400 nm and 700 nm, though some individuals have shown the ability to see out to around 800 nm.



For the purposes of laser safety regulations, the portion of the electromagnetic spectrum that covers lasers is generally accepted to be between 100 nm and 1 mm. This means that there is a very large portion that is invisible to the human eye. Let’s take a look at how the human eye perceives colors:



The highest sensitivity is at about 550 nm where we are able to detect 100% of the green light. Our sensitivity trails off rapidly in a bell curve as we move farther away in each direction.

As you can see, there is a very large portion that is invisible to the human eye. By no means does this imply that these “invisible” lasers are eye safe. Most users would not question the ability of a Class 4 invisible laser to cause eye injury, and therefore do not hesitate in wearing laser eye protection. The hesitation comes when an individual is using “visible” higher powered lasers, especially during alignment operations.

The perception issue arises when we look at lasers of equivalent average power. In the picture below, the green appears to be several times brighter and thus more hazardous than the red. In actuality, they are equal in average power output.

This is a very important point to remember for those working with Ti:Sapphire or other lasers operating near the edge of the visible spectrum. Remember, as with an iceberg, you are only seeing a small percentage of the real hazard. BE SAFE!

The second property of laser radiation is that the wavelengths are in phase in space and time or are ***coherent***. The third property which makes lasers far more dangerous than other types of light is that they are collimated or ***highly directional***. This means that coherent laser radiation is emitted in a relatively narrow beam in a specific direction.

Parts of a Laser

There are three fundamental parts of a laser:

1. An Excitation Mechanism
2. An Active or Lasing Medium
3. An Optical Resonator

The **excitation mechanism** provides the energy that is used to excite the lasing medium and is the source of optical gain. This is the initial source of energy input. Examples of energy sources include flash tubes, lamps, electricity, chemical reactions, or even another laser.

The **active or lasing medium** of a laser is a substance that emits coherent optical radiation as a result of exposure to the excitation mechanism. Lasers are often described by the kind of lasing medium they use. The medium can be a gas, liquid, solid, or semi-conducting material.

The **optical resonator** or optical cavity serves to reflect optical radiation from the lasing medium. It contains 100% reflective and partial reflective mirrors at opposite ends. The photons bounce back and forth between the mirrors, amplifying its energy. At certain intensity, some of the light is not reflected back into the lasing medium and passes through the partially reflecting mirror.

Modes of Operation

A laser may be operated in either a **Continuous Wave (CW)** or a **Pulsed** mode. A pulsed laser emits short discreet packets of photons in fractions of seconds. If the pulse length is ≥ 0.25 seconds, the laser is considered a CW.

A CW laser is usually described as using average power. For a pulsed laser, it becomes more complicated. These lasers are described in terms of energy per pulse, or peak power, and require determination of the pulse length and repetition rate.

In terms of their hazard, average power being equal, a pulsed laser is considered to be far more hazardous than a CW laser, but why is this?

If we take a laser that emits five pulses in one second (5Hz) with a pulse-duration of one μsecond each and an average output of 1 watt, the peak power of each pulse is 2E5 watts. The difference is astronomical when compared to a CW laser that has the same 1 watt average power.

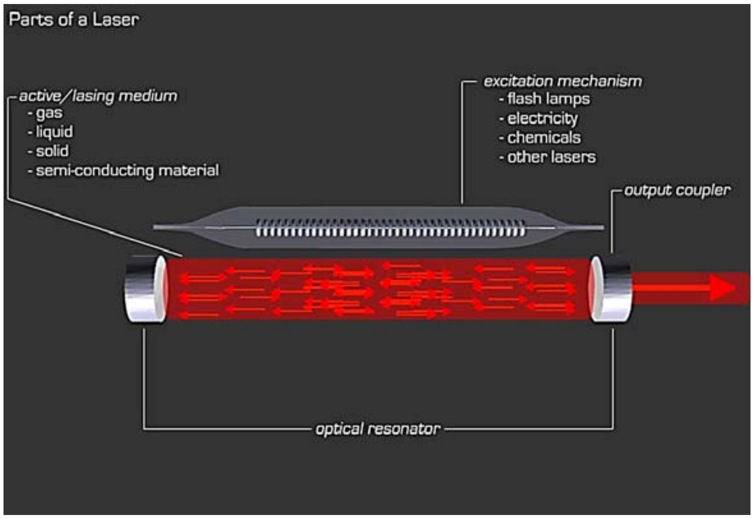
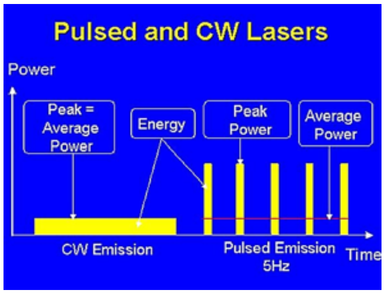


Figure 2. Parts of a Laser



Here you can see that the peak power is much higher during a pulse than the comparable average power.

