Nuclear Instruments and Methods in Physics Research B xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Extreme ultraviolet spectra of S IX and S X relevant to solar coronal plasmas

Safdar Ali *, Hiroyuki Kato, Nobuyuki Nakamura

Institute for Laser Science, The University of Electro-Communications, Tokyo 182 8585, Japan

A R T I C L E I N F O

Article history:
Received 15 November 2016
Received in revised form 18 May 2017
Accepted 21 May 2017
Available online xxxx

Keywords:
Atomic data
Extreme ultraviolet
Atomic process
Solar corona
Plasmas
Line identification

A B S T R A C T

We present extreme ultraviolet laboratory spectra of highly charged S IX and S X measured using a compact electron beam ion trap. The data were recorded using a flat-field grazing incidence spectrometer in the wavelength range between 210 and 290 Å. The beam energy was tuned for three different values at 365, 410 and 465 eV while keeping electron beam current constant at 10 mA. By measuring the beam energy dependence, we identified several lines originating from S IX and S X ions with the support of collisional-radiative modeling. We compared them with the present calculations and transitions listed in the NIST data base and found in good agreement.

1. Introduction

Spectroscopy is a fundamental tool to diagnose astrophysical plasmas. The extreme ultraviolet (EUV) emission band is in particularly provides unique and valuable tool to obtain physical conditions and properties of hot solar and stellar plasmas [1,2]. For example, with the aid of EUV spectroscopy one can address and understand the effects of magnetic activity in the solar atmosphere [3]. The fluctuations in the EUV flux from the Sun may affect the "space weather" and is currently a hot topic of heliophysics [4]. Besides these, fundamental problems of the solar physics, such as solar corona heating, acceleration of the solar wind, and abundance variations, require information such as wavelength and ionization stages. Accurate wavelengths are particularly important and prerequisite to extract the information contained in the observational spectra from the Sun [5]. The region between 150 and 300 Å has received adequate attention since it contains plethora of EUV lines useful for these applications [6–8].

Sulfur is an astrophysically abundant element with a photospheric abundance of 2.14×10^{-5} that of hydrogen and contains a wealth of strong lines in the EUV range [9–11]. Highly charged sulfur ions have been frequently detected from solar atmosphere with different astrophysical observatories [10,12]. In the past several theoretical studies have been reported to obtain wavelength and intensity ratios for highly charged sulfur ions [10–13]. The experimental atomic data for this element is however scarce with only few EBITs measurements for line identifications [14–16]. These motivated us to perform present work to extract spectroscopic data for astrophysical needs.

In the present work, we report laboratory observations for the emission of EUV radiation from highly charged S IX and S X ions in the wavelength range of 210–290 Å. We report several lines from these charge states and compared with present collisional-radiative modeling calculations and wavelengths listed in the NIST atomic and spectra data base [17].

2. Experiment

The present measurements were performed at the Tokyo EBIT laboratory using a low energy electron beam ion trap called CoBIT. Its design and operation principle is given in more detail elsewhere [18]. Briefly, CoBIT essentially consists of an electron gun, trapping region and an electron collector. The trapping region is further composed of three cylindrical drift tubes surrounded by a superconducting magnet. The electron gun is used to produce a mono-energetic electron beam with tunable energy which serves to produce, trap (radial) and excite atoms under ultra-high vacuum conditions. The axil potential to the ions was provided by applying a 30 V potential to the outer drift tubes with respect to the middle one, thus forming a well shape potential.

* Corresponding author.
E-mail address: safdaruetian@gmail.com (S. Ali).

http://dx.doi.org/10.1016/j.nimb.2017.05.048
0168-583X/

Please cite this article in press as: S. Ali et al., Extreme ultraviolet spectra of S IX and S X relevant to solar coronal plasmas, Nucl. Instr. Meth. B (2017), http://dx.doi.org/10.1016/j.nimb.2017.05.048

