CHAPTER 1

INTRODUCTION AND OVERVIEW

ABOUT THIS CHAPTER

This chapter will introduce you to lasers. It will give you a basic idea of their use, their operation, and their important properties. This basic understanding will serve as a foundation for the more detailed descriptions of lasers and their operation in later chapters.

1.1 THE IDEA OF THE LASER

Optics was a sleepy backwater of physics when Theodore Maiman demonstrated the first laser in 1960. His announcement made headlines, and for many years afterward, lasers were novelties that attracted attention. Today, lasers are commonplace in developed countries. Thanks in large part to the laser, optics has become a dynamic field, expanding far beyond the binoculars, cameras, and spectacles that were the main products of the optical industry half a century ago.

We take lasers almost for granted today, as just another wonder of our technological age along with satellites and electronic chips. Most of us think of lasers as cylindrical devices that emit pencil-thin beams of red or green light, and shine bright spots on the wall. The first kind of laser to come to your mind is likely to be the pen-like laser pointers you can buy for $10 or less at an electronics or stationary store.

But lasers come in many other sizes, shapes, and forms. Most of them are tiny semiconductor chips that we never see because

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they are hidden inside electronic equipment such as CD players, CD-ROM drives, and DVD, or Blu-Ray players. Others are tubes filled with gas that emit laser light. Some are boxes the size of a filing cabinet or a refrigerator that emit powerful beams to cut or drill holes in metal or plastic. The largest lasers fill the interior of a building and generate pulses of light that for a fleeting billionth or trillionth of a second can deliver more power than the whole U.S. electric power grid. Laser output may not be visible; many lasers emit at infrared or ultraviolet wavelengths invisible to the human eye.

What makes them all lasers is that they generate light in the same way, by a process called "light amplification by the stimulated emission of radiation." The word "LASER" is an acronym for that phrase. It is the process of amplifying stimulated emission that makes laser light special. The sun, light bulbs, flames, and other light sources emit light in a different way, spontaneously. That leads to important differences between laser light and other kinds of light, which we will explain later.

Most of us also are familiar with fictional weapons that resemble lasers and sometimes are called lasers. The deadly heat rays used by the Martian invaders of Earth in *The War of the Worlds* seem uncannily like lasers, emitting beams of invisible infrared light. Yet H. G. Wells wrote the book in 1896, long before anyone had thought of stimulated emission or lasers. Wells just imagined a searchlight beam that could burn rather than illuminate.

Pulp science fiction writers soon churned out tales of ray guns or death rays, which fired deadly beams of light or other (often undefined) forms of radiation. The writers may have heard rumors that legendary inventor Nikola Tesla and a handful of other scientists were working on death rays in the 1920s and 1930s, but there was no real science behind their weapons. They were just futuristic props to avoid arming 25th century heroes with six-shooters. But thanks to those stories, when the laser was invented the public thought of it as a "death ray," much to the annoyance of the people working with real lasers.

It is true that military researchers are trying to develop laser weapons. That is not new; it has been going on since the 1960s and so far has consumed many billions of dollars to shoot down a few targets. As you will learn in Section 12.8, laser weapons are big, and they try to destroy targets by focusing a lot of light energy on them. In short, it is not easy to make lasers into weapons.

This book is about real lasers, so we will start by looking at the fundamental concepts behind real-world laser technology, briefly explaining what they are and how they developed.

1.2 WHAT IS A LASER?

You have already seen than the word “laser” is shorthand for the phrase “light amplification by the stimulated emission of radiation.” Each part of that phrase has a special meaning, so we will look at it piece by piece, starting from the end.

Radiation means *electromagnetic radiation,* a massless form of energy that travels at the speed of light. It comes in various forms, including visible light, infrared, ultraviolet, radio waves, microwaves, and X-rays. Light and other forms of electromagnetic radiation behave like both waves and particles (called *photons*). You will learn more about the details in Chapter 2.

Stimulated emission tells us that laser light is produced in a special way. Ordinarily, atoms or molecules spontaneously emit energy in the form of light or other types of electromagnetic radiation. The sun, flames, and fluorescent lamps all release energy by emitting light spontaneously. However, in certain cases atoms and molecules can be stimulated to emit that extra energy as light. This process is called stimulated emission, and you will learn more about it in Chapter 3.

