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Guide to Laser Safety

WE PROTECT YOUR EYES

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Contents

WE PROTECT YOUR EYES

1. Laser

1.1 Electromagnetic Radiation

Laser radiation, like all light, consists of electromagnetic radiation. Electromagnetic radiation travels in waves like sound and is produced by the movement of charged particles. In contrast to sound, electromagnetic radiation does not need a medium in which to travel. Some examples of electromagnetic radiation are the radiation in the form of warmth, x-rays and γλ-rays that emerge from radioactive decomposition and radiation artificially generated by radio transmitters. In fact, electromagnetic radiation is found as a natural phenomenon in almost all areas of daily life.

When the electromagnetic radiation is within the range visible to the human eye, between 380 and 780 nm (nm = nanometer = one billionth of a meter), it is called light. This range is called the visible spectrum. When all wavelengths in the visible spectrum are emitted simultaneously, it is perceived as white light.

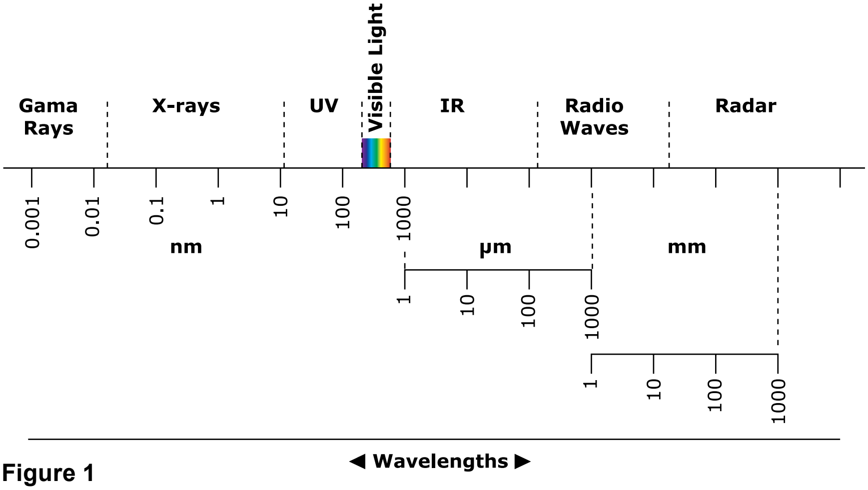

Figure 1

When white light falls on an optically dispersive element such as a prism or birefringent filter you can see the visible spectrum due to refraction. It starts at the short wave as the color violet, turning to blue, green, then yellow and goes to the long wave, which appears as red. Beyond the long wave (red) of the spectrum is the near and far infrared range. Below the shortwave range (blue) is the ultraviolet range.

Lasers are sometimes thought to emit radiation only in the visible portion of the electromagnetic spectrum; however, this is not exclusively true. The term 'light' refers to a specific range of the electromagnetic spectrum between 150 nm up to 11000 nm, i.e. from UV-'light' up to far infrared 'light.'

1.2 Why Laser Safety

Why must we be protected from laser radiation?

The ‘light’ from powerful lasers can be concentrated to power densities (power per area or watts/cm^2) that are high enough to evaporate tissue, metal or ceramics. Because our eyes are much more sensitive to light they are at increased risk. In fact, it is possible to cause irreversible ocular injury with just one glance into a direct or reflected laser beam even at lower power output levels.

What makes lasers dangerous compared to conventional light sources?

The main danger from hazardous exposure to laser light is due to their ‘spatial coherence’. That refers to the fact that the wave trains of the laser beam have:

- a fixed relation to time and space (coherent)
- are all of the same wavelength (monochromatic)
- can travel over great distances as a nearly parallel beam (collimated)

All of this means that the power that impacts an area, such as the eye, is independent of the distance to the radiation source.

