Sinmyung Laser System and Study on the X-ray Generation

신명(新溟) 레이저와 X-선 발생 연구

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A high-power Nd:glass laser system(Sinmyung I) has been constructed and tested. In this system, we used a Nd:YLF laser as a master oscillator, a 4-pass amplifier for pre-amplification, 5 stages of rod amplifiers, and spatial filtering and image relaying units. The system has demonstrated in excess of 80J(2TW) with 40 psec(FWHM) pulse duration. Output energy, gain and spatial profile were measured at each amplification stage. With this laser system a preliminary X-ray generation experiment was performed. Pinhole images, X-ray diode signals and X-ray spectrum were obtained for the irradiated target of copper. Detailed descriptions of the system performance and the X-ray generation experiment are presented.

I. Introduction

KAIST completed the construction of a one beam Nd:glass laser system named as Sinmyung I capable of delivering 80J(2TW) in 40 psec pulse at system firing rates of 6 shots/hr[1]. Basic features of this system include the adoption of a Nd:YLF laser as a master oscillator, the employment of a 4-pass amplifier for pre-amplification, the use of Nd-doped phosphate glass for rod amplifiers up to 90-mm diameter, and the utilization of spatial filtering and image relaying units.

In this paper, the overall explanation of Sinmyung I system is described in Section II; the output caracteristics of Sinmyung I system and the results of a preliminary X-ray generation experiment with this system are presented in Section III and IV, respectively; finally, the system performance is summarized in Section V.

II. The Overall explanation of Sinmyung I System

In this section, we introduce the scheme of the TW laser system(Sinmyung I) consisting of the master oscillator, the 4-pass amplifier and the 5-stage amplifier. Fig.1 shows the schematic diagram of the laser system. The optical path length was about 40m from the master oscillator to the AMP5. As shown in Fig.1, a single pulse selected by a Pockels cell propagated into the 4-pass amplifier and then was reflected by a polarizing beam splitter of the Pockels cell 1 because the Pockels cell had no applied voltage when the pulse returned back. This reflected laser pulse was sent to the following 5 amplifier stages. To increase the contrast ratio of the laser pulse and protect the optical elements from the pulse reflected at the target surface, we installed the Pockels cell 2 between VSF2 and AMP3.

The 5-stage rod amplifier system consists of two types of cavity. One type(AMP1 and AMP2) was a quadruple elliptical cavity with a silver(Ag) coated reflector and pumped by 4 flashlamps. The other one(AMP3, AMP4 and AMP5) was a circular cavity with a barium sulfate($BaSO_4$)

diffuse reflector and pumped by 12 flashlamps. Ellipticities of the reflectors of AMP1 and AMP2 were 0.62 and 0.67. The values were determined to give the maximum and most uniform pumping efficiency[2]. For all amplifiers we used phosphate-based laser glass to take advantage of the lower nonlinear index of refraction and higher specific gain than typical silicate-based laser glass[3]. Table 1 lists the parameters of Nd:Glass rods installed in each amplifier cavity. We used the flashlamps with 300mm arc length, 19mm bore diameter and Xe gas of 450Torr. The lamps were energized by a 450μsec critically damped pulse-forming network(PFN) consisting of a 200μF capacitor and a 100μH inductor. We operated the flashlamps at the charging energy of about the 5% explosion energy(24kJ).

Table 1. Parameters of Laser Rods.

Title		AMP1	AMP2	AMP3	AMP4	AMP5
Glass Type		LG750	LG760	LG750	LG760	LHG-8
Size	Diameter(mm)	16	30	40	64	90
	Length(mm)	360	360	360	360	360
Doping % of Nd^{3+}		1.50	1.00	0.60	0.40	0.40
Fluorescence Lifetime(μsec)		405	411	428	400	408
Face Angle(degree)		6.0	6.0	6.0	6.0	6.0

Ⅲ. The Output Characteristics of Sinmyung I System

The Nd:YLF laser(Quantronix, Model 4216) was Q-switched and mode locked at the wavelength of 1.053μm. A single pulse of this output was selected by the Pockels cell. The pulse width of the single pulse was 40 psec(FWHM).