Amplification means increasing the amount of light. In stimulated emission, an input wave stimulates an atom or molecule to release energy as a second wave, which is perfectly matched to the input wave. The stimulated wave, in turn, can stimulate other atoms or molecules to emit duplicate waves, causing further amplification. It may be easier to think of stimulated emission as one light photon stimulating an atom or molecule to emit an identical photon, which in turn can stimulate the emission of another identical photon. In both cases the result is amplification, producing more light.

Light describes the type of electromagnetic radiation produced. In practice, that means not just light visible to the human eye, but also electromagnetic radiation that our eyes cannot see because it is either longer in wavelength (infrared) or shorter in wavelength (ultraviolet.)

It took a long time to put the pieces of the idea together. Albert Einstein first suggested the possibility of stimulated emission in a paper published in 1917. Although stimulated emission was first observed in the 1920s, physicists long thought that spontaneous emission was much more likely, so stimulated emission would always be much weaker. The first hints that stimulated emission could be stronger came in radio experiments shortly after World War II, but the key experiment came in the 1950s.

Charles H. Townes, then at Columbia University, conceived of a way to build up stimulated emission at microwave frequencies in 1951. His idea was to isolate ammonia molecules with extra energy, then stimulate them to emit their extra energy at a particular microwave frequency as they were passing through a cavity that reflected the microwave frequency emitted by the ammonia molecules. He called his device a “maser,” an acronym for microwave amplification by the stimulated emission of radiation.

It took until 1954 for Townes and his graduate student James Gordon to make the maser work. It could serve either as an amplifier or an oscillator. Some ammonia molecules spontaneously emitted microwaves at a frequency of 24 gigahertz, and that spontaneous emission could stimulate other excited ammonia molecules to emit at the same frequency, building up a signal that oscillated on its own. Alternatively, an external 24-GHz signal could stimulate the ammonia molecules to emit at 24 GHz, amplifying the signal.

In principle, the maser process could be extended to other types of electromagnetic radiation if the right materials could be found. The next logical step was to optical wavelengths, and a number of people thought seriously about the possibility. However Townes was the first to start serious research in 1957. In the course of gathering information, he talked with Gordon Gould, a Columbia graduate student who was using an important new idea called optical pumping in his doctoral research project. Townes thought he could use optical pumping to excite atoms in a laser, and the laser idea intrigued Gould.

Townes went on to enlist the help of his brother-in-law, Arthur Schawlow, who knew more about optics, to work out how to amplify stimulated emission of light. Meanwhile Gould quietly tackled the problem with a pile of reference books on his kitchen table. They essentially independently solved the same physics problem, and both proposed building cylindrical laser resonators with mirrors on opposite ends so the light would bounce back and forth between the mirrors while it was being amplified. Gould set out to patent the his ideas; Townes and Schawlow published their proposal in a scientific journal, *Physical Review Letters.* Their work launched a race to build a laser, which I chronicled in *Beam: The Race to Make the Laser* (Oxford University Press 2005).

Townes shared in the 1964 Nobel Prize in physics for his pioneering work on "the maser/laser principle," and after a long series of legal battles, Gould earned tens of millions of dollars from his patent claims. However, the winner of the laser race was Theodore Maiman, who on May 16, 1960 produced laser pulses from a fingertip-sized crystal of synthetic ruby at Hughes Research Laboratories in Malibu, California. Figure 1-1 shows Maiman and

Figure 1-1. Theodore Maiman and Irnee J. D'Haenens with a replica of the world's first laser, which they made at Hughes Research Laboratories in 1960. (Reprinted from Hughes Research Laboratories, courtesy of AIP Neils Bohr Library.)

his assistant Irnee D'Haenens holding a replica of his elegant little device, the world's first laser.

The ruby laser was in many ways typical of the many other types of lasers that followed it. Energy from an external source—in this case, a bright flash of light from a photographic flash lamp—excited chromium atoms in a ruby cylinder. Some excited chromium atoms spontaneously emitted light, and that light stimulated other excited chromium atoms to release their excess energy as an identical light wave. Silver film mirrors coated onto the ends of the ruby rod formed a resonant cavity, so light bounced back and forth between them, stimulating more emission from chromium atoms and amplifying the red light to build up a beam. The laser beam emerged through a hole in one of the silver coatings on the ends of the rod. The laser light was at a single wavelength—694 nanometers (1 nm = 10^{-9} meter) at the red end of the visible spectrum. The light waves were coherent, all aligned with each other and marching along in step.