Irradiance

Irradiance is the incident power per unit area upon a surface. This is expressed in W/cm^2. The beam size is dependent on the size of the aperture, divergence of the beam, and the distance of the surface from the incident beam.

We can look at irradiance in two different perspectives:

- component damage
- biological effect

For component damage, let’s say that we have a 10kW/cm^2 square beam. If we were to expand this beam to 10 cm/side, we reduce the overall incident power seen on the optic to 100W/cm^2. This is vital in protecting expensive optics from damage.

This philosophy can also be used when trying to find a place to “dump” the beam. Expand the beam and commercial options are available. If you don’t, you may be left to engineer your own.

The second perspective on this is in terms of biological effect. For this we answer the question of why laser light is so dangerous. Let’s look at two optical sources, a 100 watt light bulb and a 1mW laser pointer. The light bulb (extended source) will project an image on the retina of approximately 200μm where the laser (point source) projects an image on the retina of only about 20μm.

Other variables come into play, such as the properties of light described previously. However, looking at just spot size on the retina and irradiance, we find that the light bulb puts about 100µwatts/cm2 onto the retina where the 1mW laser puts 150 W/cm2. This is a difference of over 100 million!

Remember that the diameter of a cone is about 5µm. This is one of the reasons why a laser, or a collimated-coherent light source, is so much more dangerous than an incoherent source. The sole mechanism the retina has for protection from the massive thermal load imparted upon it is blood flow. With such a high irradiance directed to such a small spot on the retina, the rods and cones are helpless.

Reflectivity

Reflectivity plays an important part in relation to the hazard level of the laser beam. This is especially true when the Nominal Ocular Hazard Zone (NOHZ) for the primary beam in a lab space is considered to be the entire room. The type of reflection is dependent on the imparted surface material along with the wavelength of the incident beam. There are two types of reflections, specular and diffuse.

Specular

A specular reflection occurs when an incident beam strikes a mirror-like surface. We tend to think of specular surface as flat and shiny. However, there are many specular surfaces in a lab space that are not flat and do not appear to be shiny. Examples of these are machine screws, optic carrier posts, and even certain types of laser eyewear. For certain wavelengths in the infrared, even anodized aluminum can be a very reflective surface.

Depending on the type of specular surface, most of the incident beam's energy may be transferred in the reflected beam. This can be a serious problem in a lab.

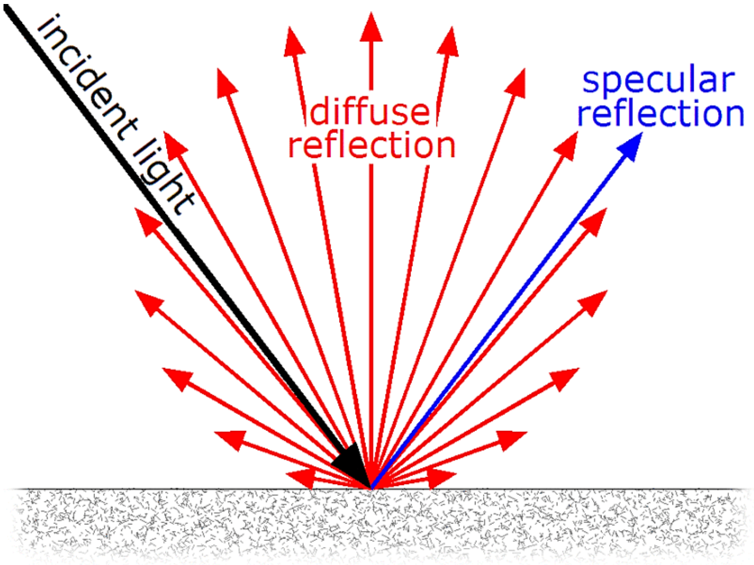


Figure 3. Specular vs. Diffuse Reflection

Diffuse

A diffuse reflection results from an incident beam striking an uneven surface. Its reflected beams are scattered into different directions independent of the angle of the incident beam.