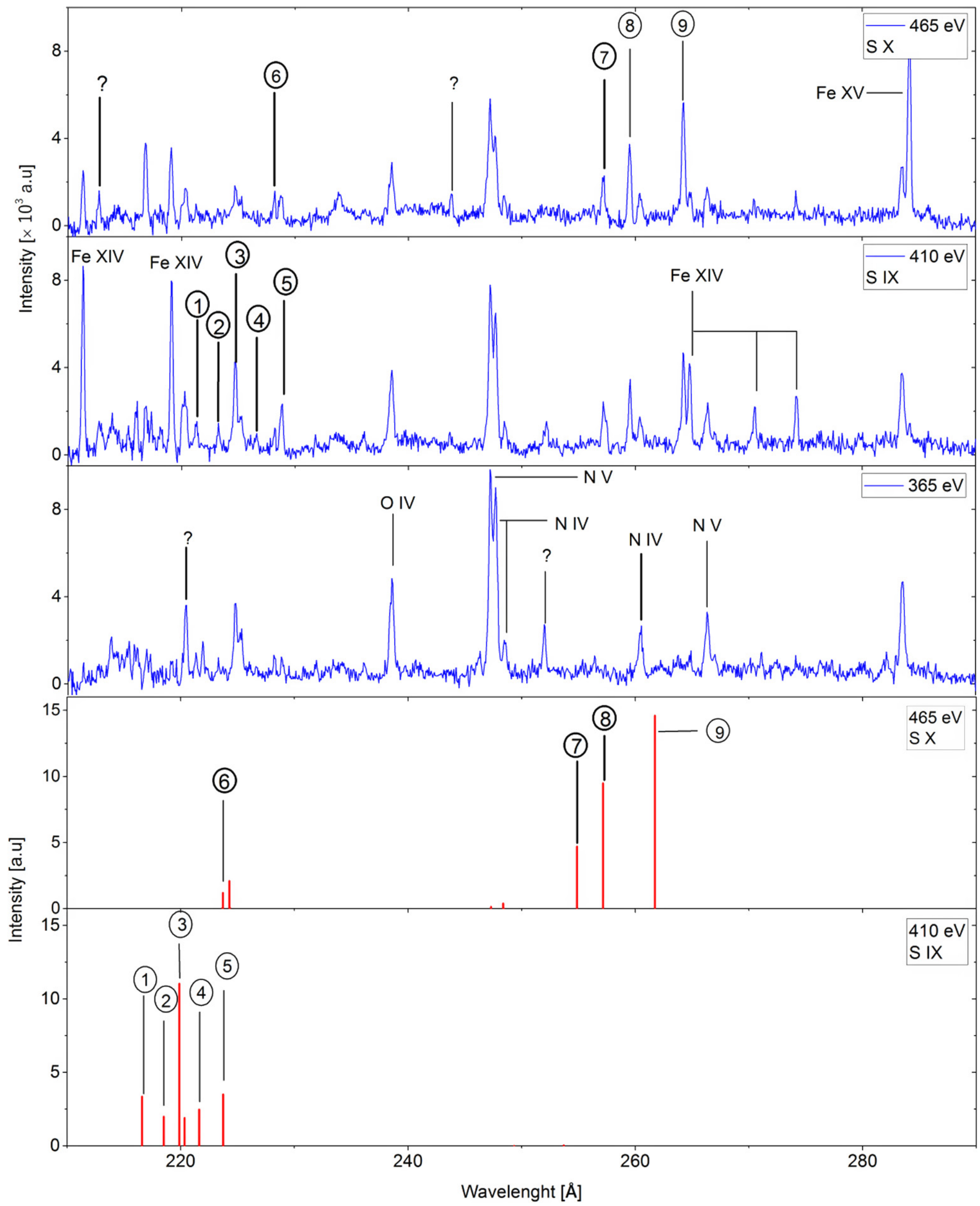

Fig. 1. EUV spectra of highly charged sulfur recorded with a CoBIT covering the wavelength range of 210–290 Å. Identified features from S IX and S X are labeled with numbers 1–5 and 6–9, respectively. The lines from impurities are labeled with the corresponding impurity ion. The question mark represents unidentified lines. The CR model spectra for S IX and S X were obtained by assuming mono-energetic beam conditions at 410 and 465 eV, respectively. The electron beam density was chosen to be $1 \times 10^{10}\ \mathrm{cm}^{-3}$.

Table 1
Emission lines identified from S IX and S X in the wavelength band between 210 and 290 Å. Wavelength values from the present collisional-radiative model calculations and the NIST data base are also listed. The wavelength uncertainty in the present measurements is estimated to be 0.06 Å.

Energy (eV)	Feature	Ion	Transition	Wavelength [Å]		
				Present		NIST
				Experiment	Theory	
410	1	S IX	2s-2p	221.27	216.60	221.24
	2	S IX	2s-2p	223.25	218.52	223.26
	3	S IX	2s-2p	224.74	219.88	224.73
	4	S IX	2s-2p	226.56	221.64	226.58
	5	S IX	2s-2p	228.80	223.75	228.83
465	6	S X	2s-2p	228.18	223.69	228.16
	7	S X	2s-2p	257.16	254.86	257.15
	8	S X	2s-2p	259.49	257.15	259.50
	9	S X	2s-2p	264.22	261.73	264.23

Please cite this article in press as: S. Ali et al., Extreme ultraviolet spectra of S IX and S X relevant to solar coronal plasmas, Nucl. Instr. Meth. B (2017), http://dx.doi.org/10.1016/j.nimb.2017.05.048