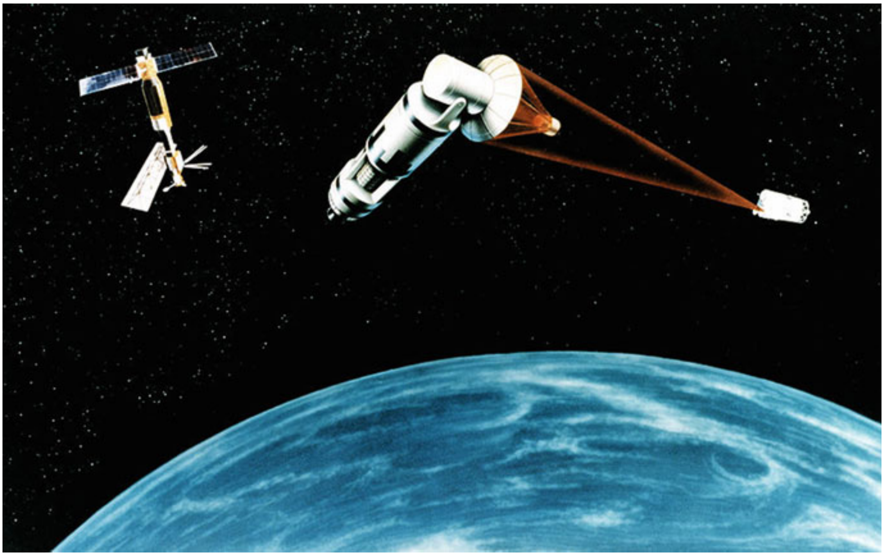
Directed Energy Weapons



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Directed Energy Weapons

Physics of High Energy Lasers (HEL)

Springer

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This book is dedicated to my mother and father Marzieh and Akbar Zohuri.

Without their encouragement, this book would not have been written.

Preface

Directed energy weapons are nothing new to mankind; historically the origination of such weapons began centuries ago when the famous Greek mathematician, physicist, engineer, inventor, and astronomer; Archimedes of Syracuse used different mirrors to collect sunbeams and focused them on the Roman fleet in order to destroy enemy ships with fire. This is known as the Archimedes Heat Ray. Archimedes may have used mirrors acting collectively as a parabolic reflector to burn ships attacking Syracuse. The device was used to focus sunlight onto approaching ships, causing them to catch fire. Of course the myth or reality of the Archimedes Heat Ray still is questionable, but with the help of a group of students from Massachusetts Institute of Technology certain experiments were carried out with 127 one-foot (30 cm) square mirror tiles in October of 2005 that were focused on a mockup wooden ship at a range of about 100 feet (30 m). The flames broke out on a patch of the ship, but only after the sky had been cloudless and the ship had remained stationary for around 10 min. It was concluded the device was a feasible weapon under these conditions.

The battles of tomorrow will be fought with different weapons that have more lethal effects and faster delivery systems. One of mankind's greatest achievements in the twentieth century is the ability to destroy the entire human race several times over. At this time of intensive arms more money is invested in the next generation of weapons. It is in the best interest of every citizen to be aware and able to make an informed judgment on the best possible direction for the arms race. Offensive or defensive weapons are a cruel reality that nevertheless must be addressed.

The scientific work during the 1950s that led to the invention of the laser was followed closely by work in military research institutes and organizations all over the world and this opened a new door to the Archimedes Heat Ray. Lasers have found many military applications, not as new weapons, but rather as the supporting technology to enhance the performance of other weapons such as laser-guided bombs and so on. Our fascination and appreciation of modern weaponry is at an all-time high. It was not until the 1970s that the possibility of laser weapons again captured the imagination of military planners. High-energy and other directed energy weapons finally became a reality, and the possibility of using them in the battlefields of tomorrow has been investigated vigorously ever since.

The development of laser weaponry and other directed energy weapons technology conjures up the Heat Ray of Archimedes and Flash Gordon-like images of vaporizing enemies, demolishing buildings, and burning through metal. In this book introduces such weaponry to readers of different technical backgrounds as well as to introduce a certain technical approach to such research and to help better understanding of such weapons utilizing various technical and research resources.

The next 10 years will see the emergence of high-energy lasers as an operational capability in US service. These weapons will have the unique capability to attack targets at the speed of light and are likely to impair the effectiveness of many weapon types significantly, especially ballistic weapons. Constrained by propagation physics, these weapons will not provide all-weather capabilities, and will perform best in clear sky–dry air conditions.

