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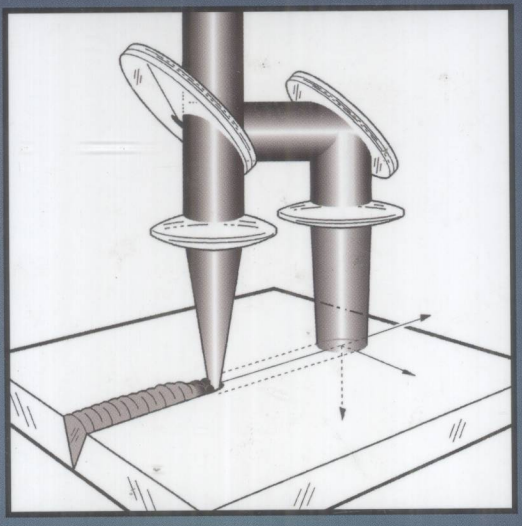
Principles of Laser Materials Processing



ELIJAH KANNATEY-ASIBU Jr.

WILEY

PRINCIPLES OF LASER MATERIALS PROCESSING

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PRINCIPLES OF LASER MATERIALS PROCESSING

To the memory of my parents
Kofi Kannatey and Efuwa Edziiba
And to my children
Bianca, Araba, and Kwame

PREFACE

Applications of lasers in materials processing have been evolving since the development (first demonstration) of the laser in 1960. The early applications focused on processes such as welding, machining, and heat treatment. Newer processes that have evolved over the years include laser forming, shock peening, micromachining, and nanoprocessing. This book provides a state-of-the-art compilation of material in the major application areas and is designed to provide the background needed by graduate students to prepare them for industry; researchers to initiate a research program in any of these areas; and practicing engineers to update themselves and gain additional insight into the latest developments in this rapidly evolving field.

The book is partitioned into three parts. The first part, Principles of Industrial Lasers (Chapters 1–9), introduces the reader to basic concepts in the characteristics of lasers, design of their components, and beam delivery. It is presented in a simple enough format that an engineering student without any prior knowledge of lasers can fully comprehend it. It helps the reader acquire a basic understanding of how a laser beam is generated, its basic properties, propagation of the beam, and the various types of lasers available and their specific characteristics. Such knowledge is useful to all engineering students, irrespective of their specific interests or area of application. It will enable them to select an appropriate laser for a given application and help them determine how best to utilize the laser. The coverage starts with a discussion of laser generation—basic atomic structure and how it leads to atomic transitions (absorption, spontaneous emission, and stimulated emission). The concepts of population inversion and gain criterion for laser action are introduced. Optical resonators (planar and spherical) are discussed in relation to beam modes (longitudinal and transverse) and stability of optical resonators. Techniques for line and mode selection are outlined. Various pumping techniques that can be used to achieve inversion are then presented, including more recent developments such as diode pumping. The rate equations are then introduced to provide some insight into the conditions necessary for achieving population inversion for both three- and four-level systems. This is followed by a discussion of the broadening mechanisms that are responsible for the spread of a laser's frequency over a finite range. These include both homogeneous (natural and collision broadening) and inhomogeneous (Doppler) broadening. Beam modification mechanisms such as Q-switching and mode locking are presented. After obtaining a fundamental background on laser generation, the characteristics of beams that have a more direct impact on their application are then discussed. These include beam characteristics such as divergence, monochromaticity (with reference to broadening), coherence, polarization, intensity and brightness, frequency stabilization, and focusing. Different

types of lasers are then discussed with specific emphasis on high-power lasers used in industrial manufacturing. These include solid-state lasers (Nd:YAG and Nd:glass); gas lasers (neutral atom, ion, metal vapor (copper vapor), and molecular (CO_2 and excimer lasers); dye lasers; and semiconductor (diode) lasers. Finally, beam delivery systems are introduced, discussing concepts such as the Brewster angle, polarization, beam expanders, beam splitters, and transmissive, reflective, and fiber optics.

The second part, Engineering Background (Chapters 10–13), reviews the engineering concepts that are needed to analyze the different processes. Topics that are discussed include thermal analysis and fluid flow, the microstructure that results from the heat effect, solidification of the molten metal for processes that involve melting, and residual stresses that evolve during these processes.

The third part, Laser Materials Processing (Chapters 14–23), provides a more rigorous and detailed coverage of the subject of laser materials processing and discusses the principal application areas such as laser cutting and drilling, welding, surface modification, laser forming, rapid prototyping, and medical and nano applications. Sensors that are normally used for monitoring process quality are also discussed, along with methods for analyzing the sensor outputs. Finally, basic concepts of laser safety are presented. The range of processing parameters associated with each process is outlined. The impact of the basic laser characteristics such as wavelength, divergence, monochromaticity, coherence, polarization, intensity, stability, focusing, and depth of focus, as discussed in Part I, for each process is emphasized.

The material in this book is suitable for a two-course sequence on laser processing. The material in Part I is adequate for an upper-division/first-year graduate course in engineering. Parts II and III can then be used for a follow-up course, or the material in Part I can be skipped if only one course needs to be offered. In either case, Part II can be quickly reviewed, and more time can be spent on Part III.

Two sets of nomenclature are used in this text. There is an overall nomenclature that is reserved for variables that are used throughout the text. In addition, each chapter has its own nomenclature for variables used primarily in that chapter.

The author wishes to express his gratitude to all his colleagues and friends who have provided feedback on the manuscript. Special gratitude goes to all the graduate students who critiqued the course pack on which the book is based and to Mr. Rodney Hill (rodhillgraphics.com) for the skillful illustrations.

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