

## Preface

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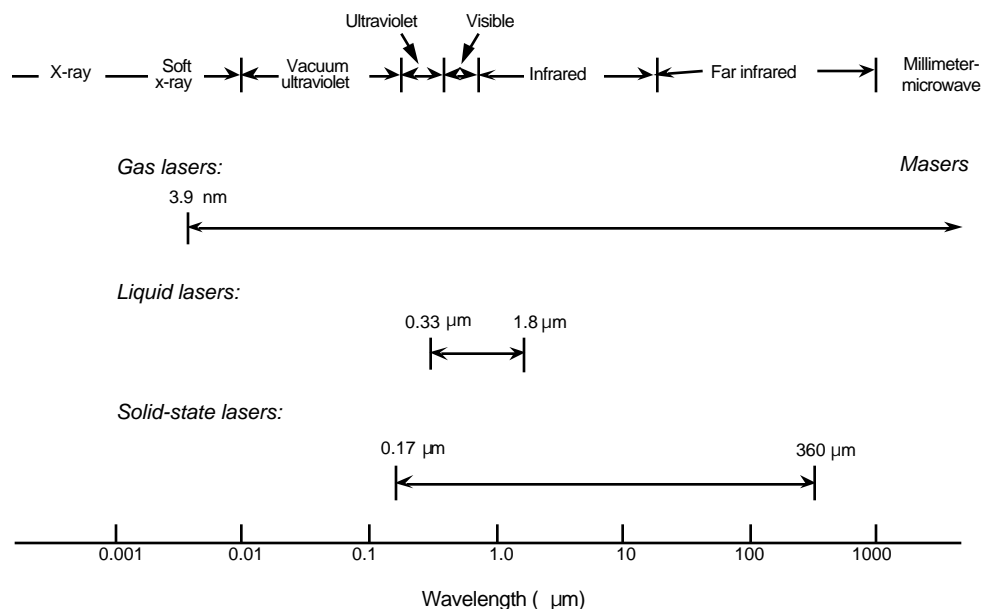
Lasers continue to be an amazingly robust field of activity, one of continually expanding scientific and technological frontiers. Thus today we have lasing without inversion, quantum cascade lasers, lasing in strongly scattering media, lasing in biomaterials, lasing in photonic crystals, a single atom laser, speculation about black hole lasers, femtosecond-duration laser pulses only a few cycles long, lasers with subhertz linewidths, semiconductor lasers with predicted operating lifetimes of more than 100 years, peak powers in the petawatt regime and planned megajoule pulse lasers, sizes ranging from semiconductor lasers with dimensions of a few microns diameter and a few hundred atoms thick to huge glass lasers with hundreds of beams for inertial confinement fusion research, lasers costing from less than one dollar to more than one billion dollars, and a multibillion dollar per year market.

In addition, the nearly ubiquitous presence of lasers in our daily lives attests to the prolific growth of their utilization. The laser is at the heart of the revolution that is marrying photonic and electronic devices. In the past four decades, the laser has become an invaluable tool for mankind encompassing such diverse applications as science, engineering, communications, manufacturing and materials processing, medical therapeutics, entertainment and displays, data storage and processing, environmental sensing, military, energy, and metrology. It is difficult to imagine state-of-the-art research in physics, chemistry, biology, and medicine without the use of radiation from various laser systems.

Laser action occurs in all states of matter—solids, liquids, gases, and plasmas. Within each category of lasing medium there may be differences in the nature of the active lasing ion or center, the composition of the medium, and the excitation and operating techniques. For some lasers, the periodic table has been extensively explored and exploited; for others—solid-state lasers in particular—the compositional regime of hosts continues to expand. In the case of semiconductor lasers the ability to grow special structures one atomic layer at a time by liquid phase epitaxy, molecular beam epitaxy, and metal-organic chemical vapor deposition has led to numerous new structures and operating configurations, such as quantum wells and superlattices, and to a proliferation of new lasing wavelengths. Quantum cascade lasers are examples of laser materials by design.

The number and type of lasers and their wavelength coverage continue to expand. Anyone seeking a photon source is now confronted with an enormous number of possible lasers and laser wavelengths. The spectral output ranges of solid, liquid, and gas lasers are shown in Figure 1 and extend from the soft x-ray and extreme ultraviolet regions to millimeter wavelengths, thus overlapping masers. By using various frequency conversion techniques—harmonic generation, parametric oscillation, sum- and difference-frequency mixing, and Raman shifting—the wavelength of a given laser can be extended to longer and shorter wavelengths, thus enlarging its spectral coverage.

This volume seeks to provide a comprehensive, up-to-date compilation of lasers, their properties, and original references in a readily accessible form for laser scientists and engineers and for those contemplating the use of lasers. The compilation also indicates the state of knowledge and development in the field, provides a rapid means of obtaining reference data, is a pathway to the literature, contains data useful for comparison with predictions and/or to develop models of processes, and may reveal fundamental inconsistencies or conflicts in the data. It serves an archival function and as an indicator of newly emerging trends.



