Thin Solid Films xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Thin Solid Films

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

Development of a compact polarization analysis apparatus for plasma soft X-ray laser

Takashi Imazono, Masato Koike

Quantum Beam Science Directorate, Japan Atomic Energy Agency (JAEA), 8-1-7, Umemidai, Kizugawa, Kyoto 619-0215, Japan

ARTICLE INFO

Available online xxxx

Keywords:
Soft X-ray laser
Multilayer
Polarizer
Ellipsometer

ABSTRACT

Laser-driven plasma soft X-ray laser, XRL, at a wavelength of 13.9 nm is generated from nickel-like silver plasmas. The polarization state at an end station is considered to be vertically linearly polarized due to the reflections at some Mo/Si multilayer mirrors installed in the XRL beamline, but the detail has not been verified experimentally. To evaluate and control the polarization state, a compact polarization analysis apparatus to adapt for the XRL end station is developed. Two Mo/Si multilayer mirrors are fabricated and the polarization properties are evaluated by using synchrotron radiation, SR. As a preliminary test of the apparatus, the reflectivity of the multilayer is measured by the XRL and it shows good agreement with that by SR.

1. Introduction

A laser-driven plasma soft X-ray laser, XRL, system has been constructed and operated at Kansai Photon Science Institute, KPSI, of JAEA [1]. The XRL is generated from nickel-like silver plasmas created by 10 J and several-ps-duration Nd:glass laser pulse and has a 7-ps-duration pulse at a wavelength of 13.9 nm with high spectral purity of $<10^{-4}$. The XRL is helpful for speckle measurements and surface observations in the nano-scale [2–4]. The characteristics of XRL depend on the gradient of plasma density and the electron temperature of plasmas generated by Nd:glass laser pulses [5]. Therefore, it is important to obtain the information on the plasmas, which is associated with the polarization state. Hence, the polarization of plasma should be characterized by polarization analysis. It is of importance in light source development. Also, it is considered that the polarization state at an XRL end station changes due to the reflections from some Mo/Si multilayer mirrors at an angle of incidence of ~45° installed between the XRL source point and the end station for the sake of focusing and spatial management, because a Mo/Si multilayer mirror designed at around 45° acts as a good polarizer. The pseudo-Brewster angle is ~45°, resulting from the fact that the refractive index is almost unity in a soft X-ray region. However, the detail of the polarization state has not been evaluated since the construction of the XRL beamline. The information on the polarization state is helpful for calibrating experimental data. Therefore, it is an important subject to characterize the polarization state in polarization dependent measurements.

We have developed a soft X-ray polarimeter and ellipsometer for complete polarization analysis, SXPE, for use in a synchrotron radiation, SR, facility [6–8]. The SXPE can be equipped with a pre-polarizer, P, and analyzer, A, and perform polarization measurements based on rotating-analyzer ellipsometry by means of nine axes, i.e., the azimuth and incidence angles and height of P, the azimuth and incidence angles, and height of A, the arm angle connected to a rotating-analyzer unit, the detector arm angle, and a variable slit in just front of a detector in high vacuum. It is currently operated at a soft X-ray SR beamline, BL-11 [9], of the SR Center, Ritsumeikan University, Shiga, Japan [10]. Unfortunately, since it is somewhat large to install at an XRL end station of KPSI, a more compact polarization analysis apparatus than SXPE is required to evaluate and control the polarization state of the XRL.

In this paper, we describe the design of the compact polarization analysis apparatus to adapt for an XRL end station along with the polarization characterization of Mo/Si multilayer mirrors using SR. Furthermore, a reflection measurement of the Mo/Si multilayer mirror using XRL is performed as a preliminary test of the apparatus showing good agreement with that measured by SR.

