Experimental observation of hot electrons produced by laser with small scale-length and shorter wavelength*

Qi Lan-Ying, Jiang Xiao-Hua, Zhao Xue-Wei, Zheng Zhi-Jian, Li San-Wei
Ding Yao-Nan, Ding Yong-Kun, Li Chao-Guang and Zhang Wen-Hai
(*Laser Fusion Laboratory, Southwest Institute of Nuclear Physics and Chemistry, Chengdu 610003*)

Abstract The experiments on gold-disk and hohlraum targets irradiated by laser beams with wavelength of 0.35 μm (Xingguang-II) and 0.53 μm (Shenguang-I) are performed. The characteristics of hot electrons and the SRS (stimulated Raman light scattering) produced by shorter wavelength laser are experimentally studied. Associated with the measurement of backward SRS, the production mechanism of hot electrons is preliminarily analyzed in laser plasma with shorter wavelength.

Keywords Shorter wavelength laser, Gold-disk target, Hohlraum target, Hot electron, Stimulated Raman scattering

1 Introduction

Hot electrons have been taken seriously in X-ray driven inertial fusion for a long time, since they can make it more difficult to achieve high-gain implosions through penetrating and preheating the fusion fuel. Many experiments have confirmed that hot electrons can be reduced to an acceptable level by shortening laser wavelength to 0.26 and 0.35 μm[1~2]. Since we use the shorter wavelength laser beams from "Xingguang-II" ($\lambda = 0.35\,\mu$m) and "Shenguang-I" ($\lambda = 0.53\,\mu$m) facilities, it is able to study the characteristics of hot electrons and stimulated Raman scattering (SRS), and seek the methods to suppress them to a harmless level.

2 Experimental arrangement

The experiments were conducted on "Shenguang-I" and "Xingguang-II" laser facilities. The laser parameters were as follows: output laser energy E_L=30~130 J, τ=630~1000 ps, focal spot $\Phi_o = 50 \sim 200\,\mu$m for λ=0.351 μm; E_L=100~200 J, $\tau = 800 \sim 1000$ ps, $\Phi_o = 100 \sim 300\,\mu$m for $\lambda = 0.53\,\mu$m. Targets used in the experiments were gold-disk targets and Au hohlraum targets.

In our experiment, the K-edge spectrometer[3] is used for measuring low fluence 10~88 keV X-ray spectrum. The K-edge channels use K-edge filters along a line of sight to obtain higher sensitivity. The SRS energy is measured by a laser energy meter. The time integrated spectra of SRS are measured by using an optical multiple-channel analyser (OMA). Time resolved spectrum of backward SRS is measured by using an OSC (streak camera for visible light).

3 Experimental results and analysis

In this report, we focus our attention on the hot electrons with SRS behavior and the hot electron production mechanism of Au disk targets and hohlraum targets irradiated by 0.351μm and 0.53 μm laser light, respectively. T_h and T_e, the temperature of hot electrons and thermal electrons are commonly deduced from the slope of hard X-ray spectrum. We used an iterative unfolding procedure that did not constrain the shape of the spectrum to evaluate the X-ray spectra. Fig.1 shows the measurement results of the high-energy X-ray fluence versus X-ray energy in Au disk target experiments under normal conditions by using 0.35, 0.53 and 1.06μm laser light, respectively.

The results show that spectrum of hard X-rays has two temperatures ($T_e = 0.9 \sim 1.5$ keV, $T_h = 6.5 \sim 15$ keV). The experimental results[4] also show that hot electron energy (E_{he}) and