The book in its laser technology section talks about the interaction between high-power laser beams and matters whereas other aspects of directed energy weapons, such as particle and high-power radar beams as a weapons of tomorrow can be found in the literature provided by other authors. Laser-beam interactions with materials, treat, from a physicist's point of view, the wide variety of processes that lasers can induce in materials. Physical phenomena ranging from optics to shock waves are discussed. The approach that is taken emphasizes the fundamental ideas both from a newcomer's or research worker's point of view to provide important background for material science, mathematics, optics, and the like, or a most critical up-to-date review of the field.

A directed energy weapon (DEW) such as a high-energy laser emits energy in an aimed direction without the means of a projectile. It transfers energy to a target for a desired effect. Some such weapons are real or in development; others are at present only in science fiction.

The energy can come in various forms:

- Electromagnetic radiation (typically lasers or masers)
- Particles with mass (particle beam weapons)
- Sound (sonic weaponry)
- Fire (flamethrowers)
- High-power laser weapons

Some lethal directed energy weapons are under active research and development, but most examples appear in science fiction, nonfunctional toys, film props, or animation.

In science fiction, these weapons are sometimes known as death rays or ray-guns and are usually portrayed as projecting energy at a person or object to kill or destroy. Many modern examples of science fiction have more specific names for directed energy weapons, due to research advances.

For those readers who need to dive deep into the technologies behind such research a short course in various topics of mathematics and physics has been offered in the appendices in order for them to brush up on these topics and be able to understand different solutions and mathematical modeling that are offered for the solution, for example, of the heat diffusion equation for different boundary and initial conditions. In the case of application of lasers as weapons, the book has attempted to serve both scientists interested in the physical phenomena of laser effects and engineers interested in practical applications of laser effects in industry. Thus, several sections are devoted to reviewing and dealing with the solution of the diffusion equation utilizing the aid of integral transform techniques. Among the several different approaches to solve the boundary value problems for heat conduction; the integral transform technique offers the most straightforward and elegant solution, provided that the transforms, the inversions, and the kernels are readily available.

Some appendices at the end of the book are devoted to systematic mathematics and physics of the heat conduction solution and its boundary value problems. As a result of the transforms, the inversions, complex variables, and their examples are presented and the kernels are tabulated, and the Laplace and Fourier transforms are also introduced. The appendix on introduction to ordinary and partial differentials is also presented to help the reader understand the solution techniques used to solve the heat conduction problem for various boundary values. Appendices on optics and the electromagnetic field also help better understanding of the behavior of the physics and mathematics of these weapons.

Note: In most of the appendices of different topics either the references mentioned at the end of each appendix have been used and quoted directly or indirectly or it is up to each reader to refer to them separately for more knowledge and information. I have also decided to shift these appendices around by eliminating some of their content that I believe is no longer necessary, as well as converting some content into part of the main chapters of different subjects of Volume II here and finally keeping the rest as appendices as originally planned.

Those left as an appendix of their own for those readers needing some refresher and review on the topics that are presented by these appendices are:

Appendix A: Short Course in Taylor Series
Appendix B: Short Course in Vector Analysis
Appendix C: Short Course in Ordinary and Partial Differential Equations
Appendix D: Short Course in Complex Variables
Appendix E: Short Course in Fourier and Laplace Transforms
Appendix F: Short Course in Electromagnetics
Appendix G: Short Course in Optics
Appendix H: Short Course in Heat Conduction Equation
Appendix I: Data and Plots of Thermal Parameters of Different Materials
Appendix H: Acronyms and Definitions

In this book, I have also taken under consideration to show the solutions and present the heat conduction complex problem and those boundary values that are very much related to problems of high- power laser interaction with materials. Most cases have looked at one-dimensional heat conduction with semi-infinite slab configuration with a heat resource as part of heat conduction equations making dealing with it a more difficult and complex problem. Wherever was needed the best possible references were given for further investigations by readers interested in doing their own research beyond what is given here.

Albuquerque, NM Bahman Zohuri

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I am indebted to the many people who aided and encouraged me and the people who supported me beyond expectations. Some of them are not around to see the end result of their encouragement in the production of this book, yet I hope they can see this acknowledgment. I especially want to thank Nancy Reis of Sandia National Laboratory who both put the idea in me to start the book based on some work that I was contracted to do for them. My thanks go also to Joe Rogers of NASA, retired now, one of my best friends who helped with most of the computer codes that are presented in this book to bring them to their present status from their legacy stages and to be able to transfer them from a mainframe to a personal computer platform under the Windows operating system.