Imagine a laser pointer with a beam spot that remains about the same size over great distances. If you compare a thermal source of radiation like a light bulb, with a laser you will observe several differences. The light bulb emits light over a very broad spectrum of wavelengths with no specific direction of dispersion. A physicist would say that the bulb produces incoherent light.

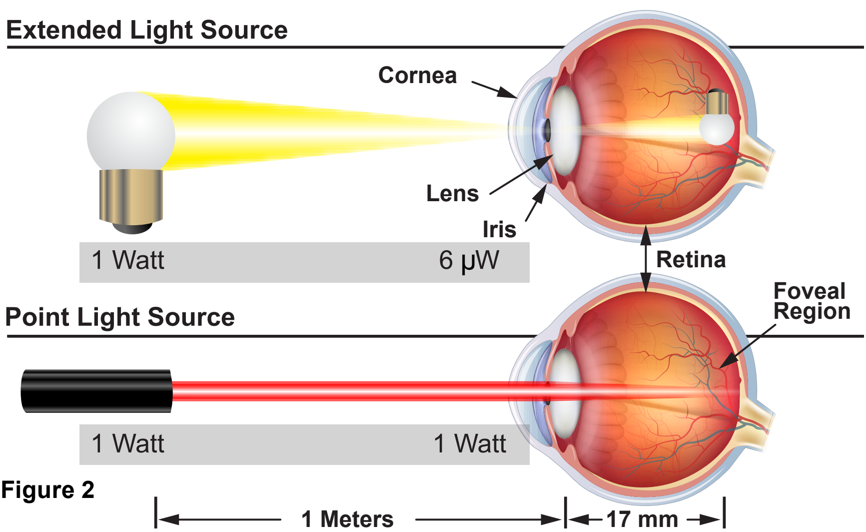

Figure 2

When comparing a light bulb with a laser, both emitting 1 W optical power, the power of the bulb that may reach the eye decreases with distance because the bulb radiates in all directions.

If there is a 1 meter distance between our eyes and the light source, then the quantity of light coming from the laser would increase by a factor of 100,000 compared to the light quantity from the bulb (this assumes a normally dilated pupil diameter of 7 mm – i.e. eyes adapted to darkness).

The quantity of light that can hit the eye is not the only danger. While the bulb creates an image on the retina of approximately 100μm, the laser light, which can be much more easily focused, is reduced to a spot of just a few micrometers (~ 10 μm) in diameter.

Therefore, the light quantity that hits the eye is concentrated on a much smaller spot. The power density (power per area or watts/cm^2) resulting from this concentration may be sufficiently high that any tissue in the focus will be heated up and very quickly destroyed.

Since the fovea (responsible for sharp central vision and located on the retina) also has a size of just a few micrometers, it is possible to lose one’s eyesight by one single laser pulse.

2. Laser Safety Regulations

2.1 Laser Categories According to ANSI Z136.1 and EN 60825-1

Lasers have been categorized into four hazard classes based on accessible emission limits or AELs. These limits indicate the class of the laser and are listed in the American National Standards ANSI Z136.1 for Safe Use of Lasers and European standard IEC 60825-1.

Class	Concept	Comment
1	The radiation emitted by this laser is not dangerous.	No need for protection equipment.
1M	Eye safe (visible, 0.4 to 0.7µ) when used without optical instruments, may not be safe when optical instruments are used.	No need for protection equipment, if used without optical instruments.
2	Eye safe (visible, 0.4 to 0.7µ) by the aversion response including the blink reflex.	No need for protection equipment.
2M	The light that can hit the eye has the values of a class 2 laser, depending on a divergent or widened beam, it may not be safe when optical instruments are used.	Dangerous to the eyes, safety glasses are recommended.
3R	The radiation from this laser exceeds the MPE values (MPE: maximum permissible exposure). The radiation is max. 5 x AELs of class 1 (invisible) or 5 x of class 2 (visible). The risk is slightly lower than that of class 3B.	Dangerous to the eyes, safety glasses are recommended.
3B	Old class 3B without 3R. The view into the laser is dangerous. Diffuse reflections are not regarded as dangerous.	Dangerous to the eyes, safety glasses are obligatory.
4	Old class 4, even scattered radiation can be dangerous, also danger of fire and danger to the skin.	Personal safety equipment is necessary (glasses, screens).