**Figure 1** Reported ranges of output wavelengths for various laser media.

In this volume lasers are categorized based on their media—solids, liquids, and gases—with each category further subdivided as appropriate into distinctive laser types. Thus there are sections on crystalline paramagnetic ion lasers, glass lasers, polymer lasers, color center lasers, semiconductor lasers, liquid and solid-state dye lasers, inorganic liquid lasers, and neutral atom, ionized, and molecular gas lasers. A separate section on "other" lasers which have special operating configurations or properties includes x-ray lasers, free electron lasers, nuclear-pumped lasers, lasers in nature, and lasers without inversion. Brief descriptions of each type of laser are given followed by tables listing the lasing element or medium, host, lasing transition and wavelength, operating properties, and primary literature citations. Tuning ranges, when reported, are given for broadband lasers. The references are generally those of the initial report of laser action; no attempt is made to follow the often voluminous subsequent developments. For most types of lasers, lasing—light amplification by stimulated emission of radiation—includes, for completeness, not only operation in a resonant cavity but also single-pass gain or amplified spontaneous emission (ASE). Thus, for example, there is a section on amplification of core-valence luminescence.

Because laser performance is dependent on the operating configurations and experimental conditions used, output data are generally not included. The interested reader is advised to retrieve details of the structures and operating conditions from the original reference (in many cases information about the output and operating configuration is included in the title of the paper that is included in the references). Performance and background information about lasers in general and about specific types of lasers in particular can be obtained from the books and articles listed under Further Reading in each section.

An extended table of contents is provided from which the reader should be able to locate the section containing a laser of interest. Within each subsection, lasers are arranged according to the elements in the periodic table or alphabetically by materials, and may be further separated by operating technique (for example, in the case of semiconductor lasers, injection, optically pumped, or electron beam pumped).

This *Handbook of Lasers* is derived from data evaluated and compiled by the contributors to Volumes I and II and Supplement 1 of the *CRC Handbook Series of Laser Science and Technology* and to the *Handbook of Laser Wavelengths*. These contributors are identified in following pages. In most cases it was possible to update these tabulations to include more recent additions and new categories of lasers. For semiconductor lasers, where the lasing wavelength may not be a fundamental property but the result of material engineering and the operating configuration used, an effort was made to be representative with respect to operating configurations and modes rather than exhaustive in the coverage of the literature. The number of reported gas laser transitions is huge; they constitute nearly 80% of the over 16,000 laser wavelengths in this volume. Laser transitions in gases are well covered through the late 1980s in the above volumes. An electronic database of gas lasers prepared from the tables in Volume II and Supplement 1 by John Broad and Stephen Krog of the Joint Institute of Laboratory Astrophysics was used for this volume, but does not cover all recent developments.

Although there is a tremendous diversity of laser transitions and types, only a few laser systems have gained widespread use and commercial acceptance. In addition, some laser systems that were of substantial commercial interest in past years are becoming obsolete and are likely to be supplanted by other types in the future. Nevertheless, separate subsections on commercially available lasers are included throughout the volume to provide a perspective on the current state-of-the-art and performance boundaries.

To cope with the continued proliferation of acronyms, abbreviations, and initialisms which range from the clever and informative to the amusing or annoying, there is an appendix of acronyms, abbreviations, initialisms, and common names for lasers, laser materials, laser structures and operating configurations, and systems involving lasers. Other appendices contain information about laser safety, the ground state electron configurations of neutral atoms, and fundamental physical constants of interest to laser scientists and engineers.

Because lasers now cover such a large wavelength range and because researchers in various fields are accustomed to using different units, there is also a conversion table for spectroscopists (a Rosetta stone) on the inside back cover.

Finally, I wish to acknowledge the valuable assistance of the Advisory Board who reviewed the material, made suggestions regarding the contents and formats, and in several cases contributed material (the Board, however, is not responsible for the accuracy or thoroughness of the tabulations). Others who have been helpful include Giuseppe Baldacchini, Eric Bründermann, Federico Capasso, Tao-Yuan Chang, Henry Freund, Claire Gmachl, Victor Granatstein, Eugene Haller, John Harreld, Stephen Harris, Thomas Hasenberg, Alan Heeger, Heonsu Jeon, Roger Macfarlane, George Miley, Linn Mollenauer, Michael Mumma, James Murray, Dale Partin, Maria Petra, Richard Powell, David Sliney, Jin-Joo Song, Andrew Stentz, Roger Stolen, and Riccardo Zucca. I am especially grateful to Project Editor Mimi Williams for her skill and help during the preparation of this volume.

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