LASER TECHNOLOGY…CHANGING DAILY LIFE,
FORGING NEW OPPORTUNITIES rev 1.6 FINAL

As the world moves into the 21st century, there are few people who have not been affected by the laser, that mysterious device that has become so common in our modern popular culture. Although there are now lasers that begin to approach the power levels of those portrayed in science fiction, lasers find the most use as tools in thousands of applications, some of which you may have never imagined!

Before we can understand what a laser is and how it works, we must first understand some basic properties of light. Light is a type of radiant energy and is part of the electromagnetic spectrum that extends from radio waves all the way up to x-rays and beyond. The main difference between electromagnetic waves is the wavelength, or the distance between the crests of individual waves.

With visible light, the wavelength determines its color. Red light has a longer wavelength than green or blue light. Infrared light has a longer wavelength than red, while ultraviolet light has a shorter wavelength than blue light.

As wavelength gets shorter, more energy is present as well. Starting in the ultraviolet region, the waves contain enough energy to knock electrons off atoms that the light interacts with. These wavelengths are known as "ionizing radiation" and is the primary reason why ultraviolet, x-ray and shorter-wavelength radiation can be hazardous. Ionizing radiation can damage living tissue leading to cancers, eye cataracts and other ailments.

Unlike many other modern inventions, the birth of the laser was not just a single event. Because the concepts of laser operation are so far removed from the realm of classical physics, it took many years for scientists to put the pieces of the puzzle together and build a working laser.

In 1917, Albert Einstein came up with some of the basic ideas that make laser action possible. But it wasn't until the early 1950's that someone put Einstein's theories to the test when almost simultaneously, scientists in the United States and Soviet Union developed a device for amplifying microwaves for advanced radio communications. The device was called a MASER, using electrically excited ammonia gas to act as an amplifier, and it worked very well. As masers proliferated throughout the 1950s, Arthur Schawlow and Charles Townes began thinking about using some of the same concepts to amplify light.

In 1960, Theodore Maiman at Hughes Research Labs in California, proudly demonstrated the world's first laser, made from a rod of synthetic ruby crystal.

The word “laser” is an acronym that stands for Light Amplification by Stimulated Emission of Radiation. Although it is quite a mouth-full, it accurately describes how a laser works.

Lasers are very different from ordinary light sources and they come in many forms. One main difference between them is the active material used to generate the laser light, which can be a gas, liquid, crystal, or semiconductor. What all lasers have in common is “stimulated emission”, the concept that Einstein came up with in 1917.

Einstein theorized that under special conditions, a light wave interacting with certain substances could stimulate the substance to emit a brand new light wave, identical to the first wave. This concept of “one wave in – two waves out” provides the amplification that was used so successfully by the inventors of the maser in the 1950s.

In the laser, the concept is taken one step further by adding feedback so the amplifier becomes an oscillator, or generator. One good way to visualize the process is to compare the laser to an audio amplifier connected to a microphone and loudspeaker. When you speak into the microphone, your voice is amplified, and is much louder when it exits the speaker.

However, if you move the microphone too close to the speaker, you get an ear-piercing tone called “feedback”. The amplifier simply takes some ambient room noise and starts re-circulating it between the microphone and the speaker. The amplifier now becomes an “oscillator”. Instead of amplifying sound, it is now generating a very loud, single frequency tone.

A similar process occurs in the laser. An active “lasing” material is specially chosen for its ability to generate and amplify light. Energy is added to this material, and feedback is provided in the form of specially designed mirrors that capture and direct the light back and forth through the active material. One of the mirrors is fully reflective, while the other mirror is made only partially reflective, which allows some of the light to escape, forming the laser beam. The mirrors must be aligned to be perfectly parallel before the laser will work.

It all seems so simple! However, taking a light bulb and attaching a pair of mirrors to it does not make a laser. There are many technical issues that must be addressed before a laser can operate, the most important of which is choosing a laser material that is capable of “stimulated emission”, the “S,E” in the word LASER.