Figure 3

2.2 Laser Operating Modes

Working Mode		Typical pulse length
Continuous wave D (cw)*	…is the continuous emission of laser radiation.	> 0.25 s
Pulsed mode I	…is the short-term single or periodically repeated emission of the laser radiation.	> 1 μs to 0.25 s
Giant pulsed mode R	… is like pulsed mode, but the pulse length is very short.	1 μs to 1 ns
Modelocked M	… is the emission of laser radiation with all the energy stored in the laser medium released within the shortest possible time.	< 1ns

Figure 4
Lasers can operate in one or more of the above modes. *cw: continuous wave.

2.3 Laser Safety Worldwide

The World of Laser Safety in the USA (ANSI Z136)

ANSI Z136 standard requires specification according to optical densities (OD) only. ANSI also allows a Nominal Hazard Zone (NHZ) to be determined by the laser safety officer (LSO). Outside of the NHZ, diffuse viewing eyewear is allowed. Most Asian countries refer to these ANSI regulations. Australia has adopted new laser safety regulations that are based on the European laser safety regulations (EN 207/EN208).

The World of Laser Safety in Europe (EN207/208/60825)

In Europe there is a second criteria to be taken into consideration -- the power/energy density (i.e. the power/energy per area = per beam area). ‘Diffuse viewing’ condition is not allowed and laser safety glasses must protect against a direct laser exposure. Protection due to Optical Density alone is not sufficient when the material of the eyewear cannot withstand a direct hit. The following regulations are called the ‘norm,’ but in fact they are legal requirements and enforceable. Other legal requirements (e.g. the regulations for industrial safety as well as the medical equipment regulations) refer to them as well.

EN207 - See figures 5 and 6

Laser eye protection products require direct hit testing and labeling of eye protectors with protection levels, such as D 10600 L5 (where L5 reflects a power density of 100 MegaWatt/m^2 as the damage threshold of the filter and frame during a 10 seconds direct hit test at 10,600nm). Filter and frame must both fulfill the same requirements. It is not acceptable to select glasses according to Optical Density alone. The safety glasses must be able to withstand a direct hit from the laser for which they have been selected for at least 10 seconds (CW) or 100 pulses (pulsed mode).

Testing conditions for laser type	Typical laser type	Pulse length (s)	Number of pulses
D	Continuous wave laser	10	1
I	Pulsed laser	10^{-4} to 10^{-1}	100
R	Q Switch pulsed	10^{-9} to 10^{-7}	100
M	Mode-coupled pulse laser	$>10^{-9}$	100

Figure 6

EN 208 - See figures 7

This norm refers to glasses for laser alignment. They will reduce the actual incident power to the power of a class II laser (< 1 mW for continuous wave lasers). Lasers denoted as class II are regarded as eye safe if the blink reflex is working normally. Alignment glasses allow the user to see the beam spot while aligning the laser.

This is only possible for visible lasers according to this norm ‘visible lasers’ are defined as being from 400 nm to 700 nm. Alignment glasses must also withstand a direct hit from the laser for which they have been selected, for at least 10 seconds (CW) or 100 pulses (pulsed mode).

Scale Number Acc. to EN 208	CW lasers and pulsed lasers with pulse length of $>2x10^{-4}$	Pulsed lasers with a pulse length $>10^{-9}$ - 10^{-4} s max. pulse energy in J
R1	0.01 W	$2 \cdot 10^{-6}$
R2	0.1 W	$2 \cdot 10^{-5}$
R3	1 W	$2 \cdot 10^{-4}$ Reference: EN 208
R4	10 W	$2 \cdot 10^{-3}$
R5	100 W	$2 \cdot 10^{-2}$

Figure 7

EN 60825

Requires that laser safety eyewear provide sufficient optical density to reduce the power of a given laser to equal to or less than the listed Maximum Permissible Exposure levels (MPE). It allows specification according to optical densities in extreme situations, but recommends the use of EN 207 with a third party laser test. In neither standard is a nominal hazard zone allowed; the only consideration is protection against the worst-case situation such as direct laser radiation.

