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. After a brief introduction to lasers, this chapter will introduce important laser properties and applications.

1.1 LASERS, OPTICS, AND PHOTONICS

To understand lasers, you should first understand where lasers fit into the broader science and technology of light. That field was long called *optics*, but now part of it is sometimes called *photonics*. The differences in the meanings of the two words reflect how the field has changed since the mid-20th century, and understanding those differences will help you understand both lasers and the larger world of light, optics and photonics.

Optics dates back to the origin of lenses in ancient times. It is the science of telescopes, spectacles, microscopes, binoculars, and other optical instruments that manipulate light using lenses, mirrors, prisms, and other transparent and reflective objects. Isaac

Understanding Lasers: An Entry-Level Guide, Fourth Edition. Jeff Hecht.

Newton famously described the fundamentals of optics in his 1704 book *Opticks*. He thought light was made of tiny particles, but a century later an experiment by Thomas Young indicated light was made of waves, and opinion shifted for a while.

In the late 19th century, physicists discovered that light was a type of electromagnetic radiation, along with radio, infrared, ultraviolet, X-rays, and gamma rays. They differ in the lengths of the waves and in how fast they oscillate. The wavelength and frequency depend on each other because electromagnetic waves always travel at the speed of light. In the early 20th century, Albert Einstein showed that electromagnetic radiation could behave both as particles—called *photons*—and as waves, depending on how you looked at them. The only fundamental difference among electromagnetic waves was their wavelength, which could also be measured as frequency or (photon) energy.

The science and technology of light have also grown increasingly connected with electronics in the past century. Electronic devices can measure light by converting it into electronic signals and measuring them. Television cameras and displays include both optics and electronics. The first electronic circuits used vacuum tubes, but semiconductor devices began replacing tubes in the mid-20th century. That brought a new generation of *electro-optic* devices, including semiconductor electronics that emitted and detected light, converting signals and energy back and forth between photons and electrons.

In the late 20th century, the word *photonics* was coined to describe devices that manipulate photons, like electronics manipulate electrons. The use of the new term became controversial because many people who worked in optics in the field saw it as an attempt to “rebrand” their profession. Photonics has come to refer to things that manipulate light when it acts more like a particle (a photon) than a wave. By that definition, a laser or a sensor that converts light (a series of photons) into an electronic signal is considered photonics, but a lens that refracts and focuses light waves is considered optics. However, that definition remains somewhat hazy. Today, both terms are used, but at this writing, Google tells us that optics remains far ahead, indexed on 622 million web pages, compared to a mere 17.6 million for photonics.

Whatever you want to call the field, you should learn the physical basics of light, optics and photonics, to understand how lasers work. Chapter 2 will go into more detail.

1.2 UNDERSTANDING THE LASER

The laser was born in 1960, long before the word “photonics” came into use. Lasers retain a youthful image, thanks largely to continuing advances in the technology. They vary widely. Some lasers are tremendously sophisticated and incredibly precise scientific instruments costing tens or hundreds of thousands of dollars. Others are tiny semiconductor chips hidden inside optical disk players or pen-shaped red pointers used as cat toys. The world’s biggest laser, the National Ignition Facility at the Lawrence Livermore National Laboratory, cost over a billion dollars and fills an entire building. The tiny lasers inside CD or DVD players are the size of grains of sand and cost pennies apiece. Red laser pointers sell for only a few dollars and are often given away.

We now take many laser applications for granted. For decades, laser scanners at store checkouts have read bar codes printed on packages to tally prices and manage their inventory. Laser pulses carried through optical fibers are the backbone of the global telecommunications network. Builders use laser beams to make sure walls and ceilings are flat and smooth. Offices use laser printers to produce documents. Medical and scientific instruments use lasers to make precise measurements. Lasers cut sheets of metals, plastics, and other materials to desired shapes, so some parts of your car are likely made with a laser. Chapters 12–14 describe many more examples.

Laser light has special properties that make it useful in many ways. You can think of a laser as a very well-behaved light bulb, emitting a narrow beam of a single color rather than spreading white light all around a room. You would not use a laser to illuminate a room, but you can use a tightly focused single-color laser beam to make precise measurements, to transport information around the world at the speed of light, or to cut sheets of metal. Lasers have become tools in industry, medicine, engineering, and science, as well as components in optical systems.

