# Laser Technology

by

Hrand M. Muncheryan,
B. Sc., M. Sc.

# Laser Technology

by

**Hrand M. Muncheryan, B. Sc., M. Sc.**

A Revision of
Laser Fundamentals & Applications
by Hrand M. Muncheryan B.Sc., M.Sc.

Howard W. Sams & Co., Inc.
4300 WEST 62ND ST. INDIANAPOLIS, INDIANA [illegible] USA

SECOND EDITION
FIRST PRINTING—1979



International Standard Book Number: 0-672-21588-8
Library of Congress Catalog Card Number: 79-62989

*Printed in the United States of America.*

# Preface to the Second Edition

During the past five years, since the appearance of the first edition under the title of *Laser Fundamentals and Applications*, there has been a virtual revolution in the laser technology. These years have been filled with intense research activities and a rapid increase in the large-scale application of laser beams. These activities have led to the employment of many technicians and engineers, the practical laser experience of some of them having been achieved by empirical rather than pedagogical methods. The time has come for the laser technology to be treated as modern science of optical phenomena. Thus, the newcomers intending to work in this field could have a formal education in this fast maturing technology just as those graduates presently engaged in the electronic, chemical, or mechanical professions. Laser engineering has emerged from infancy to a mature profession that is recognized and important.

Much thought has been given to the development of the present edition to make it useful to the reader from a primarily practical standpoint of the laser technology rather than from a theoretical principle supported by highly advanced mathematical precepts, since books are already available and excellently treated from that point of view. However, to the engineer who is eager to have a basic concept of laser technology for earning his everyday living, this book combines sufficient theoretical background with practical approach to support a thorough knowledge of laser technology, preparing him to become engaged in the field with a background of authoritative knowledge. To this end, special effort has been made to make this book more sufficient unto itself as the intent of the first edition with the knowledge available at the time of writing.

## PREFACE

In a single text of moderate length as is this book, it is virtually impossible to include details of all the developments of lasers and their applications in the industrial, medical, dental, chemical, military, and aeronautical fields. No attempt has been made in this book to exhaustively treat the subjects included in it. However, a digest of the available knowledge is presented in a form that will benefit both the newcomer to the field and the engineer and technician already engaged in laser activity.

No change in the concept as presented in the first edition has been made, but important changes have been included in the scope and arrangement of the treatments. Several chapters have been combined together under one heading; material in some chapters has been enlarged to include recent advances in the developments and applications of the laser principles; and new material has been inserted to include atomic origin of laser radiations and the optical principles used in the control and judicious application of the radiation energy in the various professional fields including nuclear fission effort. A new chapter for the treatment of atomic structure in relation to radiation energy emission, and electrical concepts and units of measurements have been added to give a comprehensive knowledge to the newcomer as well as to give a background review to the engineer or technician involved in the development and application of the laser technology in new fields of endeavor. The appendixes contain material pertinent to the subjects discussed, including commercial outlets from which devices, instruments, and systems can be procured to carry out tasks detailed in the text.

The author, encouraged by the cordial reception and wide use of the earlier edition of this book, anticipates that this new edition will serve the needs of even greater number of individuals and institutions giving curricula on practical aspects of laser technology. He further hopes that the content of this book will stimulate new lines of thought in both scientific and technical aspects of laser technology.

HRAND M. MUNCHERYAN

# Preface to the First Edition

The discovery of lasers has created much interest both in the general public and among scientists. With this in view, this book is written for those who are making their first acquaintance with laser technology and for those who are now engaged in laser work. It is designed to expand their knowledge and stimulate their imagination so that new laser products can be developed by using the fundamental concepts presented here. The material in this text will help the reader understand the various underlying principles of laser technology. The material is organized so that the reader is progressively introduced to increasingly more complex systems. In this respect, the first chapter discusses the basic fundamentals that are applied in the use and application of lasers in industry and in the scientific laboratory. After the beginner has gained this preliminary knowledge, it is anticipated that he will readily understand the successive chapters covering varied technical and practical laser instrumentation.

The author has refrained from the use of highly mathematical expressions in the treatment of various subjects, but of necessity some exemplary problems have been presented and solutions worked out using a minimum of applicable mathematical relations and physical terms. What little mathematics that has been used is all that one will require in applied developmental work. These mathematical relations are merely introduced to verify and support the technical statements about any one subject treated in this book.