Figure 5

Scale number	Maximum spectral transmittance for laser wavelength $\tau(\lambda)$	Power and energy density (E, H) for testing the protective effect and stability to laser radiation in the wavelength range								
		180 nm to 315 nm			>315 nm to 1400 nm			>1400 nm to 1000 nm		
		For test condition								
		D $>3\cdot10^{4}$	I, R 10^{9} to $3\cdot10^{4}$	M $<10^{-9}$	D $>5\cdot10^{-4}$	I, R 10^{9} to $5\cdot10^{-4}$	M $<10^{-9}$	D $>0,1$	I, R 10^{9} to 0,1	M $<10^{-9}$
		E_D W/m²	$H_{I,R}$ J/m²	E_M W/m²	E_D W/m²	$H_{I,R}$ J/m²	H_m J/m²	E_D W/m²	$H_{I,R}$ J/m²	E_M W/m²
L1	10^{-1}	0,01	$3\cdot10^{2}$	$3\cdot10^{11}$	10^{2}	0,05	$1,5\cdot10^{-3}$	10^{4}	10^{3}	10^{12}
L2	10^{-2}	0,1	$3\cdot10^{3}$	$3\cdot10^{12}$	10^{3}	0,5	$1,5\cdot10^{-2}$	10^{5}	10^{4}	10^{13}
L3	10^{-3}	1	$3\cdot10^{4}$	$3\cdot10^{13}$	10^{4}	5	0,15	10^{6}	10^{5}	10^{14}
L4	10^{-4}	10	$3\cdot10^{5}$	$3\cdot10^{14}$	10^{5}	50	1,5	10^{7}	10^{6}	10^{15}
L5	10^{-5}	100	$3\cdot10^{6}$	$3\cdot10^{15}$	10^{6}	$5\cdot10^{2}$	15	10^{8}	10^{7}	10^{16}
L6	10^{-6}	10^{3}	$3\cdot10^{7}$	$3\cdot10^{16}$	10^{7}	$5\cdot10^{3}$	$1,5\cdot10^{2}$	10^{9}	10^{8}	10^{16}
L7	10^{-7}	10^{4}	$3\cdot10^{8}$	$3\cdot10^{17}$	10^{8}	$5\cdot10^{4}$	$1,5\cdot10^{3}$	10^{10}	10^{9}	10^{18}
L8	10^{-8}	10^{5}	$3\cdot10^{9}$	$3\cdot10^{18}$	10^{9}	$5\cdot10^{5}$	$1,5\cdot10^{4}$	10^{11}	10^{10}	10^{19}
L9	10^{-9}	10^{6}	$3\cdot10^{10}$	$3\cdot10^{19}$	10^{10}	$5\cdot10^{6}$	$1,5\cdot10^{5}$	10^{12}	10^{11}	10^{20}
L10	10^{-10}	10^{7}	$3\cdot10^{11}$	$3\cdot10^{20}$	10^{11}	$5\cdot10^{7}$	$1,5\cdot10^{6}$	10^{13}	10^{12}	10^{21}

3. Laser Protection

3.1 How do Laser Wavelengths Influence our Eyes?

Why is laser radiation so dangerous compared to conventional light sources?

The risk of losing your eyesight from accidental exposure to laser radiation is due to the special optical properties of the human eye. When we look at the different depths of penetration in relation to the wavelengths, we see that the eye is transparent only in the wavelength range between 370 and 1400 nm.