Laser light is much different than light from conventional sources. First, laser light is very pure. The wavelength of light determines its color, and laser light consists of either a single wavelength or a very small number of wavelengths. Thus a laser beam is said to be monochromatic, from the Greek words meaning “one color”. Compare this with the light from a colored light bulb that appears to the eye to be monochromatic, but which actually contains many thousands of different wavelengths.

The second property of lasers is their brightness or intensity levels. Lasers can produce intense beams of visible, infrared, or ultraviolet light, much brighter than the surface of the sun. In addition to brightness, laser beams can be extremely powerful, in some cases, able to cut and weld metals.

The third property of lasers is coherence. This simply means that all of the light waves from a laser are in lock-step with each other. This makes laser light very efficient as all of the light can be made to work on a surface at the same time, as opposed to conventional light waves that strike materials at random times. Coherence and purity allows laser beams to be focussed to extremely small spots. This is essential for precision medical, scientific and industrial applications.

Laser beams are also highly directional so they spread out very little as they travel, unlike the beam from a flashlight. This property is a direct consequence of the laser mirrors, keeping the beam travelling along a single pathway.

Let's have a brief look at the main types of laser and how they are used as tools of modern technology.

Crystal lasers, also known as "solid state" lasers, use a rod of crystal material positioned between a pair of mirrors. The energy source can be a powerful flashlamp, an arc lamp or even a bank of high power light-emitting diodes that pump energy into the crystal.

Maiman's first laser consisted of a rod of synthetic ruby with reflective coatings at each end that served as mirrors. A high power flashlamp pumped energy into the rod. When fired, the device generated a pulsed red laser beam that was powerful enough to pierce a razor blade. Since then, hundreds of exotic crystal types have been successfully used in lasers.

Liquid lasers use fluorescent dyes to produce laser beams of many different colors. The dye is flowed through a glass tube with laser mirrors positioned on each end. Dye lasers can be tuned to produce almost any color of light by changing the type and concentration of the dye used, and by using special mirror arrangements designed to allow only a specific wavelength of light to circulate within the laser.. Dye lasers find widespread use in scientific research and in medicine where different types of living tissue respond to different wavelengths of laser light.

Gas lasers are physically different than solid or liquid lasers. They consist of a laser tube made of quartz, glass, ceramic, or in special cases, even metals. At each end of the tube are the laser mirrors, and the tube is also fitted with electrodes for applying a high voltage to the gas. Gas laser tubes are electrically similar to common fluorescent lights or neon signs. When high voltage is applied, the gas in the tube ionizes and produces a glowing light. In the gas laser, the perfectly aligned mirrors gather and concentrate a specific wavelength of light produced by the gas into an intense laser beam. Gas lasers produce extremely high quality laser beams, many of which are of very high power, suitable for cutting, welding and even some military applications.

Today, the most widespread lasers are of the semiconductor type. These lasers use semiconductor materials similar to those found in transistors, integrated circuit chips and light emitting diodes that are commonplace in today's electronic equipment.

Semiconductor lasers are very small, often the size of a grain of salt, so they are mounted in larger packages for protection and efficient cooling. In most cases they do not use separate mirrors as larger lasers do. Rather, the ends of the semiconductor material are cut so that the end faces are perfectly parallel, and then coated to enhance reflectivity.

Unlike gas lasers, they do not need dangerous high voltages to operate. In fact, the common light emitting diode on the front panel of your stereo is only one step away from being a laser!

Now that we have seen how lasers work and some of the basic types, lets look at some interesting laser applications… Lasers have affected almost every aspect of our lives, and yet many of us do not even realize it.

A trip to the store is a prime example. Almost every product you buy has been tagged with a universal product code, or UPC. At the checkout, a clerk scans the bar code to tally up your purchases. The scanners use a small semiconductor laser that is repeatedly scanned across the bar code to illuminate it. An optical sensor reads the series of black and white stripes of the bar code and converts it to digital data, which is passed to the store's computer system. Not only does this system tell you how much you must pay, but it also helps the store track and control its inventory in a fraction of the time of past methods.