There are many who have wanted a practical, one-volume treatise on lasers that will be easy to understand and that will dispel the mystery of radiation, showing it to be a scientific tool, not a science-fiction implement or an ominous destructive weapon. This volume shows the many ways lasers can be used, such as to facilitate certain industrial operations and to enable surgeons to perform operations that would be difficult and at times impossible by conventional methods. In these respects, lasers have already played prominent roles in cutting, drilling, scribing, and trimming industrial materials. In the medical field, surgery on the brain and on bleeding organs in the body has been possible through the cauterizing action of the laser beam. In dentistry, the use of lasers for restorative dental work is being developed in many scientific and dental institutions. Last, but not least, is the upcoming use of lasers in the optical communication field to replace the bulky and expensive underground or above-ground transmission cables. Lasers are also gradually finding their way into private offices and homes for protection and security purposes. The applications of lasers for making everyday life easier are just beginning to appear; their vast potentialities are still waiting to be exploited for the benefit of mankind. The successful application of a new discovery is not always a simple replacement operation but is often a matter of using the new discovery to complement an application presently in use. Initial approaches to such applications have been suggested in this volume.

The verification of the fundamental principles affecting the laser technology is unquestionably best understood by solving illustrative problems. And to this end, the author has selected a few practical problems and solved them using simple and basic mathematics. This text is developed primarily to be used by itself without supplementary information from other publications. The material contained in it is self-sufficient for practical, informational purposes.

The book has combined classical and quantum theories in the explanation of the laser-emission phenomenon. While it would be easy to compile well-known physical concepts and discuss topics already repeated in many publications, the author refrains from such schemes in order to advance his own method of treatment of the subjects discussed.

It is anticipated that the present treatise on the subject of lasers will fulfill a long-felt need for a complete presentation of practical laser technology and its present, as well as future, potentialities. It is not the intent of this book to be unduly extensive in the treatment of the subject matter. Those occupied in various phases of laser technology may wish to refer to other volumes specializing in a more-theoretical treatment. This book is for the practical solutions to everyday problems that may arise in routine and specialized work.

Appendix I lists a number of well-known manufacturers of laser and laser-oriented equipment. Appendix II contains equivalents of metric system units. Appendix III gives the definitions of some of the commonly used laser terminology, and Appendix IV contains a theoretical explanation of the concepts discussed in this book.

The author is grateful to those laser manufacturers who have permitted the inclusion of photographs of their equipment and some pertinent data.

HRAND M. MUNCHERYAN

# Contents

CHAPTER 1

# Applied Laser Principles

## INTRODUCTION

Laser has been defined as *L*ight *A*mplification by *S*timulated *E*mission of *R*adiation. The word *laser* is an acronym formed by the first letter of each word in its definition. However, to the uninitiated, this definition falls short of an explicit meaning. A simple definition for a laser would be "a light-emitting body with feedback for amplifying the emitted light." As an example, we may take an elementary light emitter or generator, such as a ruby rod of about 1 centimeter in diameter and 15 centimeters long. When this ruby rod is illuminated by a high-intensity light, such as that from a photoflash lamp, the rod fluoresces with a pink color. The fluorescence persists as long as the photoflash light persists. This effect is not a laser radiation, but just another optical characteristic of the emitter, the ruby rod, which is made of aluminum oxide (sapphire) containing 0.05% chromium which imparts to the rod the characteristic pink color.

In laser radiation, the ends of the ruby rod are highly polished so that light can pass through almost without absorption. Also, a mirror is placed at each end and aligned perpendicularly to the principal axis of the rod. When the rod is illuminated with an intense photoflash light, it emits a fluorescent light which reflects back and forth between the two mirrors, with an increase in intensity. This phenomenon, known as light amplification, is produced by the oscillation of the ruby light within an optically resonant cavity formed by the rod and the two reflecting surfaces of the mirrors. The light in the resonant cavity is known as a laser. If the flashlamp illumination (pumping) of the ruby rod continues for a few minutes, the energy accumulated within the ruby rod will be so great that the rod may crack or shatter into pieces. Accordingly, the laser energy must be removed as fast as it develops in the resonant cavity.

