

# 2

## Principles of Lasers

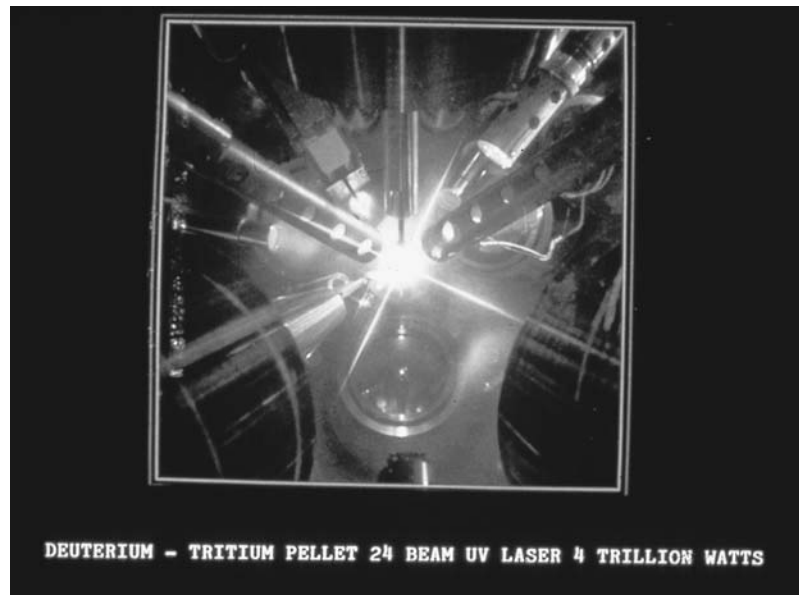
Daniel S.J. Choy

Lasers are now ubiquitous. Before 1960, no working laser existed. First came Townes and Schawlow's concept of the microwave amplification through stimulation of emitted radiation (MASER), followed by the slight change of "microwave" to "light." Then came Maiman's development of the first workable LASER, with a ruby crystal as the lasing medium in 1960.

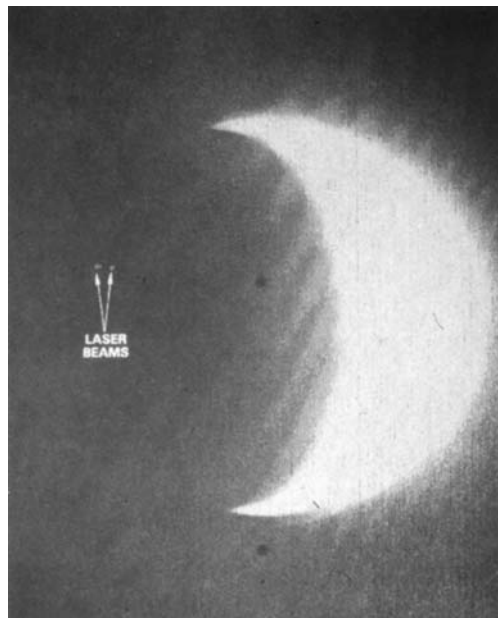
Today, lasers are used in reading of bar codes at supermarket checkout counters, as pointers in the lecture hall, to guide smart bombs, to sculpt corneas, to open arteries, to transmit information bits through optical fibers, to identify deoxyribonucleic acid (DNA) in laser flow cytometry, to perform cellular microsurgery, to flip cells around using *laser tweezers*, to compress deuterium pellets in fusion experiments, to create light shows, and to assassinate intestinal worms.

In a fusion experiment at the Institute of Optics in Rochester, New York, 24 UV laser beams are aimed and fired at the same instant at a deuterium pellet suspended by a fiber from a spider web (Fig. 2.1). The instantaneous compression of the deuterium releases fusion energy; but so far, the amount of energy generated does not surpass the total input energy of the laser beams.

