X-ray lasers

A. V. Andreev

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R. C. Elton, *X-ray Lasers* (Academic Press, Boston, San Diego, New York, Berkeley, London, Sydney, Tokyo, Toronto, 1990, p. 287.

This book is apparently the first monograph devoted to setting forth the operating principles of x-ray lasers, and it reflects the considerable progress achieved in this area in the last five years after the first successful work[1] where the generation of x radiation with a wavelength of $\sim$ 200 Å was obtained. At the time of this writing the active media for x-ray lasers have been expanded significantly, and the wavelength that can be generated has reached 50 Å. Thus, the publication of this book is completely appropriate and timely. The author of the book, Raymond Elton, an employee of the Naval Research Laboratory (USA), has made a considerable contribution to the development of a number of x-ray laser designs and is the co-author of one of the first detailed reviews on the topic of short-wavelength lasers.[2]

The book contains a description of the fundamentals of the physics of x-ray lasers and also discusses important details useful for researchers working in this area. The book is a useful manual for those who are only beginning to become familiar with the field of x-ray lasers and also for those who are carrying out active investigations in the field. In the book attention is focused primarily on x-ray lasers, the active medium of which is a plasma. However, one chapter of the book also contains a discussion of alternate versions.

Chapter 1 is the introductory chapter of the book; this history of the development of investigations is discussed briefly in it, basic concepts and definitions are introduced, and the problem of x-ray mirrors is considered.

In Chapter 2 questions associated with the kinetics of radiation generation in systems without mirrors are discussed. The threshold conditions for lasing are introduced and the principal factors governing the population of the upper laser level are discussed. The effect of collision-induced transitions and the effect of radiation imprisonment on lasing dynamics is analyzed. A number of schemes are considered that make it possible to obtain efficient quenching of the lower laser level. The effect of refraction losses on threshold conditions and lasing dynamics is investigated. The results of a numerical solution of the rate equations are presented, illustrating the dependence of the threshold conditions on the basic parameters of the active media. Sections of the book devoted to a discussion of the requirements imposed on the pumping lasers and focusing optics, the methods of measuring the gain coefficient, and a review of experimental methods for measuring the characteristics of the x-radiation of the laser plasma, are of great interest from the viewpoint of an introduction to the methods for conducting experiments. The characteristic features of recording x-ray images (camera oscura, zone plate, grazing-incidence optics), spectral measurements (normal- and grazing-incidence gratings, gratings having a variable spacing, diffraction in crystals), detection (films, photodiodes, photoresistors, ionization chambers, semiconductor detectors, charge-coupled devices), and time-resolved x-ray spectroscopy (scintillators, microchannel plates, streak cameras) are discussed.

Chapter 3 of the book is devoted to a discussion of the operating principles of two basic types of x-ray lasers—lasers with collisional excitation and with photoexcitation. These two types of x-ray lasers are the closest to traditional laser schemes. In both of these cases the starting point is the ground state of an ion, in which its electrons are unexcited, and lasing occurs between two excited levels. The upper laser level is excited from the ground state by collisional means in one case and by photoexcitation in the other. The analogy of collisional x-ray lasers with traditional laser schemes is illustrated in the example of lasers for the VUV range—molecular nitrogen and hydrogen lasers. Then experimental data on the generation of x-radiation having a wavelength of 50–200 Å in ions with different level structures are discussed at length.

In x-ray laser schemes with photoexcitation the upper laser level is pumped by the characteristic radiation of the plasma of ions of another element. The frequency of the characteristic pumping line is chosen to be the resonant frequency of the transition from the ground state to the upper laser level in the "working" ion. Comprehensive tables of such coinciding transitions of different ions are given in the book. It should be pointed out that much of these tables represents work done by the author of this monograph.

X-ray laser schemes, based on the capture of electrons in the upper laser level either from the continuum or from another ion or atom, are discussed in Chapter 4. The first case deals with lasers with recombination pumping when the electron, as a result of a collisional recombination and a sequence of cascade transitions, ends up in the upper laser level. In the second case electrons are placed in the upper laser level by electron exchange during a collision of the working ion with a neutral atom or another ion.

Chapter 5 includes an analysis of schemes based on the ionization of the electrons of the inner shells of atoms and ions. Ion-collisional, photoionization, and Auger schemes for producing inversion are considered separately.

Among alternative methods for generating coherent x radiation, the generation of harmonics, free-electron lasers, and gamma-ray lasers are considered in Chapter 6. The author shows that nonlinear-optical methods of generating x radiation make it possible, in principle, to obtain partially tunable radiation in the soft x-ray region; however, the in-

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tensity is low. A possible way to increase the intensity lies in using plasma amplifiers. The prospects for developing free-electron lasers are discussed. Investigations dealing with the gamma-ray laser problem are reviewed briefly. The possibilities of generating x radiation by channeling of electrons in crystals, stimulated by bremsstrahlung and Compton scattering, and optical pumping of relativistic ions are discussed briefly.

The concluding chapter of the book is devoted to a comparison of different x-ray laser schemes and a comparison of their characteristics. The prospects for future research are discussed and the radiation parameters that can be achieved in the next few years are estimated. The characteristics of operating x-ray lasers are compared with the characteristics of other sources of x radiation, such as x-ray tubes, synchrotron sources, and the x radiation of a high-density plasma. The prospects for using x-ray lasers in atomic and ion spectroscopy, chemical analysis, nuclear spectroscopy, and for probing high-density plasmas are discussed among possible applications of x-ray lasers. Possible technical applications are related to the development of photolithography and surface-sensitive x-ray spectroscopy methods. The author maintains that x-ray lasers can lead to significant progress in the area of x-ray microscopy and holography, which will give additional valuable information about the structure of cells and macromolecules and will help to solve the phase problem of x-ray structural analysis.

In conclusion it must be pointed out that the book will definitely find a wide audience of readers because of its timeliness. The book is written in understandable and clear language and will be useful not only to specialists in the area of x-ray lasers but also for others just beginning to become familiar with the subject, and it can also serve as a basic textbook for several special courses.

[1]D. L. Matthews *et al.*, Phys. Rev. Lett. **54**, 110 (1985).
[2]R. W. Waynant and R. C. Elton, Proc. IEEE **64**, 1059 (1976).