Experimental studies of nonlinear laser-plasma interactions and hot electrons*

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Abstract Observation shows that the stimulated Raman scattering (SRS) in a cavity target irradiated by 1.053μm laser is the dominant mechanism in producing hot electrons. In cavity targets, stimulated Brillouin scattering (SBS)and SRS are main abnormal absorption processes, they can scatter about 0.4 of the laser light energy fraction.
Keywords Cavity target, Nonlinear interaction, Hot electron, Stimulated Raman scattering, Stimulated Brillouin scattering

1 Introduction

All nonlinear processes are intensively related to parameters of laser light and characteristics of the plasmas. SRS(stimulated Raman scattering) and SBS(stimulated Brillouin scattering) are harmful to plasma stabilities because of their potentialities to decrease the amount of energy delivered to the target and increase the generation of fast electrons and hard X-rays. They can play a significant destructive role in X-rays driven implosion, as they can develop in the long scalelength plasma that expands and fills up the cavity.

2 Experimental

The experiments were performed[1,2] on the Shanghai "Shenguang-I " Nd: glass laser facility. The laser parameters were as follows: output energy $E_L = 50 \sim 700$ J for $\lambda = 1.053\,\mu$m, $E_L = 100 \sim 200$ J for $\lambda = 0.53\,\mu$m, laser intensity $I_L = 5\times10^{13} \sim 5\times10^{15}\,W/cm^2$. We categorized our experimental targets into two types: gold disk targets, gold cavity ones.

In the experiments the quantities we have measured include back-scattered SRS, SBS light energy measured by two laser energymeters; the angular distribution of SRS energy measured by the new polyvinylidene fluoride thermoelectric detectors; the time-integrated spectra of SRS, SBS; $2\omega_0$, $(3/2)\omega_0$ lights measured by using an optical multiple-channel analyser with (1/4) m grating.

An absolutely-calibrated hard X-ray spectrometer of 1.5~300 keV is composed of a ten-channel filter-fluorescer system (F·F) and a five-channel K-edge filter system (K·F)[3]. The hot electrons temperature T_h and superhot electrons temperature T_{hh} are commonlly derived from the slope of hard X-ray spectrum. The angular distribution of the hard X-rays (10~150 keV) has also been detected by a GaAs photoelectric detector array.

3 Results and discussions

3.1 Time-integrated spectra of nonlinear processes for a cavity target at $\lambda = 1.053\mu$m.

A) Spectra of harmonic and up-scattered SRS lights (see Fig.1).

a) (530nm) $2\omega_0$ light: $E \approx 2\times10^{-3}\times E_{\omega_0}(E_{\omega_0} = 340 \sim 380\text{J})$

b)(709nm) $(3/2)\omega_0$ light: $E \approx 6\times10^{-3}\times E_{\omega_0}$

c) (730~ 800nm) up-scattered SRS light

d) (1053 nm)SBS scattering light. The fraction of SBS energy is 0.2~ 0.3 of laser energy.

B) Spectrum of back-scattering SRS light(see Fig.2). Spectrum wavelength is from 1.2 to 1.9 μm. Its peak wavelength is 1.8μm, which corresponds to $n_e \sim 0.15 n_c$. Where n_e is the electrons dectrons density, n_c is the critical

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electron density. The fraction of SRS energy is 0.10~0.15 of laser energy.

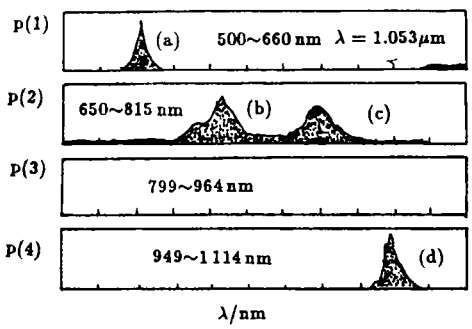

Fig.1 Time-integrated spectrum of nonlinear processes for a cavity target

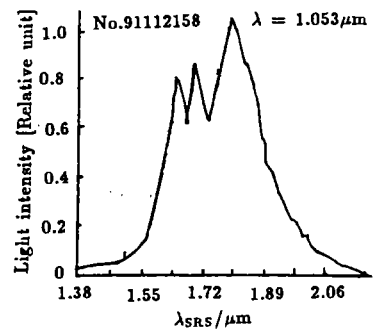

Fig.2 Spectrum of back-scattered SRS light

3.2 Angular distribution (see Fig.3) of SRS for cavity targets irradiated by 1.053 μm is the most intensive at the backward. The curve shape is similar to angular distribution of planar target[4]. This indicates that in cavity targets SRS occurs near the inlet hole.

