

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

Albert A Gayle



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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. *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.

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