

Article

Extreme Ultraviolet Radiation Sources from Dense Plasmas

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Abstract: The concept of dense and hot plasmas can be used to build up powerful and brilliant radiation sources in the soft X-ray and extreme ultraviolet spectral range. Such sources are used for nanoscale imaging and structuring applications, such as EUV lithography in the semiconductor industry. An understanding of light-generating atomic processes and radiation transport within the plasma is mandatory for optimization. The basic principles and technical concepts using either a pulsed laser or a gas discharge for plasma generation are presented, and critical aspects in the ionization dynamics are outlined within the framework of a simplified atomic physics model.

Keywords: XUV light source; plasma radiation source; laser-produced plasma; discharge plasma

1. Introduction

The spectral range of extreme ultraviolet radiation (EUV or XUV), with wavelengths from ~ 1 to 50 nm or photon energies of 20 eV–1 keV, is of growing interest for a variety of applications in analysis and patterning with nanometer resolution. The short wavelength in combination with the increasing availability of high-quality optical elements and the strong interaction with matter with high elemental sensitivity are key features. Currently, utilizing extreme ultraviolet lithography to produce more powerful semiconductor chips is the most important application, which has driven the development of optics and a compact light source for the wavelength of 13.5 nm [1]. Other examples of applications making use of compact light sources are in the field of EUV lithography, i.e., use for mirror contamination studies [2–4], qualification of optical elements and masks [5–11] or photo resist development [12,13]. Further examples are X-ray microscopy in the spectral range of the water window (2.4–4.4 nm) for the imaging of biological samples in their natural wet environment [14–18] or XUV-based reflectometry for surface analysis [19,20].

All these applications require a compact, tabletop and powerful light source. An example of source requirements is given in Ref. [21] for an ADMS inspection tool. Plasma-based sources have been proven to fulfill the demands in contrast to, for example, an X-ray tube with limited power or a synchrotron source not being compact and having restricted access for the users. In plasma-based sources, the matter is heated up to a high temperature and then transferred into the plasma state with ions and free electrons. The target temperature can be roughly estimated by making use of Wien's law for a blackbody radiator, $\lambda_{\text{max}} \times T_e = 250 \text{ eVnm}$, assuming that the electron or plasma temperature, T_e , corresponds to the radiation temperature. Here, λ_{max} is the wavelength of maximum brightness. For example, the target wavelength of 13.5 nm leads to a plasma temperature of about 20 eV or 200,000 °K. The preferred loss channel for the internal plasma energy is essentially via radiative transitions from resonance lines of ions in a highly ionized level of the respective target material. The preferred transitions are in the short wavelength region, which can roughly be estimated by making use of Wien's law, rather than being in unwanted spectral regions, including visible radiation. This implies a high conversion efficiency of input energy to XUV radiation. Sometimes, a conversion over 90% can be achieved, as shown for the example in Ref. [22]. Matter at these high temperatures cannot exist for long times in compact devices. The high plasma pressure will lead to the expansion



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Radiation In Plasmas

John Myrick Dawson



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Radiation Processes in Plasmas George Bekefi, 1966 1 Transport of radiation 2 Kirchhoff's radiation law 3 Emission and absorption from binary encounters 4 Fluctuations 5 Collective emission phenomena 6 Cyclotron emission 7 Waves in a magnetoactive plasma 8 Scattering of electromagnetic waves from density fluctuations 9 Microinstabilities 10 Experimental methods *Radiation in Plasmas* International Centre for Theoretical Physics, 1984 **Radiation from Plasmas** John M. Dawson, Princeton University. Plasma Physics Laboratory, 1964 **Radiation from Plasmas** John Myrick Dawson, 1966

Lasers-Induced Plasmas and Applications Leon J. Radziemski, 2020-09-11 This book discusses the physics of plasma initiation and reviews the features of dissipating propagating plasmas It deals with advances in diagnostics for high energy laser fusion plasmas The book reviews the basic physical processes plasma characteristics of the continuous optical discharge Radiation in Astrophysical Plasmas V.V. Zheleznyakov, 2012-12-06 Interest in the problem of interaction between radiation and astrophysical plasmas arose decades ago Initially this was closely related to the discovery of radio emission from the Sun and Galaxy which alerted theoretical radio astronomers to the problem of the origin of extra terrestrial radio emission It has been found that the observed radio emission from cosmic sources is generated by virtue of the mechanisms which work mainly in plasma an ionized gas Recently the theory of generation and propagation of radiation in astrophysical plasmas has outgrown its parent domain of theoretical radio astronomy and is being successfully applied to other fields such as high energy astrophysics General results obtained in this field may also help to better understand the complicated phenomena in laboratory plasmas on the Earth At the same time analysis of interaction between radiation and astrophysical plasmas under extreme conditions strong magnetic fields of white dwarfs and neutron stars or strong gravitational fields in the vicinity of black holes stimulates the development of plasma physics as a whole In fact the physics of plasma under extreme conditions in space is a new branch of fundamental science The monograph contains the description of physical processes involved in interaction between radiation and astrophysical plasmas It comprises the reasonable minimum necessary for understanding the emission and propagation of electromagnetic waves in astrophysical plasmas without this minimum one could not succeed in interpreting the results of a number of astronomical observations Audience This monograph will be useful for graduate and post graduate students and young scientists as a textbook on plasma astrophysics and the issues of plasma physics dealing with radiation At the same time the book can be used by specialists on astrophysics radio astronomy and plasma physics Radiation in plasmas Brendon MacNamara, 1984 Plasmas Vinod Krishan, 2014-03-06 Most astronomers believe that the universe began about 15 billion years ago when an explosion led to its expansion and cooling The present state of the universe compels us to believe that the universe was extremely hot and dense in its infancy In the beginning there was intense radiation The photons produced equal amounts of matter and antimatter and a plasma soup of particles and antiparticles was present Plasma is the first state of matter from which all the other states

