7

Safety

Laser material processing is hazardous if all the safety guidelines are not followed. Safety in working with high-power lasers should be paramount because of the serious damage they could impose. In the following, the safety issues related to the laser material processing are discussed*.

7.1 Laser Classification

All lasers are classified by the manufacturer and labelled with the appropriate warning labels. Any modification of an existing laser or an unclassified laser must be classified by a laser safety officer prior to use. The following criteria are used to classify lasers:

1. **Wavelength.** If the laser is designed to emit multiple wavelengths the classification is based on the most hazardous wavelength.

2. For continuous wave (CW) or repetitively pulsed lasers, the **average power** output [W] and **limiting exposure time** inherent in the design are considered.

3. For pulsed lasers, the **total energy per pulse** [J], **pulse duration**, **pulse repetition frequency** and **emergent beam radiant exposure** are considered.

Class 1 Lasers

These are lasers that are not hazardous for continuous viewing or are designed in such a way that prevent human access to laser radiation. These consist of low power lasers or higher power embedded lasers (i.e., laser printers).

Class 2 Visible Lasers (400 to 700 nm)

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Lasers emitting visible light that because of normal human aversion responses, do not normally present a hazard but would if viewed directly for extended periods of time (i.e., many conventional light sources).

Class 3A

Lasers that normally would not cause injury to the eye if viewed momentarily but would present a hazard if viewed using collecting optics (fiber optics loupe or telescope).

Class 3B

Lasers that present an eye and skin hazard if viewed directly. This includes both intrabeam viewing and specular reflections. Class 3B lasers do not produce a hazardous diffuse reflection except when viewed at close proximity.

Class 4 Lasers

Lasers that present an eye hazard from direct and specular reflections. In addition, such lasers may be fire hazards and produce skin burns.

In this class, CO_2 beams are much safer. The wavelength of a CO_2 beam is 10.6 μm, a wavelength that is strongly absorbed by water. Since more than 70% of the human body consists of water, an unfocused or reflected CO_2beam does not penetrate beyond the first few layers of skin. More importantly, this wavelength does not penetrate the eye if a scattered beam is observed. Processing can usually be directly observed with minimal precautions. Laser-safety eye wear is normally sufficient to meet the guidelines.

YAG beams have a 1.06 μm wavelength – just below the visible deep-red. This wavelength deeply penetrates the body. If you get hit by a YAG beam, there is more damage than just a surface burn. Worse, the 1.06 μm wavelength is focused by the eye just like "normal" light. A beam scattered from a process will be focused to a point in the eye, probably destroying the spot where it was focused. As such, all YAG workstations must be sealed off and light-tight during processing.

7.2 Laser Hazards

7.2.1 Eye Hazards

The potential for injury to the different structures of the eye (Figure 7.1) depends upon which structure absorbs the energy. Laser radiation may damage the cornea, lens or retina depending on the wavelength, intensity of the radiation and the absorption characteristics of different eye tissues.

Ocular Image

Wavelengths between 400 nm and 1400 nm are transmitted through the curved cornea and lens and focused on the retina. Intrabeam viewing of a