Today, one of the most important uses of lasers is in the field of communications. In the 1980's telecommunication systems began to move away from copper wires in favor of fiber optics. Bulky copper cable was at the limits of its signal carrying capacity and had also filled the duct space under city streets allowing no further expansion. Something had to be done to satisfy the burgeoning bandwidth demands of the new computer networks that were coming on line every day.

A single strand of glass optical fiber can carry more than half a million telephone conversations, or thousands of computer connections and TV channels. Thinner than a human hair, fiber optics promised unlimited expansion for the future.

Fiber optics has been the driving force in the enormous growth of the internet, arguably the single most influential social and technological development of the 20^{th} century… a development that was made possible by the semiconductor laser.

Laser beams carry all of the high-speed communications traffic on long-haul fiber optic networks. Lasers are used because their high intensity beams can travel for hundreds of kilometers along an optical fiber without the need for amplification. In addition, because all modern telecommunications networks are digital, the light sources used must be able to pulse at extremely high speeds with digital data, another valuable feature of semiconductor lasers.

Another interesting laser application is in “free space” optics, or FSO. Today’s cities are densely populated with high-rise towers. Businesses that have offices in more than one building, may find it too expensive or technically difficult to provide high speed fiber optic connections between these offices that can be up to several miles apart.

As long as there is a clear line of sight, free space laser transceivers may solve some of these problems at a reasonable cost. These amazing devices can carry an enormous amount of bi-directional voice, video and data traffic. They are also surprisingly tolerant of poor weather conditions and temporary obstructions like flocks of birds.

In this demonstration, even when the window blinds are fully closed, enough laser energy is still getting through to carry a clear signal.

Communications offers many applications for the laser, but there are thousands of other applications as well. Semiconductor lasers form the heart of every CD and DVD player in the world. Digital information on a commercial CD or DVD is in the form of microscopic pits on an otherwise reflective metallic substrate. When a focussed laser beam scans the disk surface the pattern of pits can be easily be read by an optical sensor and processed to form an audio or video signal.

CD-ROM or DVD-ROM writers operate in a similar way, but instead of a metallic substrate, recordable disks use a light sensitive coating similar to photographic film. To record, the laser is operated at a higher power level to fix a pattern of digital ones and zeros onto the disk. To read the data, the laser is operated at a lower power that is not sufficient to affect the coating, but bright enough to be reflected from the pre-recorded data so an optical sensor can detect it.

Among the many interesting properties of light, is the fact that shorter wavelengths can be focussed to smaller spots than longer wavelengths, so a blue laser beam can form a smaller spot than a red laser beam. The smaller the spot size, the more pits can be stored and read from a CD or DVD. Using blue lasers, the next generation CDs and DVDs will offer greatly increased storage capacities.

The common laser printer also relies on the semiconductor laser. In the printer, the laser scans a photo-sensitive drum that has been pre-loaded with a high voltage charge. While scanning, the laser is pulsed to form the light and dark areas of the printed page. The intense laser light alters the pattern of electric charges on the drum to match the data. The drum is then dusted with toner, which adheres to areas where the electric charge has not been removed by the laser beam. When the drum is rolled over a blank sheet of paper, the toner sticks and is fixed in place by a pair of hot rollers.

The reason lasers are used in these printers, is because they can be focussed to small spot sizes, allowing for high-resolution printing, something not possible with other light sources.

Because of their low cost and rugged reliability, semiconductor lasers are finding new applications every day. Thousands of people routinely use these lasers as pointers or even for entertaining the family pet. Semiconductor lasers built into torpedo levels are sold around the world in home improvement stores. These low-cost devices make it easy for the do-it-yourselfer to accurately level fence lines, home foundations and cabinetry.

Contractors use slightly more complex laser leveling equipment. This type of laser level scans the beam from a semiconductor laser in a circular path. When mounted on a properly adjusted tripod, the scanned beam forms a highly accurate reference level that can be used to measure surface grades or trench depths. When brought indoors, the beam can be scanned around a room at ceiling height, allowing the contractor to easily install a level suspended ceiling.