UV-light below 350 nm advances to the lens or is absorbed at the surface of the eye. A consequence of exposure to high power light at these wavelengths is an injury to the cornea by ablation or a cataract.

Light in the visible wavelength region (380 - 780 nm) advances to the retina. The eye is sensitive to radiation and humans have developed natural protective mechanisms.

When the light appears too bright, which means the power density exceeds a damage threshold of the eye we automatically turn away and close our eyes (i.e. aversion response or blink reflex). This automatic reaction is effective for radiation up to 1 mW power. With higher power levels, too much energy reaches the eye before the blink reflex can respond, which can result in irreversible damage.

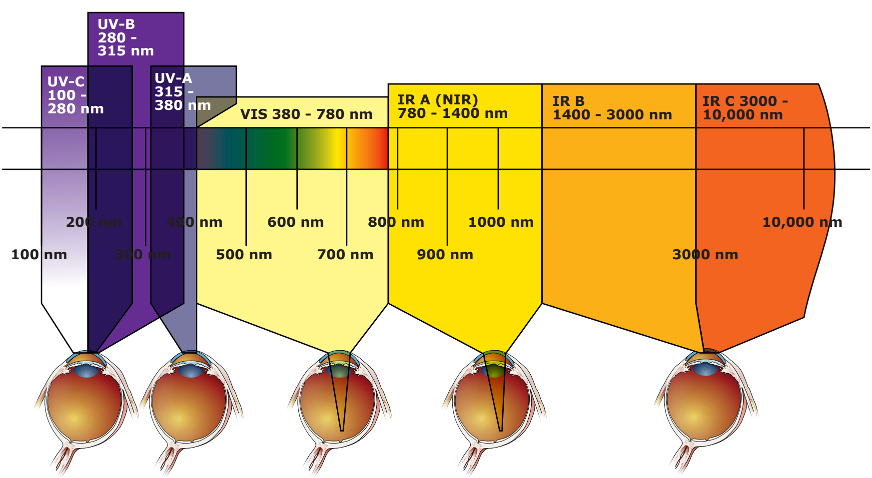

Figure 8
The above table shows the depth of penetration of electromagnetic radiation in the human eye.

The near infrared wavelengths (780 – 1400 nm) are a type of radiation that is especially dangerous to the human eye because we have no natural protection against it. The radiation advances to the retina, but the exposure is only noticed after the damage is done.

Infrared radiation (1400 – 11000 nm) is absorbed at the surface of the eye. It leads to overheating of tissue and burning, or ablation of the cornea.

3.2 Daylight Transmission (VLT) and Color Vision

When we wear laser safety glasses some wavelengths of the spectrum that would normally reach our eyes are filtered out. If we block light from the visible region, this inevitably changes our perception of our environment. First, by attenuation of the transmission the environment gets darker (similar to the effect of sun glasses). Second, blocking some wavelengths changes our perception of color.

VLT

The attenuation of light by a filter in the visible spectrum is defined by the so-called VLT (visible light transmission) the daylight transmission or the luminous transmittance. The VLT is determined in relation to a standard illuminant and evaluated according to the spectral sensitivity of the eye to daylight.

Should measured VLT-value be less than 20%, the user should ensure that their working environment receives additional illumination. With a low VLT and bad illumination one can expect our eyes to adapt to so-called night vision. In doing so the color vision is restricted and the spectral sensitivity of the eyes moves towards the shorter wavelengths. For these kinds of filters it is also useful to provide the VLT-value for night vision.

Color Vision

Since our eyes can adapt to different light situations and the total amount of light can be balanced by additional illumination, another important aspect for the selection of a laser safety filter is color vision. If color vision is impaired or restricted, some colors may not be recognized. This effect may also apply to warning lights or displays, or the ability to distinguish between instruments or vessels marked by color such as those found in medical surroundings.

