DESIGN OF CRYSTAL SPECTROMETER FOR KeV X-RAY EMISSION STUDIES

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ABSTRACT

Coherent and incoherent x-rays have been producing using laser produced plasma media. Crystal spectrometers are used to resolve spatially and spectrally emission from plasma media. In this work, design parameter of an keV crystal spectrometers will be presented. Hydrodynamic and atomic physics simulation results of Ne-like and F-like Ti resonance lines emitted from ultrashort pulse laser produced plasma will be presented. The optimized parameters of the designed keV crystal spectrometer is obtained for recording the Ti resonance lines emission.

Keywords: Crystal spectrometer, X-ray emission, Laser-produced plasmas

❖ Introduction

X-rays have been producing from laser produced plasmas [1] to tokamak plasmas [2]. X-ray spectroscopy of self-emission from hot plasmas is extensively used to measure plasma properties in a variety of physical conditions from the low-density tokamak-type plasmas to the higher density laser plasmas [3]. Crystal spectrometers and grating spectrometers are used to record x-rays emitted from laser produced plasmas. Emission from laser produced plasma below ~ 30 Å wavelengths can be resolved by crystal diffraction [4,5]. Emission from laser produced plasmas above ~ 30 Å wavelengths are usually resolved by either transmission or reflection grating. Flat field grating spectrometers can be used to resolved spectral emission longer than approximately 20 Å [6]. Spectrometers have different requirements concerning positioning and stability. Flat field crystal and curved-crystal spectrometers are used to record x-rays [7,8]. A convex crystal spectrometer is capable of simultaneously measuring spectral distribution in a wide range of interest [9,10]. However, wavelength calibration in the case of the convex crystal more complicated than that of a flat crystal [9]. In this work, design parameter of an keV crystal spectrometers will be presented. The optimized parameters of the designed keV crystal spectrometer is obtained for recording the Ti resonance lines emission.

Atomic physics, hydrodynamic and collisional radiative codes such as Ehybrid [11] and NeF [12] have been used for analysis of x-rays emitted from laser-produced plasmas. There is considerable interest in developing spectral diagnostics for plasmas using the line emission from laser-produced plasmas [13,14]. Collisional radiative simulation results of Ne-like and F-like Ti resonance lines emitted from ultrashort pulse laser produced plasma will be presented.

❖ Calculation of design parameter

When designing a crystal spectrometer three factor are considered; choosing wavelength range, spectral resolution and image brightness must be suitable. Also resolving power and linear dispersion are important parameters. Properties of different crystals used in spectrometer are given in Table 1. Figure 1 shows Bragg angles as a function of wavelength for crystals in Table 1. In this paper, Ne-like and F-like Ti resonance lines between 18 and 21 Å are considered to record using crystal spectrometer. This resonance lines are resolved by the crystal diffraction depend on Bragg's law. We chose the RAP (2d=26.12 Å)crystal to record this wavelength range. The RAP crystal have chemically stable and have a good dispersion efficiency. Angular dispersion efficiency can be expressed as

$$\frac{d\theta}{d\lambda}=\frac{n}{2d}\frac{1}{Cos\theta} \tag{1}$$

here θ is incident angle, *2d* is lattice spacing and *n* is diffraction order. Fig. 2 shows dispersion efficiency as a function of incident angle for RAP crystal. Higher order reflections are better dispersed and that the 2d-spacing of the crystal is an important factor. Where high resolution is desired, it is best to avoid low θ and wide 2d-spacings even at the loss of intensity.