The removal of the laser energy, or radiation, from the resonant cavity is accomplished by making one mirror 100% reflective and the other mirror partially reflective. This allows some of the laser light generated within the resonant cavity to pass through as a laser beam of the same diameter as the ruby rod. Also, instead of having two mirrors aligned one at each end of the ruby rod, the highly polished ends can be mirrored or coated with a dielectric material, such as magnesium fluoride or cerium dioxide. One end is fully coated and the other end is partially coated so that the emitted laser light can pass through it. As this beam emerges from the ruby rod, it has a slight divergence, which will be taken up in a later section.

During the illumination (optical pumping) of the ruby rod by the flash lamp, some of the chromium atoms in the ruby rod become excited. This causes their electrons (negative charges) to move away from the atoms and position themselves at higher energy levels, from which they spontaneously fall back to their normal energy states. During this transition, each of these electrons produces a photon of light. These photons now oscillate by reflecting from one mirror surface to the other within the resonant cavity. On their way to the mirror, some of the photons encounter (collide with) one or more atoms, which are in an excited state due to the flashlamp pumping, and interact with them to produce a photon or photons identical in energy and frequency with the initial photon(s). The newly formed photons continue to interact with other excited atoms, producing more photons, and these (photons) continue interacting to produce more photons, and so on. When a threshold energy of the total photonic energy within the resonant cavity is attained, a pulse, consisting of a very intense laser beam formed by photon waves, bursts out of the partially reflective end of the ruby rod. This beam is known as the stimulated emission of laser radiation in which all projecting photon waves propagate in phase, resulting in a coherent laser beam —unlike white light which is not coherent because the light waves are not in phase with each other.

In this book, five types of lasers will be discussed in various laser system applications:

1. *Solid-state rod-type lasers,* which use materials such as ruby, neodymium-doped glass, and neodymium-YAG (yttrium-aluminum-garnet) and in which stimulation for laser emission is the same for all.
2. *Semiconductor diode-type lasers* which use material such as gallium arsenide and which consist of a *pn junction* formed by a *p-type* material and an *n-type* material. In this type of laser,

stimulation to laser emission occurs by passing a current through the pn junction.

3. *Gas-type lasers*, such as the helium-neon laser, the argon laser, the carbon dioxide laser, the nitrogen laser, and the xenon laser. In this type of laser, stimulation to laser emission occurs by passing a current through the gas. The current causes the gas to ionize and radiate. The radiation oscillates within a tube provided with mirrored ends and then discharges from the partially mirrored end of the tube.
4. *Liquid-type lasers* which consist of solutions such as coumarine, rhodamine red, a chelate, etc. In this type of laser, the liquid-laser materials are stimulated to emission by irradiating the lasing (laser-producing) liquid or dye solution with another laser beam, such as that from a ruby, neodymium-YAG, or carbon dioxide laser.
5. *Excimer laser* is an inert-gas halide which is chemically unstable except in its excited state. Examples of an excimer laser are: ArF, XeF, KrCl, XeBr, etc.

Since laser radiation is the same as any electromagnetic radiation in the spectrum between ultraviolet and far infrared, the same optical principles that govern visible light apply to a laser beam. For instance, a laser beam can be reflected, refracted, polarized, and split by means of beam splitters, the same as a light beam can be. Also, the laser beam can be diverged and converged by means of lenses. Accordingly, whenever application of laser beams are discussed in the text, the reader should treat a laser beam optically the same as he would treat a light beam, with the exception that a laser beam is a coherent radiation and is said to be about one-million times more intense than the incident sun rays on the earth. Therefore, he should be aware that both physical and optical dangers exist when dealing with laser beams. For example, when operating a laser machine, looking directly into the rays or reflections of the rays should be avoided. Several brands of goggles suitable for wear while working with externally exposed laser beams are available on the market, and such goggles should be worn by the laser operator.