The lasers that followed generally shared key properties of the ruby laser, generating coherent beams of monochromatic light.

LASER OSCILLATION

Stimulated emission amplifies light in a laser, but the laser itself is an oscillator. So why, you may wonder, does the word "laser" come from "light *amplification* by the stimulated emission of radiation"? There's an interesting bit of history behind that.

Charles Townes created the word "maser" as an acronym for microwave amplification by the stimulated emission of radiation. When he began thinking of an optical version of the maser, he called it an optical maser. When Gordon Gould sat down to tackle the same problem, he wrote "laser" at the top of his notes, inventing the acronym for light amplification. As the competition between Townes and Gould became intense, each side pushed its own term.

Arthur Schawlow was a jovial soul, and at one conference pointed out that because the laser was actually an oscillator, it should be described as "light oscillation by the stimulated emission of radiation," making the laser a "loser." Everybody laughed, but the word laser proved a winner.

Maiman's ruby laser was pulsed; many others generated continuous beams. Some generated stimulated emission from longer, thinner rods of other crystals. Others stimulated emission from gases inside a tube with mirrors at its two ends. The most common lasers today are tiny chips of semiconductor compounds such as gallium arsenide. But some lasers occupy entire rooms in buildings, and the most powerful lasers—like the U.S. Air Force's Airborne Laser—occupy whole buildings or aircraft.

Lasers operate at wavelengths from the infrared all the way to soft X-rays. They can generate modest powers far below one watt, steady powers of thousands of watts, or concentrate light into pulses lasting less than a billionth of a second. Figure 1-2 shows commercial gas, semiconductor, and solid-state lasers designed for a variety of applications.

1.3 LASER MATERIALS AND TYPES

Maiman won the laser race because he had studied the optical properties of ruby, and carefully designed his laser to take advantage of them. Matching the laser design to the material properties was critical. Most materials won't work as lasers under most conditions. What is needed is a material containing atoms or molecules that can be excited into a state ready to be stimulated to emit light energy.

Ruby worked because it contains chromium atoms, which absorb energy as visible light, then eventually release much of that energy as a photon of red light. Maiman found that if he slipped a ruby rod inside a coiled flash lamp, the bright flash would excite most of the chromium atoms, leaving them ready to emit red light. If one chromium atom spontaneously emitted a red photon, that photon could stimulate another chromium atom to emit a second photon; and both of those photons could stimulate more emission, eventually producing a cascade of red light in a laser pulse. Figure 1-3 shows the basic idea.

Ruby is an important example of a *solid-state laser.* In these lasers, light from an external source, such as a flash lamp, excites atoms distributed within a solid. The solid must be transparent at the wavelength of the pump light so it can excite the atoms that produce the stimulated emission. In ruby, the transparent material is sapphire (aluminum oxide or Al_2O_3) and the light emitting