Lasers come in many forms. The most common lasers are tiny semiconductor chips that look like tiny pieces of metallic confetti; untold millions of them are hidden inside electronic devices, measuring devices, and communication systems. Others are glassy or crystalline solids in the form of rods, slabs, or fibers. Some are tubes filled with gases that emit laser light. Some emit light so feeble that the eye can barely detect it; others are blindingly bright; and many emit infrared or ultraviolet light outside the human visible spectrum. Some perform delicate surgery; others weld sheets of metal. Lasers are used by construction workers installing ceilings and by scientists detecting gravitational waves.

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" that gave us the word "LASER." We will start by explaining what makes laser light differ from that from the sun, light bulbs, flames, and other light sources.

1.3 WHAT IS A LASER?

Each part of the phrase "light amplification by the stimulated emission of radiation" has a special meaning, so we will look at it piece by piece, starting from the final word.

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 details in Chapter 2.

Stimulated emission tells us that lasers produce light in a special way. The sun, flames, and light bulbs all emit light *spontaneously*, on their own, in order to release extra internal energy. Lasers contain atoms or molecules that release their extra energy when other light *stimulates* them. You will learn more about that process, called stimulated emission, in Chapter 3.

Amplification means increasing the amount of light. In stimulated emission, an input light wave stimulates an atom or molecule to release its 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, amplifying the light signal more. It may be easier to think of stimulated emission as one light photon tickling or stimulating an atom or molecule so it releases an identical photon, which in turn can stimulate the emission of another identical photon, producing a cascade of photons that amplifies the light.

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

It took decades to put the pieces together. Albert Einstein suggested the possibility of stimulated emission in a paper published in 1917. Stimulated emission was first observed in the 1920s, but physicists long expected it to be much weaker than spontaneous emission. The first hints that stimulated emission could be stronger came in radio-frequency experiments shortly after World War II. In 1951, Charles H. Townes, then at Columbia University, thought of a way to stimulate the emission of microwaves. His idea was to direct ammonia molecules carrying extra energy into a cavity that would reflect the microwaves back and forth through the gas. 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. 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 emission at that frequency from ammonia molecules, to amplify the signal.

In principle, the maser process could be extended to other types of electromagnetic waves, and in 1957, Townes started looking into prospects for an optical version of the maser. Early in his research, he talked with Gordon Gould, a Columbia graduate student who was using light to energize material he was studying for his doctoral research, a then-new idea called *optical pumping*. Townes soon enlisted the help of his brother-in-law, Arthur Schawlow, to work on the optical maser project. Gould, who dreamed of becoming an inventor, quietly tackled the same idea. They essentially solved the same physics problem independently, by placing mirrors at each end of a cylinder so the laser light could oscillate between them. Gould set out to patent 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.” After a long series of legal battles, Gould earned tens of millions of dollars from his patent claims. However, a third physicist won the race to make the

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.)

first laser. On May 16, 1960, Theodore Maiman used a photographic flashlamp to excite a fingertip-sized crystal of synthetic ruby to emit pulses of red light from the world’s first laser at Hughes Research Laboratories in Malibu, California. Figure 1-1 shows Maiman and his assistant Irnee D’Haenens holding a replica of his elegant little device.

The ruby laser illustrates how a laser works. Energy from an external source, the lamp, was absorbed by chromium atoms in the ruby cylinder. A few chromium atoms spontaneously emitted photons of red light, which traveled through the ruby. Silver film coated on the ends of the cylinder reflected the red photons back into the ruby, where they stimulated other excited chromium atoms to emit identical photons in the same direction, amplifying the light. Those photons bounced back and forth between the end mirrors, oscillating (as explained in Box 1.1) within the cavity formed by the two mirrors, with some light emerging through a hole in one coating to form the laser beam. The light was all at the same wavelength, 694 nanometers (1 nm = 10^{-9} meter) at the red end of the visible spectrum. It was also coherent, with all the waves aligned with each other and marching along in step like soldiers on parade.

Maiman's laser emitted a pulse of laser light every time the flashlamp fired, and pulsed operation proved attractive for some uses. Other lasers generated a continuous beam, which was attractive for other purposes. New laser materials followed, including crystals and glasses containing various light-emitting elements, tubes filled with mixtures of light-emitting gases, and tiny chips of semiconductor compounds such as gallium arsenide or gallium nitride, which today are the world's most common lasers.