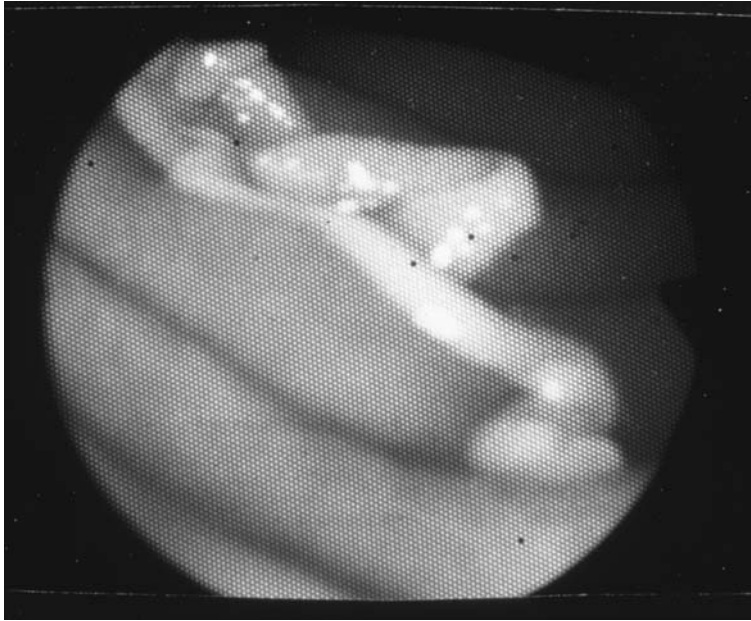
In another experiment illustrating the power and coherence of a laser beam, scientists on mountain tops in Arizona and California aimed two 3-watt argon lasers through telescopes at a dark portion of the moon in the earth's shadow, and the two spots were photographed by a circling spacecraft (Fig. 2.2). Imagine that an ordinary lightbulb is rated at 100 watts, and these two devices were rated only at 3 watts each. Three percent of energy



**Figure 2.1.** Array of 24 UV lasers aimed at a suspended deuterium pellet for a fusion experiment. (Courtesy of Institute of Optics, University of Rochester, Rochester, NY.)



**Figure 2.2.** Two 3-watt argon laser spots projected on the moon, a distance of 230,000 miles from earth, photographed by *Surveyor VII*.



**Figure 2.3.** Endoscopic view of the body of *Taenia saginata* in the intestine of a French patient. (Courtesy of Phillipe Raimbert, MD.)

used by an ordinary lightbulb was enough to power a laser beam able to produce a spot on the moon—230,000 miles away—that could be photographed. Such is the power of a *coherent* light beam.

In a clinical experiment conducted, appropriately enough, in the City of Light, Paris, a gastroenterologist, Dr. Phillipe Raimbert, treated a patient infested with the common tapeworm *Taenia saginata* that had resisted all drug attempts at purging. A Neodymium:YAG (Nd:YAG) laser beam was aimed at the worm's body (Fig. 2.3) and fired at 5 joules. The worm did not like it and raised its head, whereupon the laser was aimed between the "eyes" and 20 joules promptly dispatched the worm (Fig. 2.4), prompting the following headline in a journal, "*Safari au Taenia*" (Fig. 2.5).

How does such a versatile tool work?

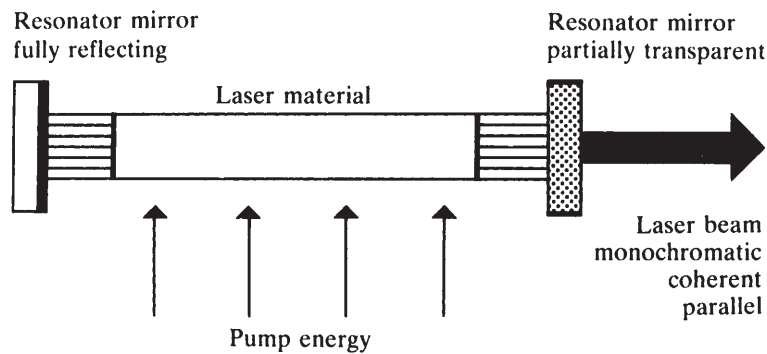
Essentially, a lasing medium, which may be a gas, liquid, or crystal, is contained in a cylindrical tube, or resonator, with a fully reflecting mirror on one end and a partially translucent mirror on the other (Fig. 2.6). External energy, usually in the form of electricity, or sometimes in the form of another laser, is applied to the medium. The electrons are excited and jump to a higher orbit. During decay, as each excited electron falls back to its home orbit, a photon is emitted. This photon is joined by other released



**Figure 2.4.** Right after a laser burst to the body, the worm has raised its head. The laser was then aimed between the *eyes*, effectively terminating the parasite. (Courtesy of Phillipe Raimbert, MD.)