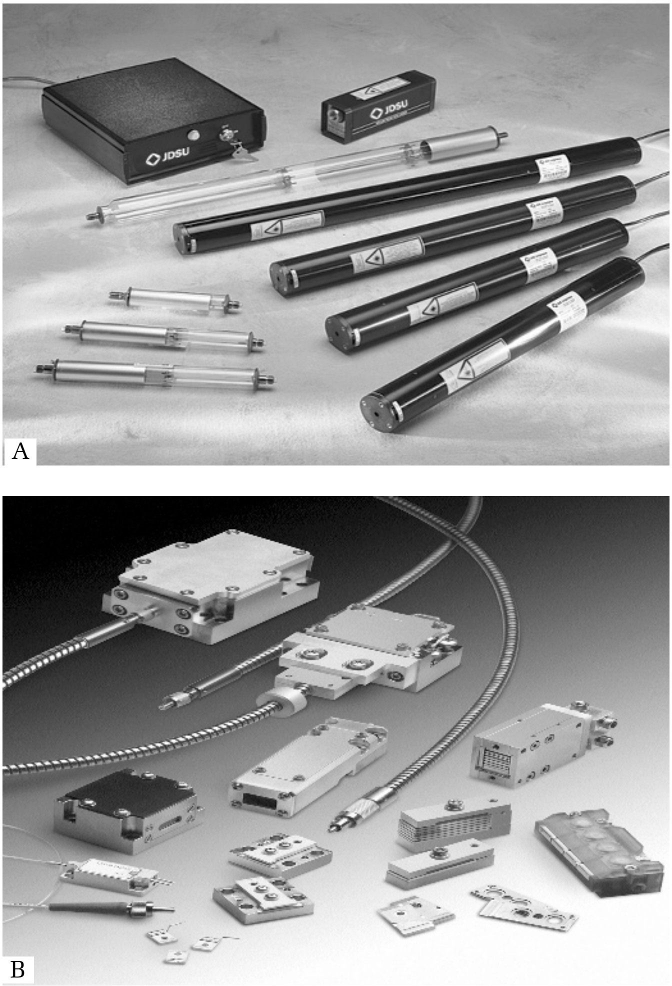


Figure 1-2. A sampling of commercial lasers. (A) A sampling of milliwatt-class helium–neon lasers, including both packaged heads and bare tubes (courtesy JDS Uniphase). (B) A sampling of commercial diode lasers packaged for various types of applications (courtesy of Spectra-Physics, a division of Newport Corporation).

atoms are chromium. Another common choice is adding a rare-earth element called neodymium to transparent materials such as the crystal yttrium–aluminum garnet (YAG) or certain types of glass. Two other rare-earth elements, erbium and ytterbium, can be added to glass that is drawn into optical fibers, to produce solid-state fiber lasers.

Figure 1-2. *Continued* (C) A diode-pumped, solid-state neodymium laser producing an average power of several watts for materials-working applications (courtesy of Coherent Inc.).

In all cases, light from an external lamp or laser passes through the transparent host material to excite the light-emitting atoms. This process is called optical pumping. Described in Chapter 8, these lasers can generate pulses or continuous beams.

A second broad class of lasers are *gas lasers,* covered in Chapter 7, in which a light-emitting vapor is confined inside a hollow tube

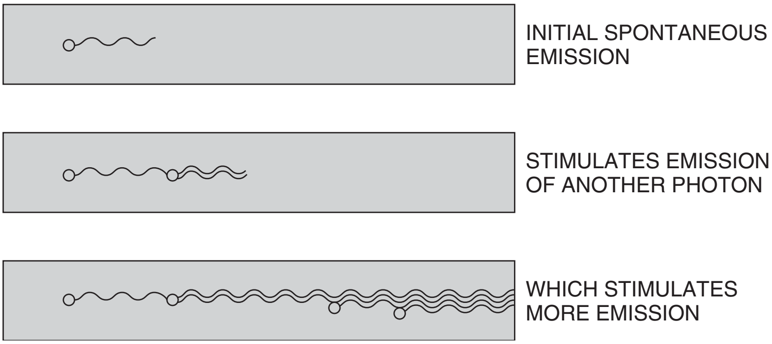


Figure 1-3. A single spontaneously emitted photon triggers stimulated emission from excited atoms, building up a cascade of stimulated emission. In ruby, the excited atoms are chromium.

with mirrors on the ends. Passing an electric discharge through the gas excites the gas atoms to states in which they can generate stimulated emission. Many gas lasers emit continuous beams.

A third broad class are *semiconductor lasers,* which in the laser world are considered distinct from solid-state lasers. Standard semiconductor lasers are actually *diode lasers* or *laser diodes,* in which current flows through a semiconductor chip in a way that generates light at a junction between two zones of different composition, as you will learn in Chapter 9. Semiconductor lasers are tiny, cheap, and efficient, and have become by far the most common types of laser. Every CD or DVD player contains at least one semiconductor laser, and hundreds of millions are produced each year.

Laboratory researchers have demonstrated laser action in a wide variety of materials, most of which fall into the three broad categories of gas, solid-state, or semiconductor. A few other types with limited applications are described in Chapter 10, including organic dye lasers, extreme ultraviolet lasers, and free-electron lasers.