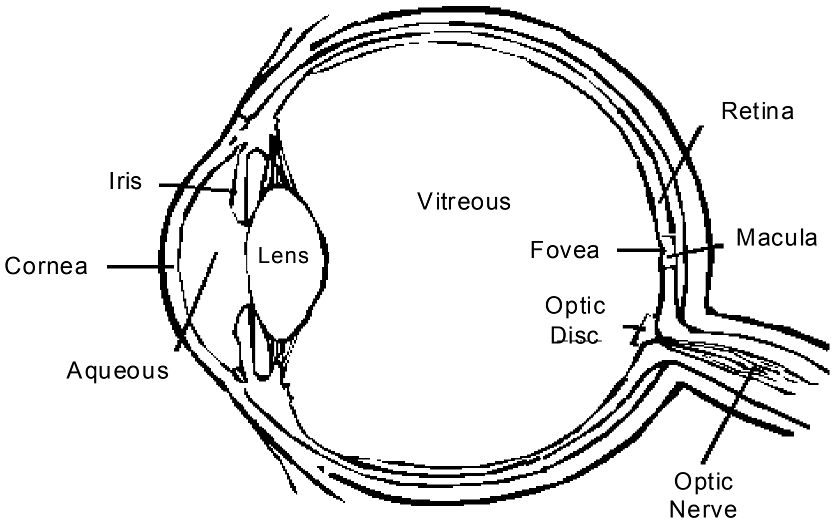

FIGURE 7.1
Structures of the eye.

point source of light (see Figure 7.2a) produces a very small spot on the retina resulting in a greatly increased power density and an increased chance of damage. A large source of light such as a diffuse reflection of a laser beam produces light called extended source which enters the eye at a large angle. An extended source produces a relatively large image on the retina (see Figure 7.2b); energy is not concentrated on a small area of the retina as in a point source.

Details of Irradiation Effects on Eyes
Cornea absorbs all UV light which produces a photokeratitis (weld).

Ultraviolet -B+C (100 – 315 nm)
The surface of the flash by a photochemical process causes a denaturation of proteins in the cornea. This is a temporary condition because the corneal tissues regenerate very quickly.

Ultraviolet -A (315 – 400 nm)
The cornea, lens, and aqueous humour allow ultraviolet radiation of 315 – 400 nm wavelengths of which the principal absorber is the lens. Photochemical processes denature proteins in the lens resulting in the formation of cataracts.

Visible light and Infrared-A (400 – 1400 nm)
The cornea, lens, and vitreous fluid are transparent to electromagnetic radiation of these wavelengths. Damage to the retinal tissue occurs by absorption

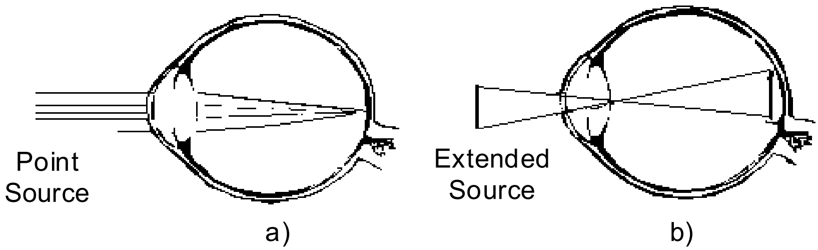

FIGURE 7.2
a) Point source viewing, b) Extended source viewing.

of light and its conversion to heat by the melanin granules in the pigmented epithelium or by photochemical action to the photoreceptor. The focusing effects of the cornea and lens will increase the irradiance on the retina by up to 100,000 times. For visible light (400 to 700 nm), the aversion reflex which takes 0.25 s may reduce exposure causing the subject to turn away from a bright light source. However, this will not occur if the intensity of the laser is great enough to produce damage in less than 0.25 s or when light of 700 – 1400 nm (near infrared) is used since the human eye is insensitive to these wavelengths.

Infrared-B and Infrared-C (1400 to 10^6 nm)
Corneal tissue will absorb light with a wavelength longer than 1400 nm. Damage to the cornea results from the absorption of energy by tears and tissue water causing a temperature rise and subsequent denaturation of protein in the corneal surface. Wavelengths from 1400 to 3000 nm penetrate deeper and may lead to the development of cataracts resulting from the heating of proteins in the lens. The critical temperature for damage is not much above normal body temperature ($\simeq 37^0$).