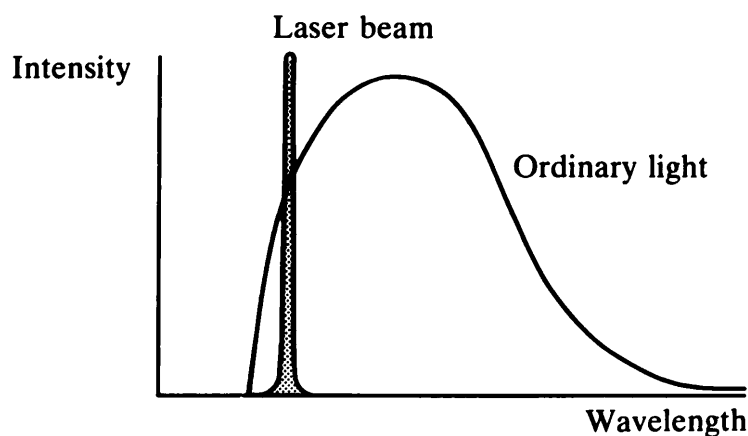
**Figure 2.5.** The headline in a French medical journal announcing the first successful in vivo assassination of a worm by laser. (Courtesy of Phillipe Raimbert, MD.)



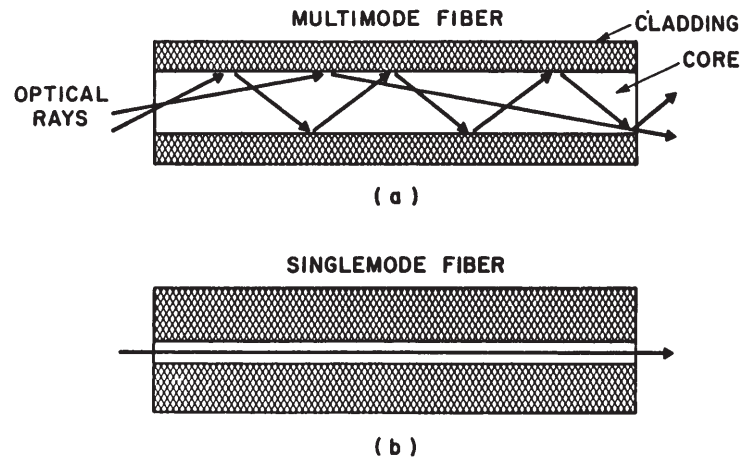
**Figure 2.6.** Diagram of a laser. The resonator tube has a fully reflective mirror on the left and a partially translucent one on the right. The laser beam emits through the right end of the tube as a coherent beam.

photons, and they bounce in all directions. The cylindrical tube favors those that travel along its long axis, and the stream of photons is reflected back and forth between the two mirrors until sufficient strength is achieved to break out through the translucent mirrored end as a coherent stream of photons vibrating in phase, at the same frequency. It is the phase-locked, monofrequency characteristic that gives the laser beam its power and coherence (Fig. 2.7).

Different lasing media produce different wavelengths. Thus the CO<sub>2</sub> laser generates a laser beam with a wavelength of 10,600 nm, the erbium:YAG 2940 nm, the argon 488–514 nm, the Holmium:YAG (Ho:YAG) 2150 nm, the excimer 193 nm, the Nd:YAG 1064 and 1318 nm, the KTP—532 nm, and the diode laser in the range of 800 to 900 nm.