1.4 OPTICAL PROPERTIES OF LASER LIGHT

Lasers can be fascinating devices in themselves, but their practical importance comes from the unusual properties of the light in a laser beam. These properties are crucial for applications of lasers ranging from cutting sheets of plastic or metal to making extremely precise and sensitive measurements in scientific research. The most important of these optical properties are:

- Wavelength(s)
- Beam power
- Variation of beam power with time (e.g., pulse duration)
- Beam divergence and size
- Coherence
- Efficiency

1.4.1 Wavelength(s)

The wavelength emitted by a laser depends both on the laser material and the design of the laser cavity. The range of possible wavelengths depends on the material, with the optical design of the laser selecting which wavelengths can be emitted. Table 1-1 lists

Table 1-1. Wavelengths of some important lasers

Type	Wavelength Range
Fluorine (F_2) excimer	157 nm
Argon–fluoride excimer	193 nm
Argon-ion (ultraviolet)	229–264 nm
Krypton–fluoride excimer	248 nm
Neodymium solid-state (4th harmonic)	266 nm
Argon-ion (ultraviolet)	275–303 nm
Xenon–chloride excimer	308 nm
Helium–cadmium (ultraviolet)	325 nm
Argon-ion (ultraviolet)	330–360 nm
Nitrogen gas (N_2)	337 nm
Xenon–fluoride excimer	351 nm
Neodymium solid-state (3rd harmonic)	355 nm
GaN/InGaN family diodes	375–440 nm
Organic dye (in solution)	320–1000 nm (tunable)
Helium–cadmium (blue)	442 nm
Argon-ion (visible)	454–515 nm
Krypton-ion (visible)	472–800 nm
Neodymium solid-state (doubled)	532 nm
Helium–neon (green)	543.5 nm
Helium–neon (yellow)	594 nm
Helium–neon (orange)	612 nm
Helium–neon (red)	632.8 nm
AlGaInP/GaAs family diodes	620–680 nm
$Ga_{0.5}In_{0.5}P$/GaAs family diodes	670–680 nm
Krypton (strongest line)	647 nm
Ruby	694 nm
Titanium–sapphire	675–1100 nm (tunable)
Alexandrite	701–826 nm (tunable)
GaAlAs family diodes	750–905 nm
InGaAs family diodes	915–1050 nm
Ytterbium-fiber	1030–1100 nm
Neodymium–YLF	1057 nm
Neodymium–YAG or Nd–YVO_4 (primary)	1064 nm
InGaAsP family diodes	1100–1650 nm
Chemical oxygen–iodine	1315 nm
Neodymium solid-state (secondary)	1320 nm
Erbium–glass or fiber	1530–1570 nm
Hydrogen fluoride chemical	2600–3000 nm
Quantum cascade (semiconductor)	3000 nm–50 μm
Deuterium fluoride chemical	3500–4500 nm
Carbon monoxide	5000–6000 nm
Carbon dioxide	9000–11000 nm

important types of lasers and their typical output wavelengths in nanometers.

Most lasers are called “monochromatic” (single-colored) and actually emit at a narrow range of wavelengths at any one time. However, some can be operated across a range of wavelengths, as shown in Table 1-1. Exactly what that range means depends on the type of laser. In some cases, the specific composition of the laser material or the design of the optics limit the laser to a narrow range of wavelengths. In other cases, the laser can emit across much or all of the range with suitable optics. You will learn more about the specifics of these lasers in Chapters 7–10.

1.4.2 Beam Power

Beam power measures the amount of energy a laser beam delivers per unit time. It is measured in watts and defined by the formula

$$\text{Power} = \frac{\Delta\ \text{energy}}{\Delta\ \text{time}} \tag{1-1}$$

One watt of power equals one joule (of energy) per second.

The powers of steady laser beams range from less than a milliwatt (0.001 watt) to kilowatts (thousands of watts), but instantaneous power can be much higher in brief intervals. No single laser emits across that entire range of power, and many types of lasers cannot be scaled beyond milliwatt or watt levels.

Note that the beam power means the total power in the whole beam, not the power per unit area, which is also important. One attraction of the laser beam is that it concentrates light energy onto a small area, and that suitable optics can also focus the light to a very small spot, producing high powers per unit area.