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SRS energy (E_{SRS}) produced on Au disk irradiated by $0.53\mu m$ laser is less than that of $1.053\,\mu m$ laser about one and two orders of magnitude, respectively, both T_h and T_e reduce about one half. T_h of Au disk is similar to the results obtained by $(I\lambda_L^2)^{0.3\sim0.4}$. Both E_{he} and E_{SRS} of hohlraum reduce about one order of magnitude. E_{he} and E_{SRS} produced on Au disk irradiated by $0.35\,\mu m$ laser is less than that of $1.053\,\mu m$ laser about two and three orders of magnitude, respectively (see Table 1); T_h and T_e reduce about two thirds and one half, respectively; E_{he} of hohlraum reduces about two orders of magnitude. Therefore, shorter wavelength laser can be used to suppress SRS and hot electron efficiently. On the basis of Ref.[5], reducing laser wavelength may raise instability threshold and reduce instability growth rate, so as to reduce hot electron production probability. On the other hand, the shorter the laser wavelength is, the deeper it goes in laser plasma and the greater plasma scalelength of underdense becomes so that T_e reduces. Shown from experiment and theory the T_e decreases as the wavelength decreases, so that the increase in electron-ion collision frequency ($v = 8.72\times10^{-11}\times\eta_e Z/T_e^{3/2}\times\ln\Lambda$) suppressed instability growth rate efficiently. Besides this, we find that when we add C_8H_8 ($0.5\,\mu m$) foil in hohlraum target SRS enhances six times obviously (see Fig.2a and Fig.2b). Because of C_8H_8 foil ($0.5\,\mu m$) is low-Z matter its expanding velocity of the forming plasma is fast, and then increases plasma scale-length L below quarter-critical so that SRS increases. The results showed up that C_8H_8 foil ($0.5\,\mu m$) is adverse for suppressing SRS.

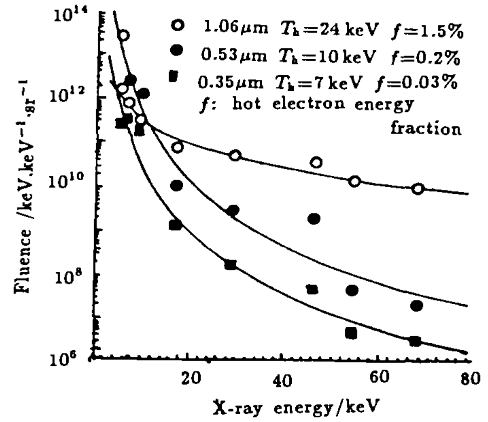

Fig.1 The fluence of high energy X-ray vs X-ray energy for gold disk targets

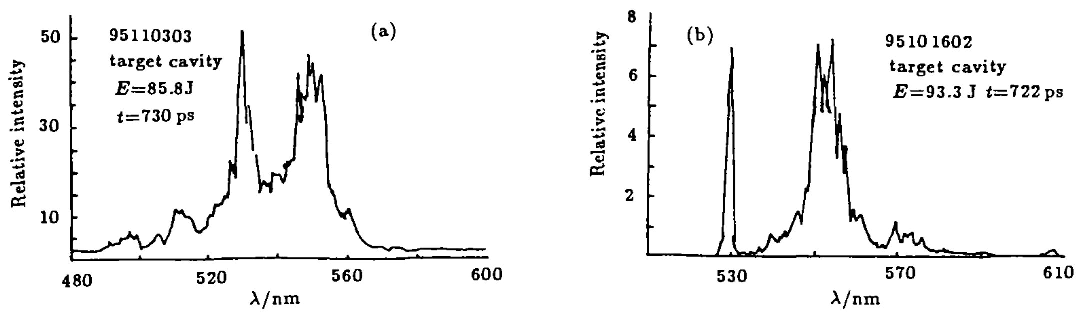

Fig.2 Time-integrated spectra of backward SRS produced on hohraum target with C_8H_8 foil (Fig.2a) and without C_8H_8 foil (Fig.2b) irradiated by $0.35\mu m$ laser light

Table 1 Hot electron characteristics from gold disk target irradiated by different wavelength laser light