Semiconductor lasers find extensive use in detection, measurement and quality control. Non-contact measurement using lasers has become the standard in many manufacturing environments. Laser surface-profiling methods can be used to quickly measure manufactured products with sub-micron accuracy.

Here, the red beam from a semiconductor laser is scanned over the surface of an automobile tire, verifying the shape and thickness of the tread. The speed and accuracy of this process means that 100 percent of a tire factory's output can be inspected for safety, as opposed to the random sample testing of the past.

Lasers have been used for years in surveying, mining and tunneling applications. Because lasers generate beams that are perfectly straight, they can ensure a tunnel or mine shaft remains straight during boring. The English Channel tunnel relied heavily on laser alignment during its construction. Because separate tunnels were started from both the English and French sides of the channel, it was imperative that accurate alignments be maintained throughout the digging if they were to meet in the middle of the channel. The lasers performed better than expected, with a misalignment of only a few inches over 15 miles.

Earlier, we saw that lasers produce "coherent" light. That is, light whose waves are all in lock-step. Many of the newest and most interesting applications of lasers depend on its coherence. One such application is laser strain measurement. In this application, the beam from a semiconductor or helium-neon laser is send through a length of optical fiber. When light travels though fiber, individual light waves arrive at the other end of the fiber at slightly different times. Thus the light is a bit less coherent than when it entered the fiber.

If the beam leaving the fiber is projected onto a sheet of paper, a speckled pattern of light and dark areas can be seen. When these light waves interact, they interfere with each other. Bright spots result where wave crests are "in phase" and add their intensities together, while the darker spots are created when waves are "out of phase" and cancel each other out.

If the fiber is bent, moved, bumped or placed under pressure, the pattern of coherence of the light in the fiber will change, which can be detected with special photo-electric sensors.

An important application for this technology is measuring stresses and strains in roads, bridges and even buildings. By embedding fiber optics in the concrete of these structures as they are built, the electronics can continually monitor stresses to detect damage and even predict failures that could lead to loss of life.

But laser measurement is not a new technique. In the early Apollo moon missions, astronauts placed a number of laser reflectors on the surface of the moon as part of a package of scientific experiments. A powerful ruby laser on earth directed a red laser pulse at the reflector. By measuring the time it took to reach the moon and then return to earth, scientists were able to calculate the distance between the earth and the moon to within a few centimeters!

Some of the most interesting uses of lasers are in materials processing. There is something about a beam of light cutting through steel that fascinates almost everyone, possibly because it is so close to the image of lasers we see in science fiction.

High power lasers are a mainstay of modern industrial manufacturing. Chief among them is the carbon dioxide gas laser. The CO2 laser can be designed to provide beam powers of a few watts to tens of thousands of watts. Typically it takes beam powers of at least 500 watts to begin to working on thin metals. Compare this to the few thousanths of a watt available from most semiconductor diode lasers!

Gas lasers typically produce higher quality beams than semiconductor lasers. There are a number of reasons for this. First, gas laser tubes are physically larger than diodes so the mirrors are separated by a greater distance. This results in a beam that is more directional than a semiconductor laser can provide.

The larger size of gas lasers also means that more active material can be placed between the mirrors, resulting in markedly higher output powers. Gas lasers are typically found in applications where size, weight, cooling and power requirements are not a problem, such as in large factories.

In cutting and welding applications, lasers can provide some distinct advantages over other methods. Lasers produce smooth, clean cuts, unlike cutting torches. The heat applied to a metal work-piece is sharply focussed so it affects only a small area around the cut. With a cutting torch, the heat-affected zone is larger. The metal in the heat-affected zone becomes more brittle than the rest of the work-piece, so in many applications such as aircraft parts, the heat affected metal must be removed by grinding. This results in longer manufacturing times, higher costs and reduced accuracy.

With the laser, the cut is very smooth and the heat-affected zone around the cut is very small, so grinding is kept to a minimum. In some cases, cuts are so smooth that no grinding is required. In this example, a 1200 watt CO2 laser is cutting parts from a steel sheet, ½ inch thick. The laser is stationary and the beam transmitted to the work-piece through a set of mirrors mounted on a computer-controlled gantry. The computer directs the laser to cut any shape out of the work-piece with perfect accuracy and repeatability.