**Figure 2.7.** A laser beam is coherent (in phase) and has monofrequency.

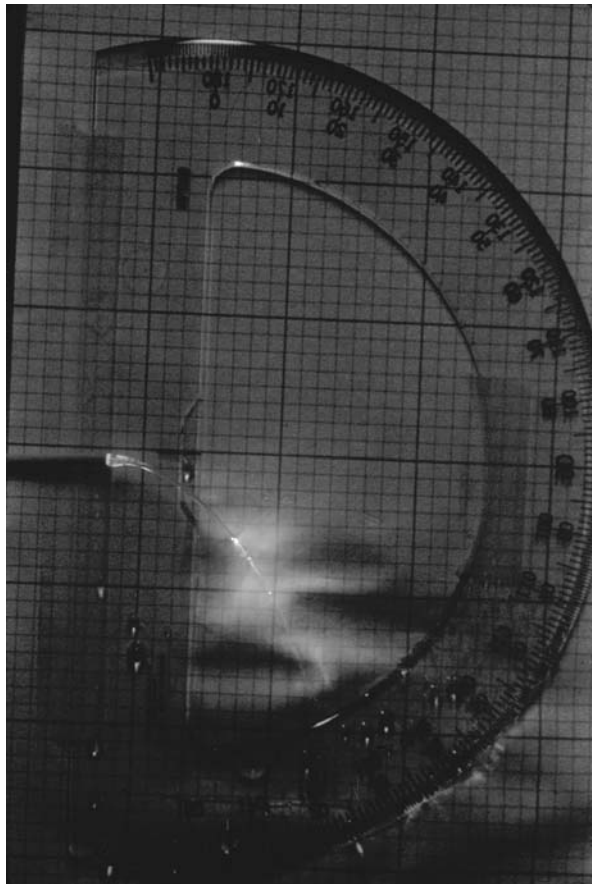


**Figure 2.8.** An optical fiber or waveguide, with a central transparent core and a reflective cladding. The laser beam is internally reflected whether the fiber is straight or curved.

Until the advent of waveguides, or optical fibers, lasers could be transmitted only through a vacuum or through air. In a liquid medium the beam would be rapidly dispersed. To date, there is still no practical waveguide for the CO<sub>2</sub> laser. Hence, the initial application of laser energy in medicine and surgery was not surprisingly in the field of ophthalmology. Argon lasers have been used to coagulate retinal vessels and to create drainage holes in the iris for the treatment of glaucoma. Corneal sculpting with the CO<sub>2</sub> and excimer lasers has made great strides and is Food and Drug Administration (FDA) approved.

In the early 1980s, single-mode and multimode optical fibers (Fig. 2.8) were developed. There is a transparent core, usually of quartz, and a reflective cladding, either of plastic or, to provide a higher melting point, quartz. Will a laser beam traveling down a fiber be continually reflected internally by the reflective cladding until it emerges from the terminal end as a laser beam, or as a noncoherent beam? When I began my first experiments with an argon laser fired through a "laser catheter" for coronary artery angioplasty in 1980, the answer to this question was not definitively known. Several physicists whom I consulted were not sure if the beam, entering the optical fiber as a laser, would emerge as a laser. In an early experiment I was able to show that a stream of water falling in an arc from a catheter would "bend" the laser (Fig. 2.9). Later when I could ignite a paper target with a 3-watt argon laser transmitted through a curved 120-degree quartz fiber, I was convinced that laser input = laser output. Simple as it may seem at this late date, the *transmissibility* of a laser beam through a waveguide *essentially unaltered* was the bedrock