2. Design of a compact polarization analysis apparatus

The SXPE at the BL-11 beamline consists of nine motorized stages. It is somewhat large to install at the XRL end station of KPSI, therefore a more compact polarization analysis apparatus than SXPE was designed. Fig. 1 shows a schematic diagram of polarization measurements based on rotating-analyzer ellipsometry using two polarization components, i.e., a pre-polarizer, P, and an analyzer, A (a), and a projection drawing of the main body of the polarization analysis apparatus (b). This apparatus allows us to perform polarization measurements, i.e., single-reflection and transmission measurements, double-reflection and transmission

E-mail address: imazono.takashi@jaea.go.jp (T. Imazono).

http://dx.doi.org/10.1016/j.tsf.2014.02.011
0040-6090/

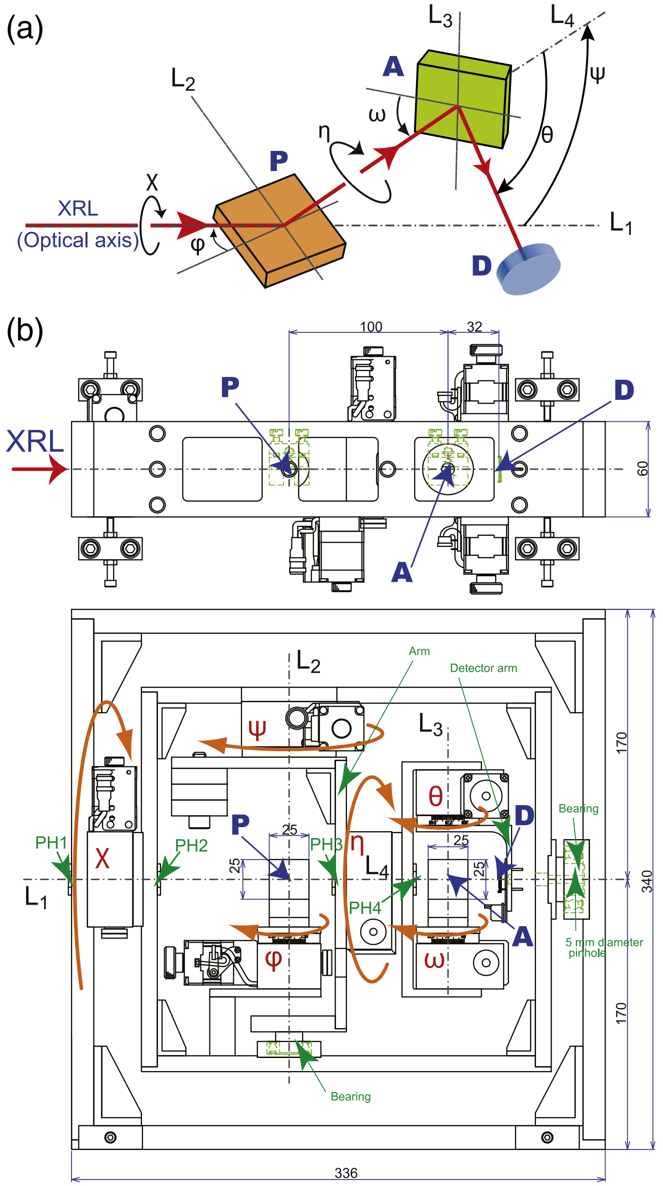

Fig. 1. Schematic diagram of polarization measurements based on rotating-analyzer ellipsometry using a pre-polarizer, P, and an analyzer, A (a), and a projection drawing of the main body of the polarization analysis apparatus (b).

measurements, reflection–transmission and transmission–reflection measurements by means of six axes in a high vacuum: azimuth angle of P, χ; incidence angle of P, φ; azimuth angle of A, η; incidence angle of A, ω; arm angle, ψ; detector arm angle, θ. All axes can be controlled individually and the specifications are listed in Table 1. In the case of double-reflection measurement shown in Fig. 1(a), an XRL beam is incident to P at φ along the optical axis identical to χ indicated by a rotation axis, L_1. The reflected beam by P is irradiated to A at ω on the arm rotated by ψ, and then the intensity of the reflected beam from A is measured by a detector, D, on the detector arm rotated by θ while changing η along a rotation axis L_4. The angles of φ and ψ, and ω and θ rotate along axes, L_2 and L_3, respectively. Also L_4 is superposed on L_1 when $\psi = 0$. The SXPE was equipped with the translation axes of polarization components and a variable slit in just front of a detector which were used for the adjustment of the angles of incidence in the vacuum. However these functions were not introduced in the instrument developed in this study because of miniaturization. Regardless of this, using 2-mm diameter pinholes denoted by PH1–PH4 in Fig. 1(b), the angles of incidence and height positions of P and A can be aligned at relatively high precision in an atmosphere. It is noted that the pinholes are removed during measurements. Also the size of a polarization component for P and A is limited up to 25 mm square × 5 mm thickness, which is about 1/2 times smaller than that of SXPE. Consequently, the instrument assembly shown in Fig. 1(b) was able to be installed in a vacuum chamber with a dimension of 400 × 400 × 400 mm^3 at the XRL end station, so it was named cSXPE after a compact SXPE. In addition, a special silicon photodiode (AXUV100Si/Zi, IRD Inc., CA, U.S.A.) having a filter deposited directly on the surface for the reduction of stray light was employed as the detector, which was the same with the one used in SXPE.