Table 1 *Properties of different crystals* [15]

Crystal	Miller İndices	2d (Å)	Chemical Formula	Useful Wavelength Range(Å)
Lithium fluoride	(420)	1.801	LiF	0.157-1.72
Lithium fluoride	(200)	4.027	LiF	0.351-3.84
Pentaerythritol (PET)	(002)	8.742	$C(CH_2OH)_4$	0.351-3.84
Sucrose	(001)	15.12	$C_{12}H_{22}O_{11}$	1.32-14.42
Thallium hydrogen phthalate (THP) ,(TIAP)	(100)	25.9	$TIHC_8H_4O_4$	2.26-24.7
Rubidum hydrogen phthalate (RHP) , (RAP)	(100)	26.12	$RbHC_8H_4O_4$	2.28-24.92
Potassium hydrogen phthalate (KHP) , (KAP)	(100)	26.63	$KHC_8H_4O_4$	2.32-25.41
Octadecyl hydrogen maleate (OHM)	?	63.5	$CH_3(CH2)_{17}OOC(CH)_2COOH$	5.54-60.6

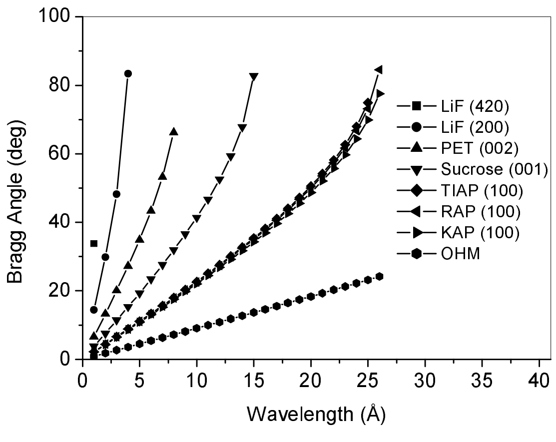

Figure 1 *Bragg Angle as a function of wavelength (Å) for different crystal.*

Figure 2 Angular d*ispersion efficiency as a function of incident angle for RAP crystal.*

Flat-field crystals have better intensity gain than curved crystal, but each part of crystal diffract limited width wavelength. Spectral resolution is determined by the size of the emitting region, by the size of the CCD pixels and by the specific properties of the crystal (rocking curve). Taking into account all these effect, resolving power of the instrument can be approximately given by [4];

$$\frac{\lambda}{\delta\lambda}=\sqrt{\frac{\tan^{2}\theta}{(\delta\theta_{c})^{2}+(\delta_{x}/L)^{2}+(\delta_{y}/L)^{2}}} \tag{2}$$

here θ_c ; rocking angle (rad), L; total distance between source and CCD camera, δ_x; size of the emitting region, δ_y; size of the CCD pixel.

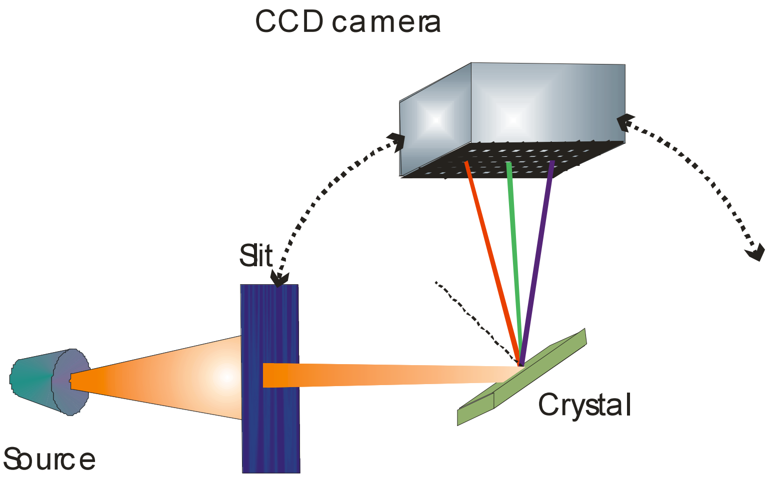

Figure 3 *Design of crystal spectrometer.*

In our calculation central wavelength is considered 19.365 Å for CCD have 256 x 1024 pixel (26 µm x 26 µm). Figure 4 shows wavelength as a function of crystal rotation angle, in where 18.1 Å corresponding to first pixel and 20.3 Å corresponding to last pixel. CCD camera position is constant in this calculation. However this assumption is not enough for simultaneously measuring spectral distrubition in range of our interest. We designed spectrometer to measure wavelength between 17 Å and 26 Å as in Figure 3. In our designing by moving CCD camera position, interested spectral lines can be recorded.