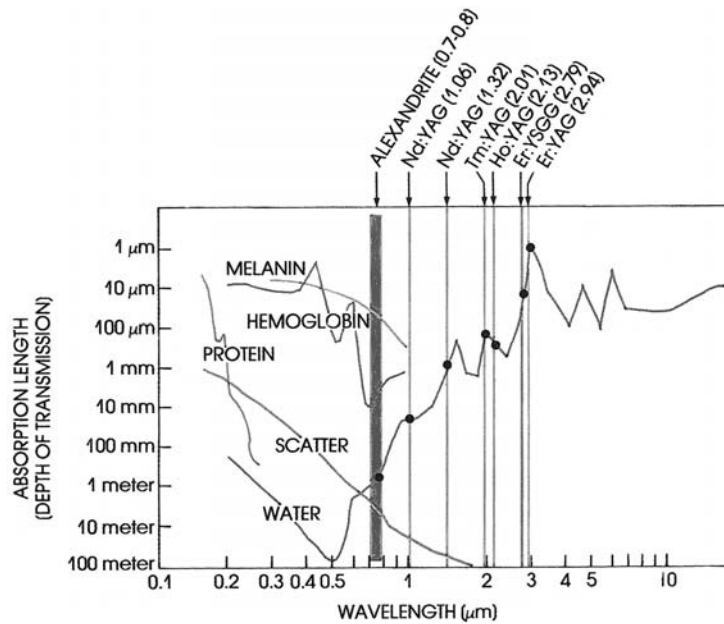




**Figure 2.9.** An early experiment illustrating how a laser beam emerging from a catheter is bent (through internal reflection by the water–air interface) as the water spout falls in a curve from the catheter tip. The critical angle for this continuous wave argon laser, at 3 watts, was 30 degrees. Beyond 30 degrees the laser “broke away” from the stream.

and foundation of present applications of laser in medicine and surgery. Not much has been written about this all-important phenomenon before, but I assure you, it is vital.

It was fine for physics to have developed the laser. But now, how to apply this new tool to medicine and surgery? Of concern to the laser surgeon (new specialty, hence a new name) is how each laser reacts with tissue. First, if a laser beam is absorbed by the tissue there will be heat generation. Thus, the argon laser (green-blue) is well absorbed by hemoglobin (red) and hence found its first application in the eye. When a tissue is transparent or nearly so, most of the laser beam will be transmitted and will therefore exert little effect on this tissue. The  $\text{CO}_2$  laser can generate short pulses of great power and is primarily absorbed



**Figure 2.10.** Laser–tissue interactions at different wavelengths.

by water. It therefore excels at surface cutting, with little penetration power. The Nd:YAG laser has greater penetration and is better suited for coagulation (Fig. 2.10). The excimer laser works through disruption of molecular bonds and excels at making fine cuts with little or no heat generation. It is also known as the “cold laser.” Not all lasers are very efficient; for instance, the argon laser produces only approximately 0.1% of the electrical power needed to activate it.

The remainder of this chapter is devoted to highlighting the essential points made by the late Nobel laureate Arthur Schawlow in his chapter for the 1995 special issue of the *Journal of Clinical Medicine & Surgery* devoted to percutaneous laser disc decompression.

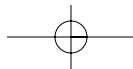
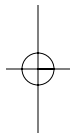
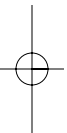
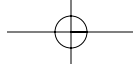
1. Only the free electron laser is adaptable to a wide range of wavelengths and power levels, but its large size and cost will keep it only in large research institutions for the foreseeable future.
2. Shock waves can arise from nonthermal processes such as laser spark breakdown from the high electric fields of a pulsed light beam focused inside a transparent medium.
3. The absorption of red light by the hematoporphyrin dye can activate singlet oxygen molecules that disrupt the cellular nuclei and lead to apoptosis. This is the basis for the photody-



namic therapy of cancer pioneered by Dr. Tom Dougherty, Roswell Park, New York.

4. The monochromaticity of the laser makes possible highly sensitive spectroscopy, in some instances the detection of as little as a single atom of an element.
5. The interference patterns of laser light make possible precise measurements by interferometry and also the emerging field of holography.
6. The helium–neon laser, invented by Ali Javan, is widely used as a handheld pointer in the lecture hall and as an aiming beam in surgical lasers, where the laser beam is invisible, as in the CO<sub>2</sub> and Nd:YAG lasers.

This, then, is the instrument, a product of man's inexhaustible ingenuity, that has revolutionized warfare, marketing, spectrometry, imaging, classroom teaching, holography, cancer therapy, ophthalmology, dermatology, and now spinal surgery.



**Percutaneous Laser Disc Decompression**

**A Practical Guide**

Choy, D.S.J.

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