4. Laser Safety Filter

4.1 Filter Technologies

Due to the unique characteristics of laser radiation (i.e. coherent, collimated and monochromatic) there is increased danger to the eyes. Therefore, special optical filters that transmit ‘normal’ light but block laser light should be used.

Since laser light has a specific wavelength dependent on the laser active medium that emits light, protectivefilters that match the wavelength and power of the specific source of laser radiation are needed.

Optical Density (OD)

Optical Density (OD or $D\lambda$) is the attenuation of light that passes through an optical filter. The higher the OD value the higher the attenuation. The mathematic expression of Optical Density ($D\lambda$) is the logarithm to the base ten of the reciprocal of the transmittance and is given by the following equation:

$$D_\lambda = -\log_{10} T_\lambda$$

Where τ_λ is the transmittance

In other words, the Optical Density is a measure that indicates how many decimal places the transmission shifts at the required wavelength.

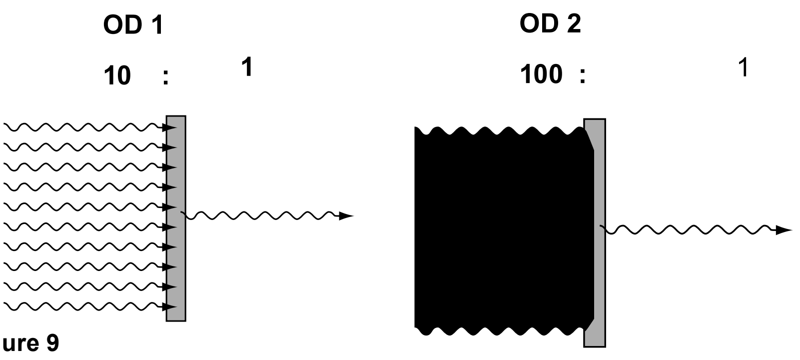

Figure 9

OD (Optical Density)	Transmission in %	Attenuation Factor
0	100%	1:1
1	10%	1:10
2	1%	1:100
3	0.1%	1:1,000
• • •	• • •	• • •
10	0.00000001%	1:10,000,000,000

Figure 10

Laser Protective Eyewear

Laser Safety Officers (LSOs) should consider the actual working environment, viewing conditions and beam delivery systems when determining the most appropriate protective equipment needed to reduce potentially hazardous exposures to laser light. Laser safety eye protection options include spectacles, goggles, eye safety filters, full face shields, etc. Regardless of the specific type of eye protection system required to minimize potential exposures to levels below applicable MPEs the following types of light attenuation materials are generally used in their construction:

- Absorptive
- Laminates
- Reflective
- Hybrid

Absorptive materials used in the construction of safety eyewear products are made with either polycarbonate or absorbing glass filters, where light transmittance at a given wavelength is a function of material thickness. This may be calculated in terms of OD by:

$OD = -\log_{10} P_d \cdot I_T(\lambda)\ (D_2/D_1)$

Where:

P_d = Reflection factor

$I_,(\lambda)$ = Transmittance at thickness D_1

D_2 = Desired material thickness (mm)

D_1 = Thickness of material for known internal transmittance (mm)