Because the beam is so powerful, stringent safety precautions must be taken by the operator, and the beam path must be completely enclosed. The beam from a CO2 laser is infrared and is invisible to the naked eye. However, you can easily see the sparks flying from the heat the beam generates.

CO2 lasers are used by a number of manufacturers for heat-treating parts to harden them against extraordinary wear. Much higher laser powers are usually required. Here, a tapered shaft is heat treated by the beam from a 15,000 watt CO2 laser. Traditional methods using torches or furnaces waste energy and can take hours, but the laser completes the task in only a few seconds. Car manufacturers make extensive use of lasers to harden transmission gear surfaces for a long and reliable service life.

Carbon Dioxide lasers are also available with lower powers, perfect for engraving and product marking. In this example, a small 20 watt CO2 laser and positioning table is connected to a personal computer and is used to make engravings in wood, plastics or in thinly coated metals. CO2 lasers can easily engrave glass or ceramics as well.

This CO2 laser is engraving serial number plates in anodized aluminum. A small computer controls a pair of mirrors that scan the beam over the surface to be engraved. This process can also be used to engrave lot numbers on soft drink cans or other consumer goods.

CO2 lasers produce excellent quality cuts in plastic materials. Here, a 500 watt beam is cutting letters and logos from a plexiglass sheet. As with metals, the speed of the cutting depends on beam power and the thickness of the material. The CO2 laser produces a polished edge in plastic as it cuts, so in most cases, no further processing is required.

Lasers are also useful in cutting materials that are difficult to process with other tools. In this example a 200 watt CO2 laser is cutting aircraft parts from solid kevlar, a very strong composite plastic. Kevlar fibers are used in bullet-proof vests, so solid kevlar is extremely tough and it quickly dulls conventional tools like saws and drill bits.

However, the laser quickly cuts this material and will never get dull, making the process very efficient and repeatable.

Solid state lasers are also found in many industrial applications. The lasers most widely used makes use of the rare-earth element neodymium as the active material. The neodymium can either be dissolved in a glass rod, or in a crystal host like yttrium aluminum garnet, or YAG. YAG lasers can be cooled more efficiently than glass lasers so they are found more often on the factory floor.

The wavelength of the YAG laser makes is more suitable for working metals like brass, aluminum and stainless steel, where the beam from a CO_2 laser would be reflected. YAG lasers can be pulsed or continuous and are often used for making precision welds in specialized applications like cardiac pacemaker housings.

Lasers can effectively cut, weld or drill hard or brittle materials like metals, ceramics and glass… or soft, spongy materials like rubber that would deform under the pressure applied by any mechanical tool.

Most industrial lasers work by applying precise amounts of heat to a work-piece. However, the Eximer gas laser processes materials in a different way. Eximer lasers produce intense beams of ultraviolet light that breaks apart the molecular bonds of the target substance, and ejecting debris in a miniature explosion.

There is no danger of any thermal damage to surrounding areas not exposed to the beam. This, combined with the ability of ultraviolet wavelengths to be focussed down to extremely small spot sizes, gives the eximer laser the precision required for micro-machining.

In this example, a tiny gear, only 300 microns in diameter is being cut from pyrex glass by the beam from an eximer laser. The next generation of super-machines will operate in a microscopic world, bringing enormous advances to science, electronics and medicine. Precision laser tools like the eximer laser will be instrumental in the development of this new technology.

Eximer lasers can etch very high resolution patterns on various materials in numerous manufacturing applications. The laser beam is scanned across a mask containing the desired pattern, while a series of lenses focuses the pattern down to the required size on the work-piece. This arrangement can be used to manufacture sensors, electronic parts, medical devices or any part that requires a high-resolution network of holes or channels.

Some of the most important uses of lasers come in the field of medicine. The infrared beam from carbon dioxide lasers is heavily absorbed by the water in human tissue, making it an excellent cutting tool for the surgeon. The heat of the beam cauterizes tissue as it cuts, resulting in almost bloodless surgery. CO_2 lasers can be used to seal cuts from conventional surgical procedures. CO_2 lasers are also used extensively for removing scars and other skin lesions.