Laser Radiation Effects on Skin
Skin effects are generally considered of secondary importance except for high-power infrared lasers. However, with the increased use of lasers emitting in the ultraviolet spectral region, skin effects have assumed greater importance. Erythema (sunburn), skin cancer and accelerated skin aging are produced by emissions in the 200 to 280 nm range. Increased pigmentation results from exposure to light with wavelengths of 280 to 400 nm. Photosensitization has resulted from the skin being exposed to light from 310 to 700 nm. Lasers emitting radiation in the visible and infrared regions produce effects that vary from a mild reddening to blisters and charring. These conditions are usually repairable or reversible; however, depigmentation, ulceration, and scarring of

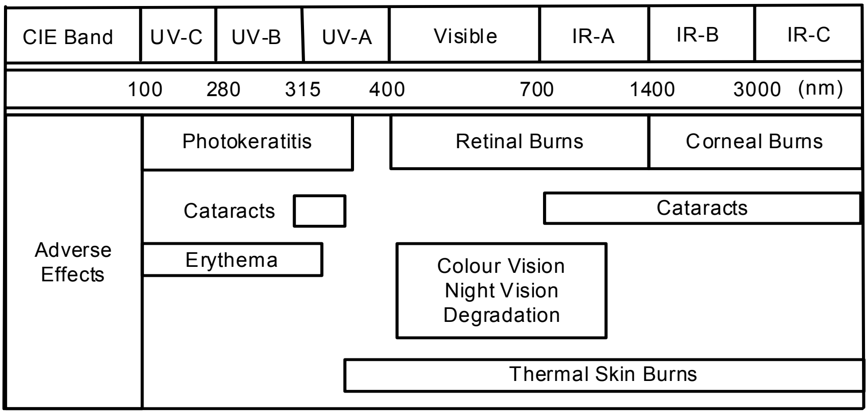

FIGURE 7.3
Interaction of optical radiation and various tissues.

the skin, and damage to underlying organs may occur from extremely high-power lasers.

Summary of Wavelengths of Light and their Effects on Tissues
A summary of interaction of optical radiation and various tissues is shown in Figure 7.3. The wavelengths are divided into bands as defined by the International Commission on Illumination (CIE).

7.2.2 Collateral Radiation

Radiation other than that associated with the primary laser beam is called collateral radiation. For example, x-rays, UV, plasma, and radio frequency emissions are collateral radiation.

Ionizing Radiation
X-rays could be produced from two main sources in the laser laboratories. One is high-voltage vacuum tubes of laser power supplies, such as rectifiers, thyratrons and crowbars, and the other is electric-discharge lasers. Any power supplies that require more than 15 kilovolts (keV) may produce enough x-rays to cause a health hazard. Interaction between x-rays and human tissue may cause a serious disease such as leukemia or other cancers, or permanent genetic effects which may show up in future generations.

UV and Visible
UV and visible radiation may be generated by laser discharge tubes and pump lamps. The levels produced may exceed the maximum permissible exposure (MPE) and thus cause skin and eye damage.

Plasma Emissions
Interactions between very high-power laser beams and target materials may in some instances produce plasmas. The plasma generated may contain hazardous UV emissions.

7.2.3 Electrical Hazards

The most lethal hazard associated with lasers is the high voltage electrical systems required to power lasers. Several deaths have occurred when commonly accepted safety practices were not followed by operators working with high voltage sections of laser systems.

Safety Guidelines

1. Do not wear rings, watches or other metallic apparel when working with electrical equipment.
2. Do not handle electrical equipment when hands or feet are wet or when standing on a wet floor.
3. When working with high voltages, regard all floors as conductive and grounded.
4. Be familiar with electrocution rescue procedures and emergency first aid.
5. Prior to working on electrical equipment, de-energize the power source. Lock and tag the disconnect switch.
6. Check that each capacitor is discharged, shorted and grounded prior to working in the area of the capacitors.
7. Use shock preventing shields, power supply enclosures, and shielded leads in all experimental or temporary high-voltage circuits.

7.2.4 Chemical Hazards

Many dyes used as lasing media are toxic, carcinogenic, corrosive or cause of a fire hazard. All chemicals must be accompanied by a material safety data sheet (MSDS). The MSDS will supply appropriate information pertaining to the toxicity, personal protective equipment and storage of chemicals.