BOX 1.1 LASER OSCILLATION

Stimulated emission amplifies light in a laser, but the laser itself is called an oscillator because it generates a beam on its own rather than amplifying light from an outside source. So you may wonder why the word "laser" comes 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 a version of the maser that used light, 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, coining the acronym for light amplification by the stimulated emission of radiation. 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 to be a winner.

Lasers operate at wavelengths from the far infrared all the way to 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 trillionth of a second. Chapters 2 through 5 will describe the basics of laser physics in more detail. Chapters 6 through 11 will describe various types of lasers, and Chapters 12 through 14 will explain important and important uses of lasers. But first let's take a quick look at various types of lasers and their properties.

1.4 LASER MATERIALS AND TYPES

Laser performance depends strongly on the materials from which they are made. Maiman won the laser race because he knew the optical properties of ruby and designed his laser to take advantage of them.

The ruby laser worked because Maiman used a flash lamp to produce a bright pulse of visible light that excited chromium atoms in the ruby rod to a higher energy level. The chromium atoms remained in that high energy level until they released their energy as red light and dropped to a lower energy level. Some of those photons then stimulated emission from other chromium atom, which also emitted red light, producing a cascade of red light that became a laser pulse. Figure 1-2 shows the basic idea.

Ruby is an example of a *solid-state laser*, in which light-emitting atoms are distributed in a transparent solid. In ruby, the transparent material is sapphire (aluminum oxide or Al_2O_3) and the light-emitting atoms are chromium. Such transparent solids do not conduct electric current, so the light-emitting atoms must be excited by light from an external source, such as a flash lamp or another laser, a process called *optical pumping*. Typically small quantities of light-emitting elements such as neodymium, erbium, and ytterbium are added to transparent crystals, glasses, and ceramics, which are shaped into rods, thin disks, slabs, or optical fibers for use in lasers.

Some solid-state lasers are excited with flash lamps or with bright lamps that emit continuously. Others are excited by light from other lasers, usually semiconductor diodes. Chapter 8 describes solid-state lasers in more detail. Chapter 9 describes fiber

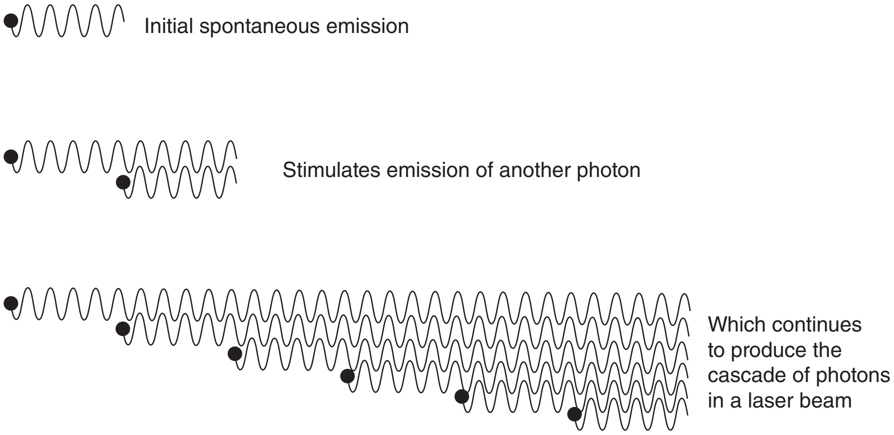


Figure 1-2. A single spontaneously emitted photon triggers stimulated emission from excited atoms, building up a cascade of stimulated emission. In ruby, the excited atoms are chromium.

lasers, a type of solid-state laser distinct and important enough to deserve their own chapter.

A second broad class of lasers are *gas lasers,* covered in Chapter 7, in which a light-emitting gas or vapor is confined inside a hollow tube with mirrors on the ends. Passing an electric discharge through the gas excites the atoms to states in which they can generate stimulated emission. Important examples are the helium–neon, rare-gas-halide and carbon dioxide lasers, described in more detail in Chapter 7. Gas lasers have been replaced by solid-state lasers for many applications but remain in use for others.

A third broad class are *semiconductor lasers,* which, in the laser world, are considered distinct from solid-state lasers. Most semiconductor lasers are called *diode lasers* or *laser diodes* because they have two electrical terminals, and current flows in only one direction between the terminals to generate stimulated emission inside the semiconductor, as you will learn in Chapter 10. Semiconductor lasers are versatile devices that can play many roles in laser technology. Some are tiny, cheap, and low-power devices used in CD, DVD, and Blu-Ray players, and laser pointers. Others are larger devices that emit hundreds of watts and can convert more than half of the electrical energy passing through them into light, for use in pumping solid-state lasers or in some industrial applications.