Alexandrite crystal lasers find widespread use in removing tatoos. The wavelength of the alexandrite laser is highly absorbed by tatoo pigments, especially the darker colors. Short pulses of laser light break down the pigments in the skin, allowing the body’s normal processes to carry them away.

Argon gas lasers produce intense green light with up to 50 watts of power, allowing this type of laser to be exploited for its heating effects as well as for its wavelength. The retina of the eye is more sensitive to green light than any other color, making the argon laser a perfect choice for many types of eye surgery. Detached retinas cause blindness in thousand of people each year. But if caught early, a pulsed argon laser may be used to “weld” the retina back in place before permanent damage results.

The heating effects of argon lasers are exploited in treating skin disorders. Here, a number of birthmarks are being removed with an argon laser beam. The pigmented cells of the birthmarks heavily absorb the green beam causing them to bleach white. After a week or two, the skin will return to a more normal color.

Today, a surgical technique that is gaining popularity is laser vision correction, or LASIK. In less than 15 minutes, this procedure can greatly reduce a patient's reliance on corrective eyeglasses. In some cases after surgery, eyeglasses will no longer be required. The surgeon first uses a high-precision instrument to separate the layers of corneal tissue and create a thin flap on the surface of the eye.

This flap is folded back, and the ultraviolet beam from an eximer laser is guided to gently reshape the underlying tissue. The cornea's new shape is what improves vision. After re-shaping is complete, the flap is replaced and the patient can resume most normal activities within 24 hours.

Optical fibers can deliver laser beams inside the body to reduce the need for more invasive surgery. An interesting example is the destruction of painful kidney or gall stones in a process called “lithotripsy”. An optical fiber is first passed through the urethra or bile ducts to the location of the stone. High power pulses from a tunable liquid dye laser cause intense shock waves within the stones that break them into tiny fragments, allowing them to pass painlessly from the body.

One of the possible future uses for lasers comes in the generation of energy through nuclear fusion. Fusion is the process used by the sun and may be the key to an unlimited supply of energy for a power hungry world.

At the Lawrence Livermore National Laboratory near San Francisco, work is being done to bring nuclear fusion to a power plant near you! In the 1970’s and 80’s, The NOVA laser was the largest solid state neodymium laser in the world, housed in a building the size of a shopping mall. It could produce laser pulses of 300 trillion watts for 1 billionth of a second. When split into 10 parts and focussed on a tiny pellet of fuel from all directions, the intense energy caused the pellet to heat up to solar temperatures and compress together until atoms began to fuse. At this point the fuel pellet begins to emit energy, much more than was applied by the laser.

The most attractive feature of fusion is its inherent safety. The reaction must be continuously triggered with new fuel pellets and new laser pulses. If the pulses stop, so does the reaction, so it would be easy to pull the plug on a malfunctioning fusion reactor… no possibility of melt-downs… no escaping radiation.

But in order to be effective for power generation, laser pulses would need to hit fuel pellets hundreds of times each second. Unfortunately it took Nova over a half an hour to charge up for a single pulse.

Today, scientists at Lawrence Livermore are building the successor to NOVA, known as The National Ignition Facility. The NIF will feature smaller, faster and more powerful lasers to finally get fusion power up and running in a practical way.

This laser, code-named "Mercury", is the next generation of fast pulsed lasers to be used in fusion experiments. No longer the size of a building, the Mercury is a solid state Neodymium-glass laser that uses banks of high power semiconductor lasers to power it.

A number of these lasers will be needed to blast a fuel pellet, but the dramatic reduction in size and cost is a hopeful sign that practical fusion reactors are not far off.

The military applications of lasers have long been touted by science fiction writers, who have attributed almost magical qualities to this practical tool. However, the military have long used lasers for tasks like pointing, aiming and the guiding of munitions to their targets. But today, serious work is being done to use the highest power lasers directly as weapons, most notably to destroy approaching missiles.