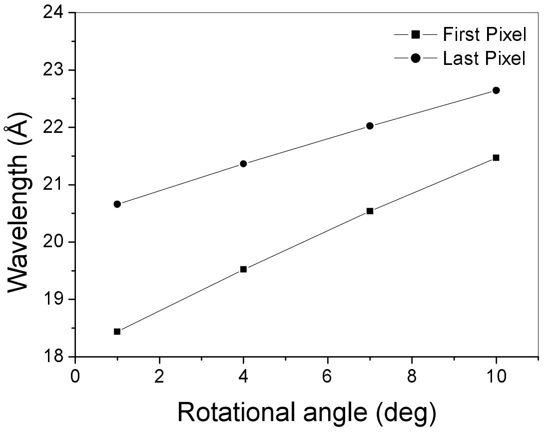

Figure 4 Rotational *angle as a function of wavelength (Å).*

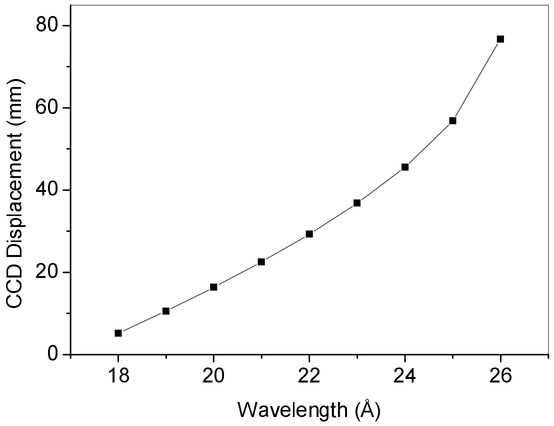

Figure 5 CCD displacement *as a function of wavelength (Å).*

We can use this crystal spectrometer to record Ne-like and F-like resonance lines (17 -27 Å) emitted from Ti plasma. By moving the CCD (See Figure 5).

❖ Collisional radiative simulation results

Resonance lines emission from x-ray laser media is recorded using crystal or grating spectrometer on transverse direction to measure ionisation balance. There is considerable interest in developing spectral diagnostics for plasmas using the line emission from Ne-like and F-like ions. For these propose we used a collisional-radiative code NeF that simulates line emission from such ions [12]. In this code resonance line intensity emitted from plasma are calculated by

$$I_k = n_k \frac{hc}{\lambda} A_{km} T \qquad \text{Photons/cm}^3\text{/s/Å} \qquad (3)$$

where n_k is the upper state population for a given transition, h is Planck`s constant, c is the vacuum speed of light, λ is the spectral line wavelength and T is an escape factor to allow for radiation re-absorption in the plasma.

In this paper we report the result of collisional radiative code NeF in steady state condition for diagnostic purposes of the Ne-like titanium x-ray laser media. We simulated the Ne-like $1s^2 2s^2 2p^6 \rightarrow 1s^2 2s^2 2p^5\, nl$ and F-like $1s^2 2s^2 2p^5 \rightarrow 1s^2 2s^2 2p^4\, nl$ resonance lines emitted from titanium plasma. Figure 6 shows Ne-like and F-like resonance lines emitted from Ti plasma at wavelength between 17 Å and 30 Å.