We used the degenerate 4-pass amplifier for a pre-amplifier of Sinmyung I laser system as shown in Fig.1. The maximum gain of the 4-pass amplifier was 2×10^5 and the merit of this amplifier is a complete compensation for a distortion of a beam polarization due to a thermal birefringence[4]. We measured the single pass gains of the 5 amplifier stages which were listed in Table 2. The gain of AMP1 is the largest due to the high Nd-ion doping density. We measured the output energy and the spatial profiles of the Sinmyung I laser system. The output energy was 80J(2TW). The energy of the amplified spontaneous emission(ASE) was less than 10μJ. In order to operate the 5-stage amplifier system safely at this energy, the output spatial profile of each amplifier should have a good quality without ripples or spikes[5]. We removed unwanted ripples and spikes by installing a spatial filter between amplifiers and used the image relaying technique in which the image of a hard aperture was relayed to the end surfaces of each amplifier rod in order to reduce significantly the deleterious effects of whole beam self-focusing. Fig.2 shows the spatial profiles of an amplified laser beam on the end surfaces of the amplifiers.

Table 2. Small Signal Gains of the 5 Amplifier Stages.

Total Pumping Energy	Small Signal Gain		Total Pumping Energy	Small Signal Gain		
	AMP1	AMP2		AMP3	AMP4	AMP5
1.80 kJ	4.6±0.3	2.2±0.5	5.40 kJ	2.1±0.1	1.7±0.1	1.3±0.1
2.45 kJ	8.5±0.4	3.3±0.7	7.35 kJ	3.2±0.2	2.1±0.1	1.4±0.1
3.20 kJ	16±2	6.2±0.6	9.60 kJ	3.9±0.4	2.4±0.1	1.6±0.1
4.05 kJ	29±3	10±1	12.2 kJ	5.4±0.5	2.6±0.3	1.9±0.1

Ⅳ. X-ray Generation Experiment

A preliminary X-ray generation experiment was performed. Pinhole images, X-ray diode signals and X-ray spectrum were obtained for the irradiated target of copper.

To find the optimal focusing lens position and determine the dimensions of the generated plasma a pinhole camera was used. Fig.3 shows two pinhole images which were obtained at two positions of the focusing lens. When optimal focusing conditions of laser beam onto the target surface were achieved, the focal spot diameter was approximately 100-200μm depending on the laser output energy.

X-ray diodes were used to provide X-ray intensity measurements with pseudo-temporal resolution. Fig.4 shows a typical oscillogram of the infrared diode and the X-ray diode signals. The signals were recorded by a 500MHz digital oscilloscope(HP 54520A).

A flat crystal spectrometer with a mica crystal was used to obtain X-ray spectra. A densitometer trace of a X-ray spectrum in the wavelength region of 11-13Å is shown in Fig.5. The dominant spectral lines are those from Ne-like CuXX ions. More detailed experimental study and data analysis are under progress.

V. Conclusion

We constructed and demonstrated the TW level Nd:Glass system(Sinmyung I) consisting of a Nd:YLF laser as a master oscillator, 4-pass amplifier and 5-stage Nd:glass amplifier. The output pulse width of the Nd:YLF laser is 40psec, which was selected from a mode-locked & Q-switched pulse train by a Pockels cell. The maximum gain of the 4-pass amplifier was 2×10^5 and the merit of this amplifier is a complete compensation for a distortion of a beam polarization due to a thermal birefringence, which was considered to be the main feature for Sinmyung I system to produce high laser energy output and no spiking in the spatial mode. Output gains and spatial profiles were measured at each amplifier stage. We obtained the very clean spatial profiles without self-focusing. The Sinmyung I laser system demonstrated in excess of 80J(2TW) with 40psec(FWHM). With this laser system a preliminary X-ray generation experiment was performed. Pinhole images, X-ray diode signals and X-ray spectrum were obtained for the irradiated target of copper. Studies on the laser produced plasma and plasma X-ray emission characteristics are actively under progress.