1.4.3 Time Variation of Output Power

Lasers may generate pulses or continuous beams, but some types can only produce pulsed beams. Pulses vary in length, typically from milliseconds (10^{-3} second) to femtoseconds (10^{-15} second). Typically, pulses are repeated at a steady rate, ranging from once a minute to billions of times a second; the repetition rate is often given in the units of hertz, or pulses per second.

The instantaneous power is the rate of energy emission, which rises and falls during a pulse. Short pulses concentrate energy in time, so the peak power in a pulse can be very high although the total amount of energy remains modest. For example, if a pulse delivers 10 millijoules of energy in 10 femtoseconds, average power during the pulse is 10^{12} watts, or 1 terawatt.

Some lasers inherently operate in a pulsed mode. Others are modulated externally or internally to generate pulses of desired characteristics. Time variation of laser output is very important both for communicating information and for controlling how the laser beam interacts with materials.

1.4.4 Beam Divergence and Size

A laser beam in dusty air looks as thin as a string or a pencil line, but beyond a meter or so from the laser, the beam actually is spreading at a very small angle. This spreading is called *divergence,* and is shown in Figure 1-4. Beam divergence depends both on the type of laser and on the external optics. Semiconductor lasers naturally have a high divergence, but external optics can focus their output into a pencil-like beam.

Typically, laser beam divergence is measured in milliradians, or thousandths of a radian, a unit equal to 0.057 degree. As long as the beam divergence is small, this is quite handy, because you can estimate the radius of a laser spot at a distance *D* from the laser by multiplying the distance by the divergence in radians. Thus, a 2-milliradian beam spreads to a 0.2 meter spot at a distance of 100 meters. This high directionality of the laser beam is important in many applications.

1.4.5 Coherence

Light waves are *coherent* if they are all in phase with one another. Figure 1-5 compares coherent and incoherent light waves. The

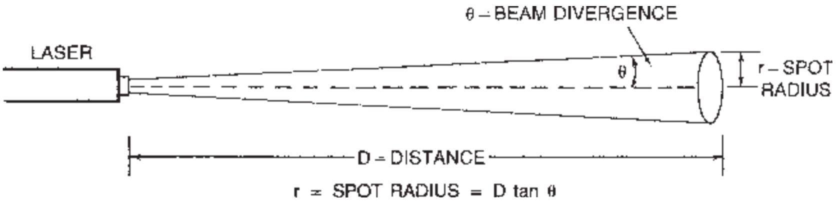


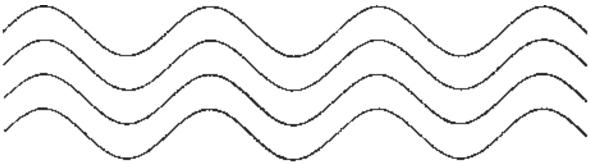
Figure 1-4. Calculating the size of a laser spot from the beam divergence.

peaks and valleys of coherent light waves (top of Figure 1-5) are all lined up with each other. The peaks and valleys of incoherent light waves (bottom of Figure 1-5) do not line up. Stimulated emission is in phase with the light that stimulates it, so laser light is coherent. The sun, light bulbs, flames and other sources that generate spontaneous emission are incoherent.

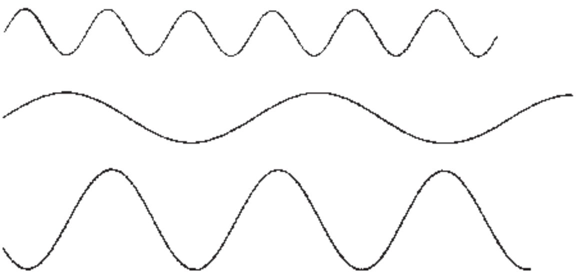
The coherence of laser light is related to the narrow range of wavelengths emitted. The more monochromatic the light, the more coherent it is, and the longer the distance over which the light waves will remain in phase. Monochromatic light need not be coherent, but light that is not monochromatic cannot stay coherent over a long distance. Lasers are the only light sources that can readily generate light that is coherent over relatively long distances.

1.4.6 Efficiency

How efficiently lasers can convert input energy into output light varies widely. The least efficient types may convert only 0.001% of the input light into laser energy, but the most efficient types can convert well over half the input power into light. Efficiency is particularly important in high-power applications, because all the



(A) Coherent light.