Table 1
Symbol, function, operation range, and resolution per pulse of each axis in cSXPE.

Symbol	Function	Operation range	Resolution per pulse
χ	Azimuth angle of P	−5–+100°	0.00125°
φ	Incidence angle of P	−10–+90°	0.0003°
ψ	Arm angle	−5–+120°	0.001°
η	Azimuth angle of A	0–+360°	0.00125°
ω	Incidence angle of A	−10–+90°	0.0003°
θ	Detector arm angle	−5–+125°	0.0003°

3. Design and fabrication of Mo/Si multilayer polarizers

A reflection-type Mo/Si multilayer polarizer for 13.9 nm was designed by means of a layer-by-layer method [11]. Fig. 2 shows the calculated reflectivities for s-polarization, R_s, and p-polarization, R_p, and the polarizance, Z, defined as $(R_s - R_p) / (R_s + R_p)$, of the Mo/Si multilayer as a function of the incident angle, assuming that the periodic length, D, the ratio, Γ, of a Mo layer thickness to D, the number of layers, N, and the topmost layer are 10.2 nm, 0.44, 47, and Mo, respectively. The value of R_s is 75% at the pseudo-Brewster angle of about 45° and two orders of magnitude higher than R_p. Because of $Z > 99\%$, the multilayer is expected to work as the polarizer with high performance at 13.9 nm.

In order to be used as a pre-polarizer, P, and analyzer, A, in the cSXPE, the designed Mo/Si multilayer mirror described above was fabricated on commercially available Si(100) wafers of 1 mm thickness with a root-mean-squire roughness of <0.3 nm at ambient temperature by ion beam sputtering method. The base pressure was lower than 1×10^{-5} Pa and the Ar gas pressure was 15 mPa during deposition. The periodic structures of the fabricated multilayers were examined by X-ray diffraction with Cu-Kα radiation. Fig. 3 shows small-angle X-ray diffraction profiles of two Mo/Si multilayer mirrors for P and A. For the comparison, the calculation curve is also shown. From the Bragg peak positions, D and Γ were determined to

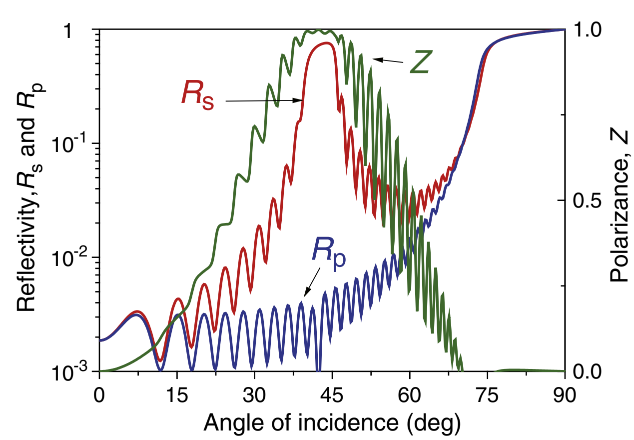

Fig. 2. Calculated R_s, R_p, and Z of the Mo/Si multilayer as a function of the incident angle.

Please cite this article as: T. Imazono, M. Koike, Thin Solid Films (2014), http://dx.doi.org/10.1016/j.tsf.2014.02.011