Sinmyung Laser System and Study on the X-ray Generation
신명(新濤) 레이저와 X-선 발생 연구

Hong Jin Kong, Ki Gwan Han, Nam Seong Kim, Hyun Soo Kim, Ki Young Um, Jong Rak Park,
Jae Yong Lee, Yun Sup Shin, Ki Ho Han and Jae Oh Byun
Department of Physics, Korea Advanced Institute of Science and Technology,
373-1 Kuseong-dong Yuseong-gu Taejon, Korea

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 ps (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 ps pulse at system firing rates of 6 shots/hr. 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 characteristics 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 (BaSO4)
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. 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. 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 450 μsec critically damped pulse-forming network (PFN) consisting of a 200 μF capacitor and a 100 μH inductor. We operated the flashlamps at the charging energy of about 5% explosion energy (24kJ).

<table>
<thead>
<tr>
<th>Glass Type</th>
<th>AMP1</th>
<th>AMP2</th>
<th>AMP3</th>
<th>AMP4</th>
<th>AMP5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter(mm)</td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>Length(mm)</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Doping % of Nd</td>
<td>1.00</td>
<td>0.60</td>
<td>0.60</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>Fluorescence Lifetime(μsec)</td>
<td>405</td>
<td>411</td>
<td>428</td>
<td>400</td>
<td>408</td>
</tr>
<tr>
<td>Face Angle(degree)</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Total Pumping Energy</th>
<th>Small Signal Gain</th>
<th>Total Pumping Energy</th>
<th>Small Signal Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMP1</td>
<td>AMP2</td>
<td>AMP3</td>
<td>AMP4</td>
</tr>
<tr>
<td>1.80 kJ</td>
<td>4.6±0.3</td>
<td>5.40 kJ</td>
<td>2.1±0.1</td>
</tr>
<tr>
<td>2.45 kJ</td>
<td>8.5±0.4</td>
<td>7.35 kJ</td>
<td>3.2±0.2</td>
</tr>
<tr>
<td>3.20 kJ</td>
<td>16±2</td>
<td>9.60 kJ</td>
<td>3.9±0.4</td>
</tr>
<tr>
<td>4.05 kJ</td>
<td>29±3</td>
<td>12.2 kJ</td>
<td>5.4±0.5</td>
</tr>
</tbody>
</table>

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 1.063 μm. 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 $2 \times 10^5$ and the merit of this amplifier is a complete compensation for a distortion of a beam polarization due to a thermal birefringence. 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 10 μJ. 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. 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.

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 100–200 μm 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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    system in KAIST(Sinmyung I), Laser
    No 140: Section 9, 321(1995)

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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.