Because a laser beam travels at the speed of light, it could provide the perfect means to hit fast moving missiles, a task extremely difficult by other means. The only drawback is getting enough laser power to do the job.

At the Wright-Patterson Air Force base in Ohio, this carbon dioxide gas laser is capable of generating a continuous beam power of 100,000 watts. Here, it blasts through a plexiglass rod more than foot thick in only a few seconds. This laser, built in the 1980's has been succeeded by a new generation of even higher power lasers that are smaller and lighter.

Most lasers require large amounts of power because they are electrically inefficient devices, but there is a class of lasers that does not use any electrical power at all, and these are of great interest to the military.

Chemical lasers use a number of reactive chemicals to generate laser light. A very strong reaction vessel is placed between a pair of laser mirrors and a number of specially chosen reactive chemicals are injected into the chamber. An explosive chemical reaction occurs that generates powerful infrared light. The chemicals are also capable of stimulated emission, so the mirrors are able to create an extremely powerful laser pulse.

In the test shown here, the infrared beam from a chemical laser is directed on a dummy missile casing. Although invisible to the camera, the tremendous power of the laser beam causes the casing to explode.

Based on this and other tests, the military has built a chemical laser into the body of a 747 jet aircraft and is conducting experiments into shooting down ballistic missiles with it. The aircraft makes a perfect platform for the laser, as it can be moved quickly to trouble spots around the world and circle the theater waiting for a hostile missile launch. Free of an electrical power source, aircraft or even space-based chemical lasers could one day eliminate the threat of missile attack.

As we have seen, lasers are powerful and highly versatile tools, but just like working with any other tool, one must keep safety foremost in mind. Lasers can pose a number of hazards depending on the wavelength and power levels involved. The semiconductor lasers used in communications systems can produce power levels that can cause eye damage, and that damage may not be immediately noticed. Special protective glasses are available for every laser wavelength in use today, and must be worn when working around lasers.

Some lasers produce beams of such low power, that when properly used, eye damage is almost impossible. Such is the case for laser bar-code scanners, surface profilers and the laser traffic radar used by police.

The dangers of high power lasers include eye damage by beam energy reflected from smooth surfaces as well as the possibility of burns to clothing and skin. Eximer lasers that produce ultraviolet beams can trigger skin cancers if the beam is allowed to reach unprotected flesh. High power lasers can also start fires many meters away from the laser if the beam path is not completely enclosed.

Because of these potential hazards, all countries now have stringent safety codes that must be followed when working with lasers.

Today we live in the world of the photon, with optical and electro-optical technologies on the cutting edge. Students today are more aware of science and technology than ever before and have a keen interest in learning and getting involved… and their diligence will pay off. There are thousands of rewarding careers that involve working with all types of lasers.

In telecommunications, for example, careers range from the technicians who install and maintain the fiber optic infrastructure all the way up to the visionaries who make their dreams of new and exciting applications a reality.

Lasers and laser based equipment are tangible products that must be designed and built. Thus, there are numerous technical jobs in design and manufacturing, assembly and testing, quality control and calibration, as well as sales and administration that require knowledge of lasers.

In medicine and other scientific fields there are challenging careers for people at all levels of education from Certificate and Associate degrees, up through the PhD and Post Doctoral levels.

But even students can participate. Research scientists rely heavily on graduate students and undergrads to help them develop cutting edge optical technologies. By acting as lab assistants, these students gain valuable knowledge and experience while helping to advance the science of photonics.

Today, it isn't just scientists that use or interact with lasers, it is every one of us. Lasers and laser-based products have become common in every area of human endeavor. Every time you pick up the telephone, watch a movie or TV, use the Internet or just carry on your daily life, you benefit from the laser.

In this program we have learned what the laser is, where it came from and how it works. We have also seen a small sampling of the thousands of laser applications currently in use or being developed. The laser, far from being the mysterious device of science fiction, is more like an optical Swiss Army knife… a practical and handy tool used every day around the world.

With today's increasing reliance on optical technologies, you can expect the laser to lead the way as we boldly enter the "Age of the Photon"!