Various gases are exhausted by lasers and produced by targets. Proper ventilation is required to reduce the exposure levels of the products or exhausts below standard exposure limits.

Cryogenic fluids are used in cooling systems of certain lasers. As these materials evaporate, they replace the oxygen in the air. Adequate ventilation must be ensured. Cryogenic fluids are potentially explosive when ice collects in valves or connectors that are not specifically designed for use with cryogenic fluids. Condensation of oxygen in liquid nitrogen presents a serious explosion hazard if the liquid oxygen comes in contact with any organic material. Although the quantities of liquid nitrogen that are used are small, protective clothing and face shields must be used to prevent freeze burns to the skin and eyes.

Compressed gases used in lasers present serious health and safety hazards. Problems may arise when working with unsecured cylinders, cylinders of hazardous materials not maintained in ventilated enclosures, and gases of different categories (toxins, corrosives, flammable, oxidizers) stored together.

7.2.5 Fire Hazards

Class 4 lasers represent a fire hazard. Depending on construction material beam enclosures, barriers, stops and wiring are all potentially flammable if exposed to high-beam irradiance for more than a few seconds.

7.2.6 Explosion Hazards

High-pressure arc lamps, filament lamps, and capacitors may explode violently if they fail during operation. These components are to be enclosed in a housing that will withstand the maximum explosive force that may be produced. Laser targets and some optical components also may shatter if heat cannot be dissipated quickly enough. Consequently, care must be used to provide adequate mechanical shielding when exposing brittle materials to high intensity lasers.

7.2.7 Eye Protection

The following is an account written by a researcher who sustained permanent eye damage viewing the reflected light of a Class 4 neodymium YAG laser emitting a 10-ns pulse of 6 mJ radiation at 1064 nm.

> "When the beam struck my eye, I heard a distinct popping sound caused by a laser-induced explosion at the back of my eyeball. My vision was obscured almost immediately by streams of blood floating in the vitreous humour. It was like viewing the world through a round fish bowl full of glycerol into which a quart of blood and a handful of black pepper have been partially mixed."
> Dr. C.D. Decker.

The researcher had eye protection available but failed to wear it. Eye protection is required, and its use is enforced by the supervisor when engineering controls may fail to eliminate potential exposure in excess of the applicable MPE. Laser radiation is generated both by systems producing discrete wavelengths and by tunable laser systems producing a variety of wavelengths. For this reason it is impractical to select a single eye protection filter that will provide sufficient protection from all hazardous laser radiation. Therefore, it is important to choose an eye protection specific for the wavelength and power of a particular laser.

Laser Protective Eyewear Requirements

1. Laser protective eyewear is to be available and worn by all personnel within the nominal hazard zone (NHZ) of Class 3B and Class 4 lasers where the exposures above the maximum permissible exposure (MPE) can occur.

2. The attenuation factor optical density of the laser protective eyewear at each laser wavelength shall be specified by a laser safety officer.

3. All laser protective eyewear shall be clearly labelled with the optical density and the wavelength for which protection is afforded.

4. Laser protective eyewear shall be inspected for damage prior to use.

The use of beam attenuators to align visible lasers will reduce laser beam intensities to a level that will allow the operator to align the beam without personal protective equipment. Laser alignment cards for ultraviolet and infrared radiation allow operators to locate the beam during alignment procedures.

7.3 Powder Hazards

It is important to consult material safety data sheets (supplied with materials), and applicable national and health regulations before using any powder or spray materials. Unusual sensitivity to powder materials is seen in some individuals that may result in health hazards.

In general, a suitable exhaust system is essential in laser material processing to avoid the toxic effects of powder and fumes that are generated by the process. In addition to the above-mentioned hazards, some materials are inherently dangerous to our health. For example, beryllium and tellurium are very harmful to the respiratory system, and the fumes of cadmium and chromium alloys are extremely hazardous. Similarly, the fumes of nickel components are potentiality hazardous. Before using any material, proper measures need to be considered by consulting an industrial hygienist.