(B) Incoherent light.

Figure 1-5. Coherent (A) and incoherent (B) light.

input energy that does not emerge in the laser beam winds up as heat that must be dissipated from the laser. Generating a kilowatt of laser power requires five kilowatts of input if the laser is 20% efficient, but 1000 kilowatts is needed if the laser is only 0.1% efficient.

1.5 HOW LASERS ARE USED

Scientists and engineers began playing with lasers almost as soon as they could lay their hands on one after the laser was invented. They fired lasers at just about everything that could not run away. They shot so many holes in razor blades that for a while laser power was informally measured in "gillettes." Yet few practical applications emerged quickly, and for a while the laser seemed to be, as Irnee D'Haenens told Ted Maiman soon after they made the first one, "a solution looking for a problem."

We are long past that stage. Lasers have become standard tools in industry and research. They align construction equipment, transmit voice and data around the globe, and perform exquisitely sensitive measurements that have earned a fair number of Nobel Prizes. Table 1-2 lists a sampling of laser applications, and Chapters 11–13 cover those applications in more detail.

Lasers are used in diverse ways. The final three chapters divide laser applications into three broad categories.

Chapter 11 covers low-power applications. One broad family of such applications uses lasers as sources of highly controlled light for transmitting and processing information, such as reading or writing data or transmitting signals. For example, the laser in a CD player is focused onto a tiny spot as the CD spins beneath it, and the player reads data recorded on the disk by observing how the light is reflected. The coherence of lasers makes it possible to create and display three-dimensional holographic images.

Another broad category of low-power applications are in measurement. Laser beams travel straight through the air, so they can draw straight lines to assist in alignment of walls or pipes during construction projects. Precision techniques can take advantage of the coherence of lasers to measure distances to within a fraction of the wavelength of light. Laser radars can measure the velocity of objects, including speeding cars for police speed traps. Scanning laser systems can record three-dimensional profiles of the surfaces of objects.

Table 1-2. A Sampling of laser applications

Information handling
Fiber-optic communications
Laser printers for computer output
Playing DVD or Blu-Ray video
Playing CD audio
Reading and writing computer data on CDs and DVDs
Reading printed bar codes for store checkout and inventory control

Measurement and Inspection
Detecting flaws in aircraft tires
Exciting fluorescence from various materials
Illuminating cells for biomedical measurements
Measuring concentrations of chemicals or pollutants
Measuring small distances very precisely
Measuring the range to distant objects
Measuring velocity
Projecting straight lines for construction alignment and irrigation
Studies of atomic and molecular physics

Medicine and Dentistry
Bleaching of port-wine stain birthmarks and certain tattoos
Clearing vision complications after cataract surgery
Dentistry
Refractive surgery to correct vision
Reattaching detached retinas
Shattering of stones in the kidney and pancreas
Treatment of diabetic retinopathy to forestall blindness
Surgery on tissue rich in blood vessels

Materials Working
Cutting, drilling, and welding plastics, metals, and other materials
Cutting cloth
Cutting titanium sheets
Drilling materials from diamonds to baby-bottle nipples
Engraving wood
Heat-treating surfaces
Marking identification codes
Semiconductor device manufacture

Military
Range-finding to targets
Simulating effects of nuclear weapons
Target designation for bombs and missiles
War games and battle simulation
Antisatellite weapons
Antisensor and antipersonnel weapons
Antimissile weapons

Table 1-2. *Continued*

Other applications
Basic research
Controlling chemical reactions
Displays
Holography
Laser light shows
Laser pointers
Three-dimensional profiling and modeling

Chapter 12 covers high-power applications, in which a laser beam delivers energy that alters the material it hits. Lasers deliver small bursts of energy to mark painted metal surfaces; the laser vaporizes the paint, exposing the shiny metal. More powerful lasers can drill holes through materials ranging from baby-bottle nipples to sheets of titanium. The laser beam does not bend soft materials like latex nipples, and does not grow dull like a drill bit.

Laser surgery works in the same way. Pulses from an ultraviolet laser can vaporize tissue from the surface of the eye, precisely removing just the right amount to correct vision defects. By selecting the right laser wavelength, surgeons can bleach dark birthmarks or tattoos.

