博士論文公聴会の公示（物理学専攻）

学位申請者：　LIU　Chang

論文題目：Experimental study on spectroscopy of laser-produced plasma for laboratory astrophysics and soft X-ray lithography application

（実験室宇宙物理学及び軟 X 線リソグラフィー応用のためのレーザー生成プラズマの分光に関する実験的研究）

日時：2020 年 11 月 16 日（月） 13:30 — 15:00

場所：理学研究科 H 棟 7 階セミナー室（H701 号室）

（部屋の換気等、新型コロナウイルス感染症拡大防止に留意しつつ、対面形式にて行います。ご来聴の方はマスクの着用をお願い致します。)

オンラインでの聴講も可能。URL 等については学内の方は下記参照。

https://www.phys.sci.osaka-u.ac.jp/naibu/kouchoukai.html

学外の方でオンライン聴講希望の方は主査 : 藤岡 (sfujioka[at]ile.osaka-u.ac.jp　[at]=@) に問い合わせること。

主査：藤岡慎介

副査：越野幹人，千徳靖彦，中井光男，MORACE Alessio，田中のぞみ

論文要旨：

Spectroscopy is a widely-used diagnostic that is essentially important for understanding plasma parameters both in fundamental sciences and industrial applications. We can evaluate the temperature and density of electrons in a plasma from the width of spectral lines and line ratio, and also, we can obtain magnetic field strength in a plasma from the distance between lines separated by the Zeeman effect. This dissertation thesis consists mainly of two parts.

In the first part, I designed an experimental scheme to validate the modeling of the Zeeman effect in a high-energy-density plasma under the kilo-tesla level strong magnetic field. The Zeeman effect is one of the measures of magnetic field strength in astronomy, however, there is no experimental data to validate the accuracy of the model and numerical code calculating the Zeeman effect in a magnetized high-energy-density plasma. I used the magneto-hydrodynamics (MHD) simulation code to optimize plasma parameters for measuring the Zeeman effect of Si ions that are plentiful in the universe. The modeling shows that we can produce 10 kT of a magnetic field in a plasma having 100 eV of electron temperature and 10^{21} cm^{-3} of

electron density by compressing a low-density (5 mg/cm^3) SiO_2 foam cylinder with multiple laser beams that are ejected from kilo-joule tera-watt laser system. I have calculated spectrum emitted from the magnetized SiO_2 plasma with consideration of the Zeeman, Stalk, and Doppler effects, and the calculation reveals we can measure Si XII line at 96 eV with a soft x-ray spectrometer with achievable spectral resolution.

In the second part, I have studied the properties of hydrogen plasma photoionized with extreme ultraviolet (EUV) light. This plasma can remove tin (Sn) contamination on the optics used in the EUV lithography system as a result of the chemical reaction $Sn + 4H^* \dashrightarrow SnH_4$, here H^* is hydrogen radical. The optics contamination is one of the critical issues of the EUV lithography system. The optics contamination limits the operation time of the system, namely this increases the running cost of the system. We measured spectra of Balmer series emitted from photoionized hydrogen plasmas to obtain electron density, electron temperature, and hydrogen radical density of them with changing observation time and hydrogen gas pressure. Based on the experimental observation, I have proposed a mechanism of hydrogen plasma production by the EUV irradation, in which firstly EUV photons ionize hydrogen atoms, and photoionized non-thermal electrons having 100 eV of kinetic energy impact with hydrogen atoms and hydrogen ions are produced by this secondary process, and finally, the hydrogen ions recombined with thermal electrons having 1 eV of temperature and 2 x 10^{12} cm^3 of density, then rich (3.7 x 10^{12} cm^{-3}) hydrogen radicals are generated in a 5 Pa hydrogen gas. We have demonstrated the cleaning of the Sn contamination with the EUV-generated hydrogen radicals.