E_L/J	$\lambda/\mu m$	$E_{HX}/\mu J\cdot sr^{-1}$	E_{he}/mJ	T_h/keV	T_e/keV	Laser setup
110	1.053	1040	3025	16.1	2.12	Shenguang I
86.1	0.351	6.02	30.2	7.1	1.6	Xingguang II
121	1.053	637	1613	24.5	2.4	Xingguang II
85	1.053	480	1373	16.1	2.02	Shenguang I
97	0.351	4.22	24.6	6.4	1.32	Xingguang II
119	0.351	11.2	60.4	8.16	1.52	Xingguang II

In "Shenguang-I" experiments, the total energy $E_{\rm he}$ and $E_{\rm SRS}$ of hot electrons and SRS from hohlraum targets irradiated by 0.53 μm laser light are typically 390~585, 750~969 mJ, respectively, and the peak wavelength of SRS light is typically $\lambda_{\rm m}$=0.78 μm. On the basis of the following energy-conservation, Mantey-Rowe equation,

$$\omega_0 = \omega_{\rm s} + \omega_{\rm pe} \qquad (1)$$

we can derive a better relation of total energy for hot electrons with total yield of SRS light. In Eq.(1) ω_0, $\omega_{\rm s}$ and $\omega_{\rm pe}$ are frequency of incident light wave, SRS scattering light wave and langmuir, respectively. So we deduced that SRS is the primary mechanism for producing hot electrons in hohlraum targets (plasma scale length $L \geq 300\,\mu$m). Our experimental results show that the total energy $E_{\rm SRS}$ of SRS is much less than the total energy $E_{\rm he}$ of hot electrons (see Table 2) as Au disks are irradiated with 0.53 μm laser light at an intensity range from 4.5×10^{14} to 4.7×10^{15} W/cm^2 that is much greater than threshold intensities $I_{\rm L} = 1 \sim 2\times10^{14}$ W/cm^2 for driving two-plasma decay (TPD). So we deduce that TPD and resonance absorption (RA) are probably the primary mechanism for producing hot electrons in Au disk targets ($L \leq 100\,\mu$m) and next SRS. But when L is between 100μm and 200μm, TPD is the primary mechanism for producing hot electrons in Au disk targets and next SRS.

Table 2 The comparison between $E_{\rm he}$ and $E_{\rm SRS}$ from gold-disk target irradiated with 0.53μm light

I/W·cm^{-2}	$E_{\rm he}$/mJ	$E_{\rm SRS}$/mJ	off focus/μm
4.7×10^{15}	~377	90	0
4.5×10^{14}	~91	0.81	300
5.8×10^{14}	~167	2.8	340

In "Xingguang-II" experiments, the total energy $E_{\rm he}$ of hot electrons from gold-disk and hohlraum targets irradiated with 0.35 μm are typically 15~ 40 and 100~180 mJ, respectively, and the total energy $E_{\rm SRS}$ are much less than 1.5 mJ and 50 mJ, respectively. So we can deduce that SRS is not the primary mechanism for producing hot electrons in hohlraum and gold-disk targets from the relation between $E_{\rm he}$ and $E_{\rm SRS}$. In time-resolved spectra of SRS observed by optics streak camera (see Fig.3) there exists an intensive disconnection in gold-disk and hohlraum targets, so we surmise that there exist another mechanism[6] that is necessary to go to a step further.

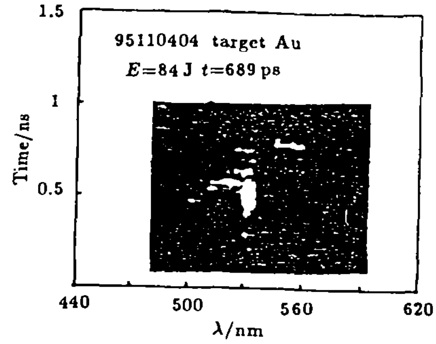

Fig.3 Time-resolved pictures of SRS produced by 0.35 μm laser light at 45° incidence in gold-disk target

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