The ultimate in high-power lasers are high-energy laser weapons. You can think of them as performing materials-working on unfriendly objects. A laser weapon might blind the sensor that guides a missile, causing it to go astray. Or a higher-energy laser might heat or punch holes in the fuel tank of a missile so it explodes before reaching its targets.

Chapter 13 covers laser applications in scientific research. Laser techniques can slow atoms to a virtual crawl and probe their energy states with exquisite precision. Laser beams can manipulate tiny objects, from bacteria to single atoms. These laser applications have led to several Nobel Prizes.

1.6 WHAT HAVE WE LEARNED?

- Most lasers are tiny semiconductor chips inside of electronic equipment.
- Lasers have become so commonplace you can buy a laser pointer as a toy for $10 or less.

- LASER is an acronym for "light amplification by the stimulated emission of radiation."
- Many people initially thought of lasers as science-fiction "death rays."
- Stimulated emission of light by excited atoms generates laser radiation.
- Charles Townes conceived of the amplification of stimulated emission for microwaves.
- Theodore Maiman demonstrated the first laser using a ruby rod pumped by a photographic flashlamp.
- Successful operation of a laser requires both an optical resonator and a suitable material.
- The three main classes of lasers are gas, semiconductor, and solid-state lasers. Note that solid-state differs from semiconductor in the laser world.
- Lasers can emit a very narrow range of wavelengths.
- Laser light is concentrated in a beam, which generally is tightly focused.
- Laser light is coherent.
- Low-power laser applications include measurement and information processing.
- High-power laser applications modify materials for tasks including surgery, machining, and weapons.
- Lasers can make precision measurements for scientific research.

WHAT'S NEXT?

The first step in understanding lasers is to learn the basic principles of physics and optics that are involved in laser operation. Chapter 2 introduces the essential physical concepts. Some of this material may be familiar if you have been exposed to physics before, but you should review it because later chapters assume that you understand it.

QUIZ FOR CHAPTER 1

1. The word laser originated as
   a. A military codeword for a top-secret project
   b. A trade name

    c. An acronym for Light Amplification by the Stimulated Emission of Radiation
    d. The German word for light emitter
2. The first laser was made by
    a. Charles Townes
    b. Theodore Maiman
    c. Gordon Gould
    d. Arthur Schawlow
    e. H. G. Wells
3. Most lasers today are
    a. Semiconductor devices used inside electronic equipment
    b. High-power weapons used in ballistic missile defense
    c. Gas-filled tubes emitting red light
    d. Ruby rods powered by flash lamps
    e. Ruby rods powered by LEDs
4. Laser light is generated by
    a. Spontaneous emission
    b. Gravity
    c. Stimulated emission
    d. Microwaves
    e. Mirrors
5. What emits light in a ruby laser?
    a. Aluminum atoms
    b. Sapphire atoms
    c. Oxygen atoms
    d. Chromium atoms
    e. Mirrors on the ends of the rod
6. Why is a semiconductor laser sometimes called a diode laser?
    a. Because the first diode lasers had to be installed in vacuum tubes so the semiconductor would not evaporate.
    b. Because the semiconductor is electrically a diode, powered by current flowing through it.
    c. Because it is powered by light from an external light-emitting diode.
    d. Because it's an acronym for "damn idiotic optical device exploded," which is what happened to the first one.
7. Which is not considered a low-power laser application?
    a. Laser illumination of a dark birthmark called a port-wine stain to bleach it
    b. Playing a CD or DVD
    c. A computer laser printer

   d. A laser system used by surveyors for measurement
   e. A laser radar used by police to spot speeders
8. Why might a laser be attractive for use as a weapon to hit a target a long distance away?
   a. It's easy to make lasers very powerful.
   b. Lasers look neat and the enemy would run away if they saw them.
   c. Laser beams travel at the speed of light, so they would be easier to aim at a moving target than a missile that took a long time to reach it.
   d. You can buy laser pointers for $10 each.
9. Stimulated emission generates light waves that are in phase with each other. This makes them
   a. A beam
   b. Coherent
   c. Pulsed
   d. Span a range of wavelengths
10. How many lasers do you own? There's no single "right" answer, but it's fun to take a mental inventory. Don't forget that some devices contain multiple lasers, such as combination DVD/CD players.