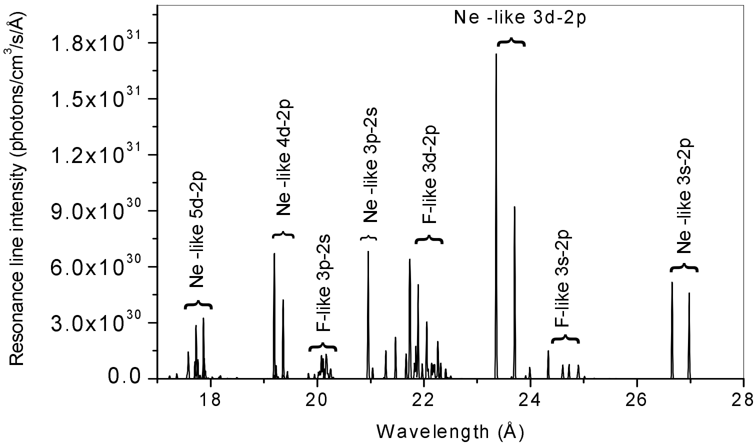

Figure 6 *The Ne-like and F-like resonance line spectrum emitted at 200 eV electron temperature and $5x10^{20}$ cm^{-3} electron density.*

The excited levels in Ne-like collisional x-ray laser media are populated mainly by electron collisions. Therefore, electron temperature can be obtained using line intensity ratio. Figure 7 shows the F-like 3s-2p lines to Ne-like 3s-2p resonance lines as a function of electron density at different temperatures. The line ratios do not strongly depend on electron density. Figure 8 shows the line ratios as a function of electron temperatures.

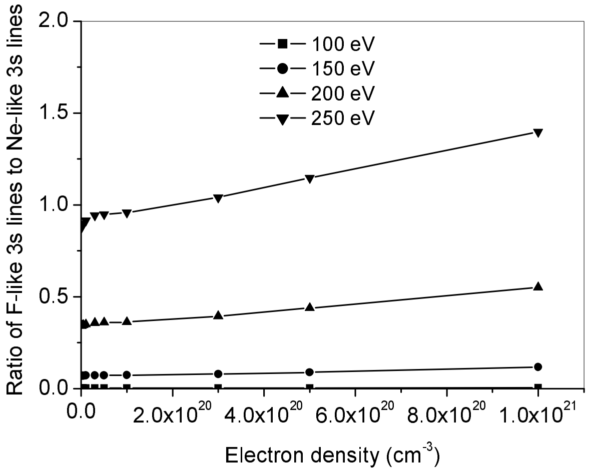

Figure 7 The *F-like 3s-2p to the Ne-like 3s-2p resonance lines as a function of electron density*

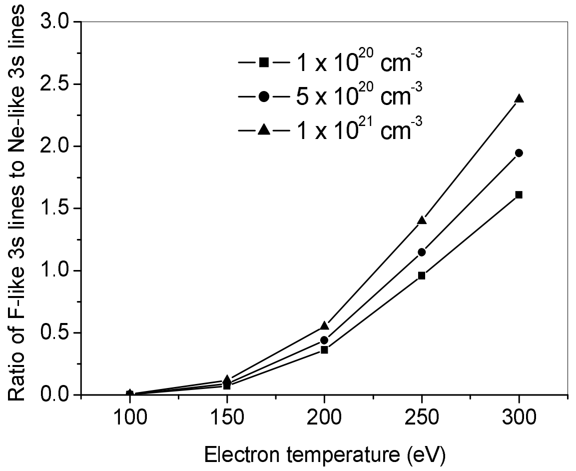

Figure 8 The *F-like 3s-2p to the Ne-like 3s-2p resonance lines as a function of electron temperature*

❖ Results

The optimized parameters of the designed keV crystal spectrometer is obtained for recording the Ti resonance lines emission. Crystal spectrometer can be used to record Ne-like and F-like resonance lines (17 -27 Å) emitted from Ti plasma. The Ne-like and F-like Ti resonance lines emitted from ultrashort pulse laser produced plasma are simulated using Collisional radiative code NeF. The Ne-like and F-like Ti resonance lines between 17 and 27 Å can be resolved using crystal spectrometer with optimized parameters.

Acknowledgements

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