originated This book discusses the diversity of cosmic and terrestrial plasmas found in the early universe galactic and intergalactic media stellar atmospheres interstellar spaces the solar system and the Earth's ionosphere and their observability with the most recent telescopes such as the Chandra X ray telescope and gamma ray telescopes It deals with different ways of creating plasmas such as thermal pressure and radiative ionization for laboratory and cosmic plasmas

Scientific and Technical Aerospace Reports ,1985 Plasma Physics and Engineering Alexander

Fridman, Lawrence A. Kennedy, 2021-02-25 Plasma Physics and Engineering presents basic and applied knowledge on modern plasma physics plasma chemistry and plasma engineering for senior undergraduate and graduate students as well as for scientists and engineers working in academia research labs and industry with plasmas laser and combustion systems This is a unique book providing a clear fundamental introduction to all aspects of modern plasma science describing all electric discharges applied today from vacuum to atmospheric pressure and higher from thermal plasma sources to essentially cold non equilibrium discharges A solutions manual is available for adopting professors which is helpful in relevant university courses Provides a lucid introduction to virtually all aspects of modern plasma science and technology Contains an extensive database on plasma kinetics and thermodynamics Includes many helpful numerical formulas for practical calculations as well as numerous problems and concepts This revised edition includes new material on atmospheric pressure discharges micro discharges and different types of discharges in liquids Prof Alexander Fridman is Nyheim Chair Professor of Drexel University and Director of C J Nyheim Plasma Institute His research focuses on plasma approaches to biology and medicine to material treatment fuel conversion and environmental control Prof Fridman has almost 50 years of plasma research in national laboratories and universities of Russia France and the United States He has published 8 books and received numerous honors for his work including Stanley Kaplan Distinguished Professorship in Chemical Kinetics and Energy Systems George Soros Distinguished Professorship in Physics the State Prize of the USSR Plasma Medicine Award Kurchatov Prize Reactive Plasma Award and Plasma Chemistry Award Prof Lawrence A Kennedy is Dean of Engineering Emeritus and Professor of Mechanical Engineering Emeritus at the University of Illinois at Chicago and Professor of Mechanical Engineering Emeritus at the Ohio State University His research focuses on chemically reacting flows and plasma processes He is the author of more than 300 archival publications and 2 books the editor of three monographs and served as Editor in Chief of the International Journal of Experimental Methods in Thermal and Fluid Science Professor Kennedy was the Ralph W Kurtz Distinguished Professor of Mechanical Engineering at OSU and the Stanley Kaplan University Scholar in Plasma Physics at UIC Prof Kennedy is also the recipient of numerous awards such as the American Society of Mechanical Engineers Heat Transfer Memorial Award 2008 and the Ralph Coats Roe Award from ASME 1993 He is a Fellow of the American Society of Mechanical Engineers the American Physical Society the American Institute of Aeronautics and Astronautics and the American Association for the Advancement of Science

The book delves into Radiation In Plasmas. Radiation In Plasmas is an essential topic that needs to be grasped by everyone, ranging from students and scholars to the general public. This book will furnish comprehensive and in-depth insights into Radiation In Plasmas, encompassing both the fundamentals and more intricate discussions.

1. This book is structured into several chapters, namely:

- Chapter 1: Introduction to Radiation In Plasmas
- Chapter 2: Essential Elements of Radiation In Plasmas
- Chapter 3: Radiation In Plasmas in Everyday Life
- Chapter 4: Radiation In Plasmas in Specific Contexts
- Chapter 5: Conclusion

2. In chapter 1, this book will provide an overview of Radiation In Plasmas. This chapter will explore what Radiation In Plasmas is, why Radiation In Plasmas is vital, and how to effectively learn about Radiation In Plasmas.
3. In chapter 2, this book will delve into the foundational concepts of Radiation In Plasmas. This chapter will elucidate the essential principles that must be understood to grasp Radiation In Plasmas in its entirety.
4. In chapter 3, the author will examine the practical applications of Radiation In Plasmas in daily life. This chapter will showcase real-world examples of how Radiation In Plasmas can be effectively utilized in everyday scenarios.
5. In chapter 4, the author will scrutinize the relevance of Radiation In Plasmas in specific contexts. This chapter will explore how Radiation In Plasmas is applied in specialized fields, such as education, business, and technology.
6. In chapter 5, the author will draw a conclusion about Radiation In Plasmas. This chapter will summarize the key points that have been discussed throughout the book.

This book is crafted in an easy-to-understand language and is complemented by engaging illustrations. It is highly recommended for anyone seeking to gain a comprehensive understanding of Radiation In Plasmas.

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