Figure 11
Examples of laser protective eyewear

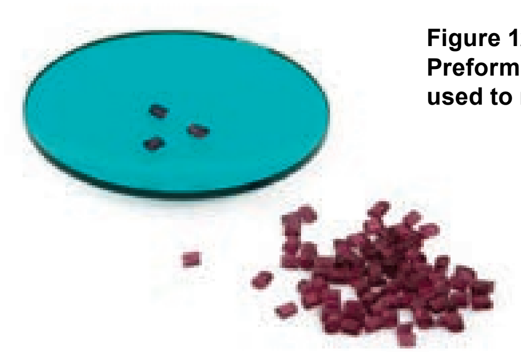

Figure 12
Preformulated polycarbonate pellets used to make filter lens blanks

Filter - Polycarbonate

Polycarbonate absorbing filters are manufactured with either clear base polycarbonate materials mixed with organic dyes or from preformulated pellets where the dyes are already added. The material is then formed into eyewear 'blanks' through a thermal injection molding process. After the lens blanks are molded a special UV-cured coating is applied to both front and back surfaces to add a scratch protective layer. Anyone who has worn polycarbonate laser safety eyewear may have observed the diffraction patterns on their eyewear as a result of this process. Loss of this protective layer due to improper cleaning or storage can result in poor visibility due to scratches and may require immediate replacement. Polycarbonate protective eyewear provides an excellent low cost, light weight safety solution, but may have slightly lower OD's and visible light transmission (VLT) values.

Verifying the light attenuation properties (OD values) of the lens filter blanks is performed by the use of an analytical instrument called a spectrometer. By this process a spectral scan is completed over an entire range of wavelengths from which optical density data is generated. Lens blanks are then cut into proper shapes and their edges beveled for insertion into laser spectacle frames or goggles. Finished eyewear meets all mechanical performance safety requirements referenced in the regulatory standards. In addition, optical density values are permanently inscribed on all laser protective eyewear.

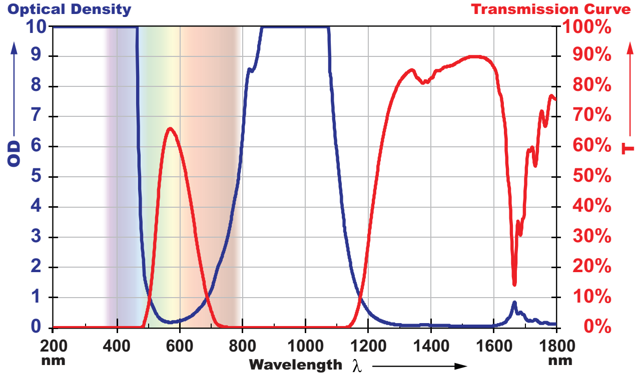

Figure 14
Filter glass after being 'slumped', shaped, polished and beveled.

Filter - Glass

Absorbing glass filters are purchased from glass manufacturers in large uncut and unpolished sheets based on their published technical performance specifications (i.e., transmittance, refractive index, reflection factors, etc.). Smaller filter glass squares are cut from these larger sheets and stacked on clay concave forms in a kiln for up to 24 hours where they are 'slumped' into an approximate base curvature. Once removed from the kiln they are polished to exact thickness, cut to required shape and the edges beveled to ensure a proper fit with various frame and goggle styles.

Optical density information is calculated as a function of filter thickness and compared to actual scans recorded from NIST traceable spectrometers. This type of protective optical filter should be periodically examined for gaps between the filter and frame or other signs of damage and returned for repair or discarded if there is evidence of cracks or breakage.

By capitalizing on the desirable absorptive characteristics of various absorbing glass filter material, laser protective eyewear manufacturers can bond or laminate two (or more) polished lenses together using special UV-cured optical adhesives. Lamination technology can extend the spectral protection range of a single type of protective eyewear to cover a broader range of wavelengths. In situations where additional durability and/or robustness of eyewear are required, a thin (~1mm) piece of glass can also be laminated to the absorptive glass filter material.

Absorbing glass filters are generally available with higher optical densities, better VLT values and the option of prescription lenses but at a slightly higher cost per pair when compared to polycarbonate safety eyewear. LSOs should periodically examine these types of protective glass filters for gaps between the filter and frame, delamination or other visible signs of damage and returned for repair or discarded if there is evidence of cracks or breakage. Delamination can result from extreme temperatures, improper cleaning or the physical stress of mishandling.

Figure 15
Reflective (thin-film) and laminate laser protective filters.