Another best friend, William Kemp of the Air Force Weapons Laboratory at Albuquerque, New Mexico is really a true friend and remains as one. Finally my many thanks to Jonathan W. Plant, Senior Editor—Mechanical, Aerospace, and Nuclear and Energy Engineering of Taylor & Francis/CRC Press who made all this happen. Finally, I am indebted to many people and the individuals and organizations that granted permission to reproduce copyright materials and published figures.

I am also indebted to Dr. John T. Schriemf and his time on the phone on so many occasions and advice about the different topics related to high-power laser interaction with matte, in particular allowing me to tap into his well-known Naval Research Laboratory (i.e., NRL Report 7728) under the title of "Response of Materials to Laser Radiation a Short Course," and allowing me to copy some of his well-written report to reflect on in this volume as presented in Chapter 1.

I also would like to thank Dr. Krzysztof Nowakowski for letting me use his efforts and research work and allowing me to utilize some sections of his research work. His work and his research under the title of "Laser Beam Interaction with Materials for Microscale Applications" was most helpful to me and Chapter 7 of the book.

Above all, I offer very special thanks to my mother and father while they were alive, and my wife and children. They provided constant interest and encouragement, without which this book would not have been written.

Their patience with my many absences from home and long hours in front of the computer during preparation of the manuscript is especially appreciated.

Contents

About the Author

Bahman Zohuri is currently with Galaxy Advanced Engineering, a consulting company that he started himself in 1991 when he left both the semiconductor and defense industries after many years of working as a chief scientist. After graduating from the University of Illinois in the fields of physics and applied mathematics, he joined Westinghouse Electric Corporation where he performed thermal hydraulic analysis and natural circulation for the inherent shutdown heat removal system (ISHRS) in the core of a liquid metal fast breeder reactor (LMFBR) as a secondary fully inherent shut system for secondary loop heat exchange. All these designs were used for nuclear safety and reliability engineering for a self-actuated shutdown system. He designed the mercury heat pipe and electromagnetic pumps for large pool concepts of LMFBR for the heat rejection purpose for this reactor around 1978 where he received a patent for it. He later was transferred to the defense division of Westinghouse where he was responsible for the dynamic analysis and method of launching and handling of the MX missile out of the canister. The results are applied to MX launch seal performance and muzzle blast phenomena analysis (i.e., missile vibration and hydrodynamic shock formation). He was also involved in analytical calculation and computation in the study of the nonlinear ion wave in rarefying plasma. The results are applied to the propagation of the "soliton wave" and the resulting charge collector traces, in the rarefactions characteristic of the corona of a laser-irradiated target pellet. As part of his graduate research work at Argonne National Laboratory Zohuri performed computation and programming of the multiexchange integral in surface physics and solid-state physics. He holds different patents in areas such as diffusion processes and design of a diffusion furnace while he was senior process engineer working for different semiconductor industries such as Intel, Varian, and National Semiconductor. Later on he joined Lockheed Missile and Aerospace Corporation as Senior Chief Scientist and was responsible for in R&D and the study of vulnerability, survivability, and both radiation and laser hardening of different payload components (i.e., IR sensor) for the defense support program (DSP), boost surveillance and tracking satellite (BSTS), and space surveillance and tracking satellite (SSTS) against laser or nuclear threat. While there he also studied and performed the analysis of characteristics of laser beam and nuclear radiation interaction with materials, transient radiation effects in electronics (TREE), electromagnetic pulse (EMP), system-generated electromagnetic pulse (SGEMP), single-event upset (SEU), blast and thermomechanical, hardness assurance, maintenance, and device technology.

He spent several years consulting for his company Galaxy Advanced Engineering with Sandia National Laboratories (SNL), where he supported development of operational hazard assessments for the Air Force Safety Center (AFSC) in concert with other interested parties. The intended use of the results was their eventual inclusion in Air Force instructions (AFIs) specifically issued for directed energy weapons (DEW) operational safety. He completed the first version of a comprehensive library of detailed laser tools for the airborne laser (ABL), advanced tactical laser (ATL), tactical high-energy laser (THEL), and the mobile/tactical high-energy laser (M-THEL), among others.

He also was responsible for SDI computer programs involved in battle management C^3 and artificial intelligence (AI), and autonomous systems. He is the author of several publications and holds various patents such as "Laser Activated Radioactive Decay and Results of Thru-Bulkhead Initiation."