Chapter 11 describes a few lasers that have found important applications but do not fall into the broad categories of gas, solid-state, fiber, or semiconductor lasers. It also covers a number of light sources that generate laser-like light but do not exactly fall under the definition of lasers. Many are nonlinear devices that shift laser light to other wavelengths in various ways.

1.5 OPTICAL PROPERTIES OF LASER LIGHT

The practical importance of lasers comes from the unusual properties of 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 and energy
- Variation of beam power with time (e.g., pulse duration)
- Beam divergence and size
- Coherence
- Efficiency

1.5.1 Wavelength(s)

Most lasers are called *monochromatic*, meaning single-colored, but that single wavelength generally can be adjusted a little or a lot, depending on the light-emitting material in the laser and on the optics used in the laser. The laser material determines the range of possible wavelengths; the optics select which of those the laser emits. The details can become complicated and are covered in Chapters 3 and 4.

Lasers typically operate in the ultraviolet, visible, and infrared parts of the spectrum. Table 1-1 lists some important lasers emitting in that range, their primary wavelengths, and the chapters that describe them. In addition, it is possible to generate additional wavelengths from these lasers, some of which can be quite important, such as the 532-nanometer green line produced by generating the second harmonic of the 1064-nm line of neodymium, as described in Section 5.6. Thousands of other laser lines have been demonstrated in the laboratory, but most are not used regularly.

Table 1-1. Some important lasers and their wavelengths

Laser name and type	Wavelengths	Chapter
Argon fluoride (ArF) gas, excimer	193 nm	7
Krypton fluoride (KrF) gas, excimer	248 nm	7
Organic dye, liquid	320–1000 nm	11
Nitride diode (InGaN), semiconductor	375–525 nm	10
Argon ion, gas	488, 514.5 nm	7
Helium–neon, gas	632.8 nm	7
InGaAlP, semiconductor	635–660 nm	10
GaAsP, semiconductor	670 nm	10
Titanium–sapphire, solid-state	700–1000 nm	8
GaAs/GaAlAs, semiconductor	780–905 nm	10
InGaAs, semiconductor	915–980 nm	10
Ytterbium, fiber, solid-state	1030–1080 nm	9
Neodymium, solid-state	1060, 1064 nm	8
InGaAsP, semiconductor	1150–1650 nm	10
Erbium, fiber, solid-state	1530–1600 nm	8, 9
Quantum cascade, semiconductor	4–12 μm	10
Carbon dioxide (CO_2)	9–11 μm	7

1.5.2 Beam Power, Energy, and Intensity

Power is a critical quantity for laser beams, and it can be measured in three different ways that give distinctly different information.

Power measures the rate of energy delivery by a laser beam. It is important to remember that power is the amount of energy delivered per unit time. It is 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. Strictly speaking, power measures how fast energy is being delivered at any given instant, so it varies with time for pulsed lasers, but is nominally constant for continuous lasers. If a laser emits a series of pulses, it can also be measured by its *average power*, the sum of the pulse energies divided by the time covered. The powers of continuous laser beams range from less than a milliwatt (0.001 watt) to over a hundred kilowatts (100,000 W), and the average powers of repetitively pulsed lasers are similar. *Peak power* measures the maximum rate of power delivery during a laser pulse and can reach much higher levels.

Energy in joules measures the total amount of energy delivered during an interval. Typically, it measures the energy delivered by a single laser pulse. The shorter the time the laser takes to deliver a given energy, the higher the peak power.

Intensity measures the power deposited per unit area. The smaller the laser spot, the higher the intensity and the more it affects what it illuminates. Think of how bright sunlight may warm a piece of paper, but focusing sunlight through a magnifier can heat the paper so it burns in a small spot.

All of these quantities are important and will be discussed in more detail later.

1.5.3 Laser Variations in Time

Some lasers can emit continuous beams, but others are limited to emitting pulses because of their internal physics. Continuous lasers can be turned on and off by modulating their output in some way. The details differ among laser types, and we will explain them when we cover the individual laser types. Inherently pulsed lasers typically fire a series of pulses at regular intervals, but some fire only a single laser shot at a time.