Filter - Reflective / Thin Film / Laminate

Reflective or thin-film coating of protective laser eyewear is achieved by the same process as that used in producing various high-reflective (HR) or anti-reflective (AR) laser optics. This is done by applying physical vapor deposition (PVD) technology of dielectric materials upon suitable substrates. Precise (¼ wavelength thickness) vapor deposition of alternate HI-LO index of refraction dielectric coatings is applied directly to absorptive polycarbonate or glass filter materials. This provides laser protection by reflective as well as absorptive properties. Thin-film protective laser eyewear is lightweight and has excellent VLT values. Visual examination of this type of protective filter should reveal evidence of ‘lifting’ or flaking of thin-film dielectric coating resulting from improper handling, cleaning or storage.

Hybrid protective materials describe various combinations of absorptive, laminates, reflective and thin-film properties that accurately and predictably attenuate hazardous levels of laser light.

Regardless of the type of protective filters used in laser safety eyewear the LSO should routinely examine them for integrity, proper labeling and storage.

Frequently Asked Questions

How long will my glasses protect me?

There is no simple answer to this question. Some glasses are worn-out after only one year, while others look like new after four years. This depends on several factors such as careful treatment, proper care, and environmental factors. A pair of glasses that are treated with care, cleaned according to instructions and used in a laboratory setting will certainly outlast a pair of glasses that are treated carelessly and perhaps even worn by several different people in a rough production environment. Glasses that show any damage whatsoever (e.g. a damaged or scratched filter, color changes in the filter, damaged metal enforcement on the inside of the frames) should not be used. If you are in doubt, please contact our technical support for a safety inspection of your glasses.

Can you repair laser safety glasses?

Yes, of course. We repair frames and replace damaged filters. Simply contact one of our customer representatives and secure a return authorization for all product service and repairs.

Can I look right into the laser beam with my laser safety glasses?

Laser safety glasses are designed to protect your eyes against an accidental direct hit of the laser beam. They are not designed for long-term or intrabeam laser viewing conditions.

You have quoted red filters. Can I have the glasses with a different color?

The color of absorption filters cannot be chosen at random, but depends on the wavelength the filters protect against. To protect against wavelengths in the UV-region or the lower visible (blue radiation), the yellow or orange filter is usually recommended. A red filter is usually used to protect against wavelengths in the green region. Please take into consideration that you may not select glasses by the color only. Always make sure that the quoted or available pair of glasses matches the requirements of your laser.

I have a pair of glasses (e.g. for a Nd:YAG Laser).
Can I use them for my new laser as well?

Before this question can be answered you must determine the specific requirements of your new laser (wavelength, operational parameters, viewing conditions, etc). When these parameters are known, verify that the marking on your existing pair of glasses matches these requirements. If you are not sure, please call us. We will carry out the calculation and check for you. Please note: The thoughtless use of a pair of laser safety glasses for a different application (different wavelength or different power/energy than calculated before) may cause the loss of your eyesight.

Why is there no pair of glasses covering all my lasers?

The radiation that is visible to humans lies between 380–780 nm (the exact limits are different in each person). In order to cover all lasers you would need a material that does not transmit any radiation for visible radiation, which means it is completely black. When you block all visible radiation, the only wavelengths left are invisible to the human eye. If you have several lasers in this area, then it is necessary to use several pairs of glasses. But even if you do not want to completely block all wavelengths or have ’just a few wavelengths‘ to cover, the glasses may be too dark. Usually the protection within a material slowly increases until it reaches the required protection level at a given wavelength. This means that it not only covers the required wavelength, but also areas below and above it (with lower Optical Density). Therefore, if you want to cover several wavelengths in the visible spectrum the Optical Density curves will overlap, resulting in dark filters or glasses.

Do you have laser safety glasses with “Class 4”?

The term ’class 4’ is the laser classification according to ANSI Z136.1 and EN 60825-1. Class 4 designation means that this is a dangerous laser and is an eye, skin and fire hazard. When you work with this laser, laser protective eyewear is mandatory. This classification, however, does not include any information regarding the wavelengths or the required protection levels that the glasses must protect against.

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