When possible, diffuse surfaces should be used to keep the NOHZ as small as possible.

Reminder: Where Class 3B lasers do not pose a diffuse reflection hazard, Class 4 lasers can have a NOHZ several meters or more from a diffuse surface.

Non-Classical

In terms of classical vs. non-classical lasers, there are a couple of important items to cover. We have already discussed the importance of irradiance and expanded beams. Increasing the beam size not only reduces the load on optics, but also reduces the Optical Density (OD) required in your LPE.

Two other important items are Diode Arrays and Non-Linear Optics.

Diode Arrays

Diode or semiconductor lasers are becoming prevalent and are used in many applications. A single bare laser diode is a highly divergent coherent source usually emitting in the near IR. They may be combined (10-50) side-by-side to create a *bar*. These can then be placed upon one another to create *stacks* or *arrays*.

Because of their high-divergence and size (extended source), many think of them as non-hazardous after a very short distance. Remember that arrays are capable of emitting tens of kilowatts and may also be lensed, collimating their output beam. Don't take them "lightly."

Non-Linear Optics

Non-Linear optics enable the harmonic generation of light waves at integral multiples of the frequency of the original wave. It is not uncommon to see second, third, and even fourth harmonics in use in many laboratories.

These types of applications produce a potential hazard of their own. All optical radiation is not fully converted, but is carried along with the generated harmonic. It is paramount that you capture the unneeded and unnecessary wavelengths or account for them in your hazard analysis and subsequent choice of LPE.

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Lesson Learned

A near miss occurred recently in one of our laser labs where a worker witnessed laser diode array pump light between the bridge of their nose and the laser protective eyewear they were wearing. This is troubling in that the worker performed all actions they believed necessary to remain safe in this lab space. We experienced a failure in our last line of defense, LPE. There was actually a failure on a couple of levels. All scattered light should be blocked such that it cannot escape from the table. In the R&D world in which we live, this is sometimes difficult if not impossible to do. Some operations may change configuration several times in a single day. With this, we must place a large amount of faith in our LPE. As with any PPE worn, it must be both appropriate for the hazard and fit properly. Here are a few reminders to follow prior to donning LPE:


Figure 4. Laser eyewear showing path to eye

1. Verify that the LPE provides adequate protection for all wavelengths present in the lab (check Work Control documents and filter specs). If a wavelength is not listed, or is in question, contact the LSO.
2. Check the overall integrity of the eyewear. This includes not only deep scratches and gouges in the filter media, but also the frame. Are there any cracks in the frame that may jeopardize the integrity? Are the lenses secure and in place? Most of our LPE is warranted against breakage from normal use. If a defective pair is found, take them out of service and contact the LSO.
3. Place the eyewear on your face and do a quick fit check. Many of the styles of LPE we use have adjustable frames (nose piece, temple, ear, etc.). Adjust the eyewear to the best fit possible. You should not be able to directly see the world outside of the filter. No spectacle style will provide a 100% seal. Dependent on your facial structure, you may find gaps at different points around your face and the LPE. Viewing indirect ambient light around the frame is ok. The point is that you should never be able to directly look and see an unfiltered world.

The above pointers are vital when using community LPE where the eyewear has not been specifically purchased for you. If you have any questions, please contact the LSO or your DLSO for clarification. If you are purchasing new LPE, you are encouraged to visit the LSO's office where you can try on nearly any type of frame available to see what provides YOU the best fit. Before proceeding into a laser lab with ill-fitting LPE ask yourself this, "Would I enter into a dangerous atmosphere with a respirator that doesn't fit properly?" Don't look at PPE as a regulatory requirement to ensure a check box is marked, but rather a vital component to ensure your last line of defense is in check!
BE SAFE!

9th Annual DOE Laser Safety Officer Workshop

The DOE held its 9th Annual Laser Safety Officer Workshop at the National Institute of Standards and Technology (NIST) in Boulder, CO September 10-12th. This gathering has become the preeminent source of "practical laser safety" and draws attendees from government, academia, and industry. The idea for this workshop was conceived at LLNL with the first being held here in 2005. At that time attendance was barely 70. This past event drew over 150 even with sequestration and bad economic conditions throughout the industry.

We have been fortunate to have been selected as host for the 10th Annual Workshop in 2014. This workshop has matured to represent the best of the best in both attendance and quality of material presented. Stay tuned for additional workshop information in the coming months.