The length of laser pulses can vary widely, ranging from milliseconds (10^{-3} second) to femtoseconds (10^{-15} second). The pulse timing and spacing may depend on the physics of the laser, but these can also be controlled by the operator. One approach is to modulate the input power so the laser switches on and off, as when you turn a laser pointer on and off. Another way to control output is by using optical accessories described in Chapter 5. Modulating laser output can be very important and will be explained later in this book.

1.5.4 Beam Appearance, Divergence, and Size

You cannot see a laser beam in the air unless something reflects the light toward you, such as smoke or fog in the air or the beam hitting a wall or your hand. When the beam emerges from the laser, it has a diameter that depends on the size of the output optics. For small lasers such as red laser pointers, this typically is a millimeter or two and looks as thin as a string or a pencil line.

Although a laser beam looks straight to your eyes, it actually spreads at a very small angle, called the *divergence,* which is shown in Figure 1-3. The divergence depends both on the type of the laser

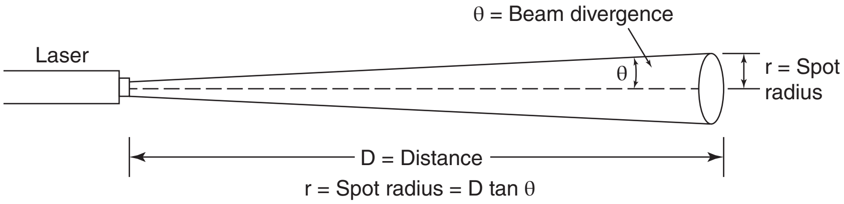


Figure 1-3. Calculating the size of a laser spot from the beam divergence.

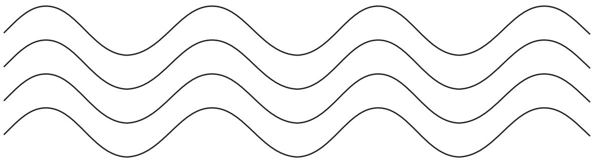
and on the external optics. Most semiconductor lasers have beams that spread widely, but laser pointers typically have optics added to focus the beam into a narrow pencil-like beam.

Typically, laser beam divergence is measured in thousandths of a radian, a milliradian, a unit equal to 0.057 degree. As long as the beam divergence is small, 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 for many applications.

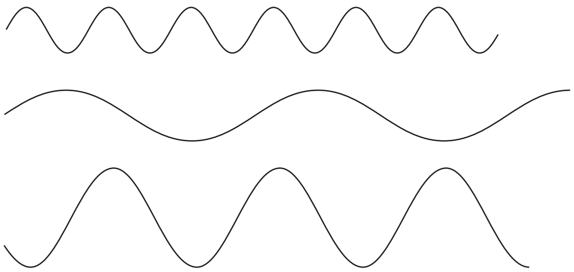
1.5.5 Coherence

Stimulated emission makes laser light coherent because output photons have the same wavelength and phase as the input photons that stimulate emission. This makes laser light *coherent*, with the peaks and valleys of the waves marching in phase like soldiers on parade. Figure 1-4 compares coherent and incoherent light. The peaks and valleys of coherent light waves (top of Figure 1-4) are all the same length and have their peaks and valleys aligned. The peaks and valleys of incoherent light waves (bottom of Figure 1-4) do not line up. Laser light gets its coherence from stimulated emission. The sun, light bulbs, flames, and most other sources generate spontaneous emission, and their output is incoherent.

The degree of coherence depends on the range of wavelengths emitted, which differs among lasers. A laser that emits only a single wavelength, called *monochromatic*, generally is more coherent than a laser emitting a broader range of colors. 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 of centimeters and up.



(A) Coherent light.



(B) Incoherent light.

Figure 1-4. Coherent (A) and incoherent (B) light.

1.5.6 Energy Conversion Efficiency

Lasers convert other forms of energy into laser light. This conversion efficiency can be very important for some laser applications, and many advances of recent years come from improvements in efficiency. In some early gas lasers, as little as 0.001% of the electrical power that went into the laser emerged as light in the output beam. What made the laser light valuable was that its beam was tightly focused, coherent, and monochromatic.

Many modern lasers convert 10% to 70% of input energy into laser light, and that is vital for applications that require large amounts of laser power, such as cutting and welding metals, or exciting other lasers. Semiconductor diode lasers can convert as much as 70% of the electrical energy passing through them into light. Solid-state fiber lasers can convert over 70% of the light energy powering them into a high-quality laser beam, making them particularly well suited for industrial machining applications.