## CONVERGENCE AND DIVERGENCE OF LASER BEAMS

A laser beam can be converged, or focused, to a point or diverged into a large solid angle by means of optical lenses. A converging lens is a convex lens and can concentrate the beam of a laser to a fine point (as small as 1 micron). A diverging lens is a concave lens, and it diverges the beam when the beam is transmitted through it. A converging lens may be biconvex or planoconvex, meaning one side

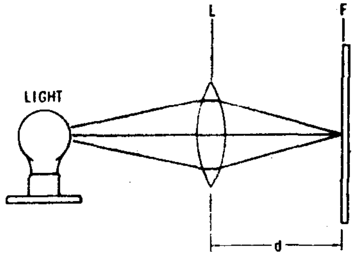


Fig. 1-1. Light beam.

is convex and the other side is plane. Similarly, a diverging lens may be either biconcave or planoconcave (one side is concave and the other side is plane).

The illustrations in Figs. 1-1 through 1-4 demonstrate this. In Fig. 1-1, a light beam projects from an incandescent lamp through a biconvex lens, which converges the beam to a focus on a piece of cardboard. The distance between focal plane F and optical plane L of the lens is called the focal length, d, of the lens. The focal length of the lens must be well remembered because it will play an important role in laser applications to be discussed in the succeeding sections. As can be seen in Fig. 1-2, the laser beam behaves in the same manner, except that the laser-beam focus is sharper.

In Fig. 1-3, the lens is replaced by a biconcave lens which causes the light beam to diverge as it leaves the lens. Similarly, in Fig. 1-4 a laser beam is transmitted through a biconcave lens, which diverges the laser beam.

It will be noted from these illustrations that the incident light beam does not focus sharply because the light beam consists of many wavelengths which refract differently as they pass through the lens. The focal point of the laser beam has a sharper delineation because it is coherent and monochromatic and because the amount of refraction is practically the same for each ray as it passes through both thin and heavy sections of the lens.

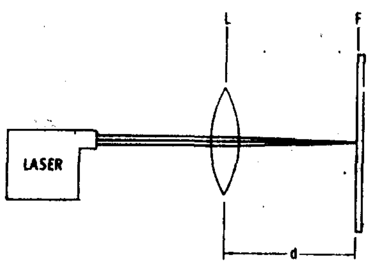


Fig. 1-2. Laser beam.

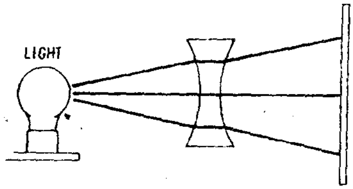


**Fig. 1-3. Divergence of a light beam.**

The principal purpose of a focused laser beam is to increase the intensity of the beam by condensing it into a small area. For instance, a 1-joule (watt-second) laser energy emanating from a ruby rod of ¼-inch diameter can be projected on a thin sheet of metal without any effect on the metal. However, when the ¼-inch diameter laser beam is condensed by means of a convex lens to a focus of, for instance, 5-mil diameter, its intensity increases more than 2000 times. The beam is now capable of drilling a hole of 5-mil diameter through thin metal, for instance steel of 2 mils in thickness. Therefore, by using a convex lens, a laser beam can be used to cut, weld, drill, and remove metal from metallic objects placed at the beam focus. In the medical and dental fields, such a focused beam can be used for cauterizing, cutting, and sterilizing human tissue or glazing human teeth in restorative dentistry. Other dental applications are in glazing fillings for cosmetic purposes and welding dental bridgework.

A combination of a concave and a convex lens is used to collimate (make parallel) the laser beam at any beam diameter desired. Such a beam can then be used in holography, diffraction, optical communication, beam splitting, and many other scientific experiments in the laboratory. Also, in range measurements, alignment, and surveying, a collimated laser beam can be projected to a greater distance than when it is not collimated. This is because the beam diverges (½ milliradian to several milliradians) as it leaves the laser emitter. Furthermore, a collimated laser beam can be focused to a much smaller area, as is necessary in medical surgery and semiconductor processing.

## COLLIMATION OF A LASER BEAM

In order to collimate a laser beam, at least two lenses are required. One is preferably a biconcave lens and the other a biconvex lens. In

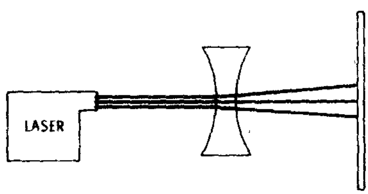


**Fig. 1-4. Divergence of a laser beam.**