References

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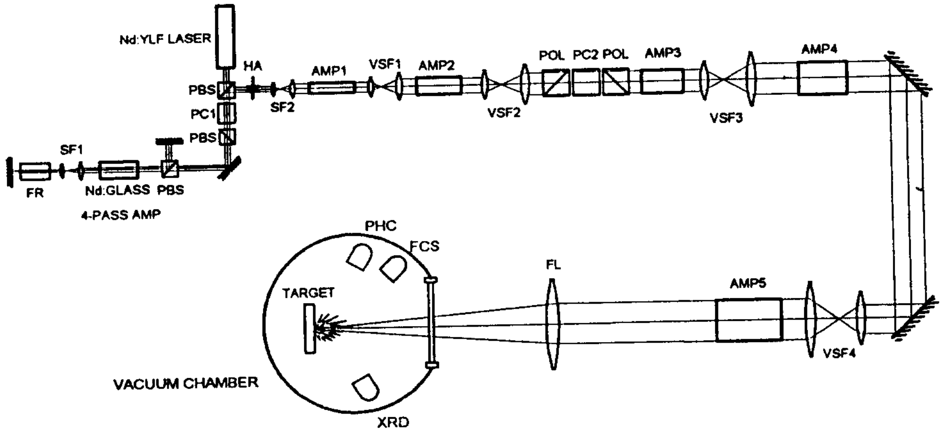

Fig.1. The schematic diagram of Sinmyung I system.
PBS : Polarizing Beam Splitter, PC : Pockels Cell, FR : Faraday Rotator,
HA : Hard Aperture, SF : Spatial Filter, AMP : Amplifier,
VSF : Vacuum Spatial Filter, POL : Polarizer, FL : Focusing Lens,
PHC : Pinhole Camera, FCS : Flat Crystal Spectrometer, XRD : X-ray Diode

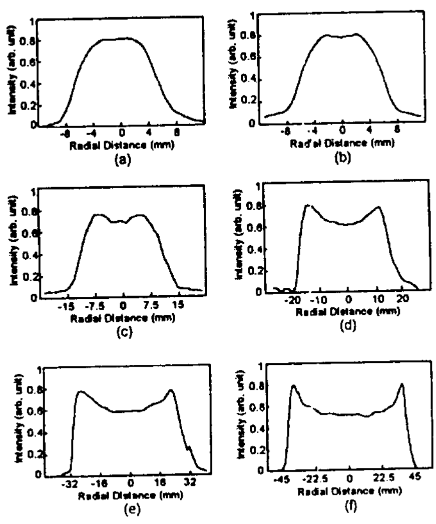

Fig.2. The spatial profiles of the amplified laser beam at the front surface of Amp1(a) and at the rear surfaces of 5 amplifier stages; (b) Amp1, (c) Amp2, (d) Amp3, (e) Amp4, (f) Amp5.

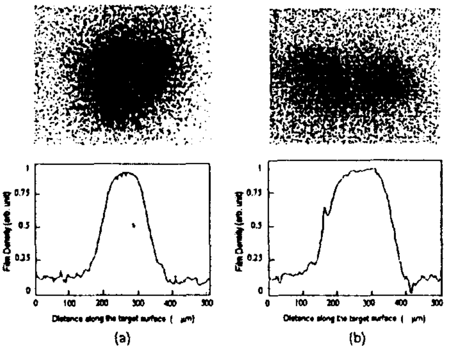

Fig.3. Two pinhole images which were obtained at two positions of the focusing lens; (a) the focusing lens was at optimal position; (b) the focusing lens was located at 5 mm nearer to the target.The densitometer traces are placed below the images.

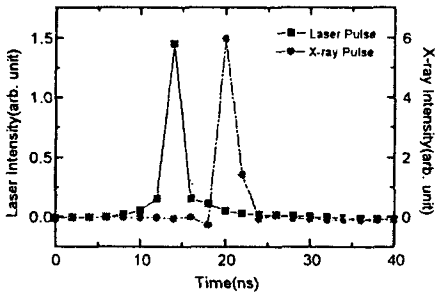

Fig.4. The oscillogram of the infrared diode and the X-ray diode signals.

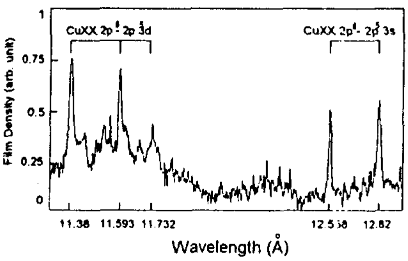

Fig.5. The densitometer trace of the spectrum with the line emissions of Ne-like CuXX ions.