1.6 HOW LASERS ARE USED?

Scientists and engineers began playing with lasers almost as soon as they could lay their hands on them. They fired laser pulses 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 some laser applications, and Chapters 12–14 cover laser applications in more detail.

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

Chapter 12 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. Laser light transmitted through hair-thin optical fibers is the backbone of the global telecommunications network; it carries phone calls from the cell tower nearest you to anywhere around the world. Lasers inside optical disk players read music from CDs and videos on DVDs and Blu-Ray disks. The coherence of lasers makes it possible to create and display three-dimensional holographic images.

Another broad category of low-power applications is measurement. Laser beams can draw straight lines in space to help construction workers align walls or pipes. Precision techniques use the coherence of lasers to measure distances to within a fraction of the wavelength of light. Laser radars can create three-dimensional profiles of our environment, digitizing dinosaur fossils for paleontologists and helping to steer self-driving cars away from potential roadside hazards.

Chapter 13 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 cutting into a hard material.

Laser surgery works in the same way. Pulses from an ultraviolet laser can vaporize tissue from the lens of the eye, precisely removing just the right amount to correct vision defects. By selecting

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
  - 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
  - Helping guide self-driving cars
- 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 titanium sheets
  - Non-contact machining
  - Drilling materials from diamonds to baby-bottle nipples
  - Engraving wood
  - Heat-treating surfaces
  - Marking identification codes
  - Semiconductor photolithography
  - Three-dimensional printing or additive manufacturing
- Military
  - Range-finding to targets
  - Simulating effects of nuclear weapons
  - Target designation for bombs and missiles
  - War games and battle simulation
  - Antisatellite weapons
  - Anti-sensor and antipersonnel weapons
  - Defense against rockets, artillery, mortars, drones, and small boats

Table 1-2. (*Continued*)

Other applications
Basic research
Controlling chemical reactions
Theater displays
Holography
Laser light shows
Laser pointers
Laser paint removal from aircraft

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 weapon can heat explosives in a rocket to their detonation temperature, soften high-pressure fuel tanks so they fail, or ignite gasoline fumes to catch an engine on fire. Lasers can also detonate unexploded shells left on a battlefield, or defend ships against attacks by drones or small boats.

Chapter 14 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 many Nobel Prizes.

1.7 WHAT HAVE WE LEARNED?

- Optics is the science of light. Photonics is another term for optics, usually covering devices that work on photons rather than on light waves.
- LASER is an acronym for “light amplification by the stimulated emission of radiation.”
- Stimulated emission of light by excited atoms generates laser radiation.
- Most lasers are tiny semiconductor chips.
- Lasers have become so commonplace in many places.
- 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 gain medium to amplify light.
- The three main classes of lasers are gas, semiconductor, and solid-state lasers.
- Fiber lasers are a type of solid-state laser in which the laser is an optical fiber.
- Solid-state is not equivalent to semiconductor in the laser world.
- Lasers can emit a very narrow range of wavelengths.
- Laser light is concentrated in a beam, which is generally 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, 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 code word 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. Which statement is not true
   a. Light sometimes acts as a wave and sometimes acts as a photon
   b. Only laser light acts as photons
   c. Light is a form of electromagnetic radiation

   d. Visible light differs from ultraviolet in wavelength
   e. Electromagnetic radiation includes radio waves
3. Most lasers today are
   a. Semiconductor devices used in electronic equipment
   b. High-power weapons used to deter drone attacks
   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 are most semiconductor lasers sometimes often called diode lasers?
   a. Because the first diode lasers had to be installed in vacuum tubes so the semiconductor would not evaporate.
   b. Because they conduct light between two terminals to generate stimulated emission.
   c. Because it is powered by light from an external light-emitting diode.
   d. Because it is an acronym for "damn idiotic optical device exploded," which is what happened to the first one.
7. You have a laser that emits one watt of light and is 1% efficient. How much of the input power ends up as heat rather than light?
   a. One watt
   b. Three watts
   c. 10 watts
   d. 30 watts
   e. 99 watts
8. You have a laser that emits one watt of light and is 25% efficient. How much of the input power ends up as heat rather than light?
   a. One watt
   b. Three watts

   c. 10 watts
   d. 30 watts
   e. 99 watts

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 is no single “right” answer, but it can be fun to take a mental inventory. Do not forget that some devices may contain multiple lasers, such as a Blu-Ray player that can also play DVDs and CDs.