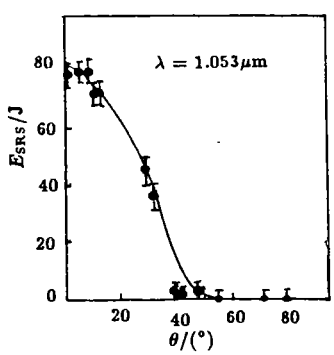

Fig.3 Angular distribution of SRS

3.3 Spectrum (see Fig.4) of hard X-rays inside the cavity has three temperatures (thermal electron temperature,T_e = 1.7 ~ 3.5 keV, T_h = 35 ~ 50 keV, T_{hh} = 130 ~350 keV) which shows that two groups of high energy electrons obey Maxwellian distribution in cavity targets. Although the energy of incident laser is nearly the same for the planars as the cavity targets, the fraction of hot electrons and T_h of cavity targets both are bigger than those of planar targets (see Fig.5). Because of the cavity confinement for the plasma, the density-gradient scale-length L in the density region $n_e < n_c$ /4 for a cavity target is larger than that for a planar target, which results in increasing electron energy and SRS, and hardenig the corresponding X-ray spectrum.

In order to correct theoretical model and improve accuracy of calculating the total energy of hot electrons in cavity, it is urgent to identify the traveling direction of hot electrons and the regions of hard X-ray generation. In our experiment reported here we designed two kinds of specific structure gold cavities: JC-4 and JC-3[5]. There were two layers of Formvar foils in cavities. The first layer of foil is 0.3 μm thick, and 250 μm from the entrance, the input laser beam impinged it first. The second layer of foil was mounted at the bottom of the cavity. We called the structure of target as JC-3. The difference of target JC-4 from target JC-3 is that there is a piece of 20μm thick gold disk mounted closely behind the second foil. The typical experimental results of specific structure cavity targets are shown in Fig.6. E_{HXT} is total energy of hard X-rays (10~100 keV) outside cavity targets, it is corrected by the angular distribution of hard X-rays. The E_{HXT} is normalized by the E_{SRS}, i.e. $\eta = E_{HXT}/E_{SRS}$, $\eta_{(JC-4)}/\eta_{(JC-3)} \approx 2.5$, $\triangle\eta \approx 1.5$. It is clear that the increased 1.5 times energy of hard X-rays is produced by hot electrons interaction with the additional gold disk in target JC-4. The results show that most of the hot electrons in cavity travel along the direction of laser beam, collide with cavity wall and emit hard X-rays through bremesstrahlang effect.

Theoretically, hot electrons are produced by Langmuir waves in laser-produced plasma, which are excited by incident laser wave. Res-

onance absorption (RA), Two plasmon decay(TPD), Ion acoustic decay(IAD) nonlinear processes, etc are regarded as the main mechanism to drive Langmuir wave. Many experimental results showed that under the condition of large focus dimension or large scalelength, the hot electrons are mainly produced by stimulated Raman plasma scattering[6,7]. Our experimental results of cavity targets show that total energy of hot electrons has a linear relation with total energy of SRS light(see Fig.7), E_{SRS} is roughly equal to E_{HE} for $E_L \approx 320 \sim 400$J, $\tau \approx 800 \sim 900$ps, $\lambda = 1.053\mu$m. Generally, fraction of the energy is ~ 0.1 of incident laser energy. The highest is up to 0.2. And $E_{2\omega_0}$ and $E_{(3/2)\omega_0}$ are nearly 0.001~0.002 and 0.004~0.005 of incident energy fraction, respectively. So our conclusion agrees well with those other researchers have got[8,9].

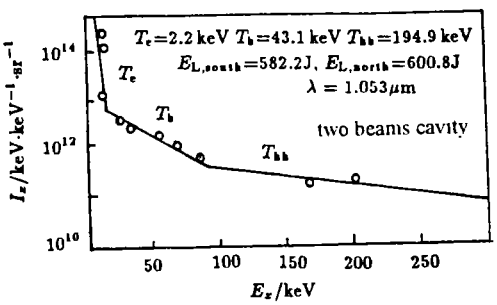

Fig.4 Spectrum of hard X-rays inside the cavity

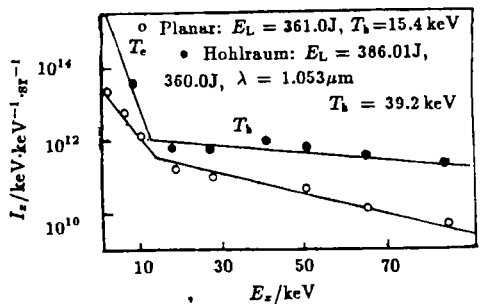

Fig.5 Comparison of spectra of hard X-rays between the planar target and cavity target

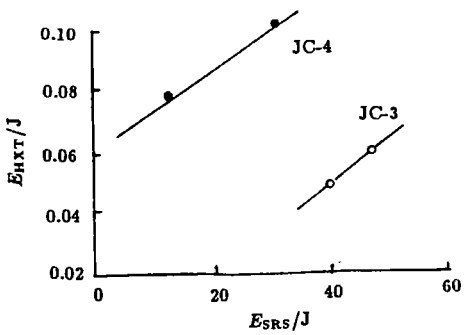

Fig.6 Experimental results of cavity targets

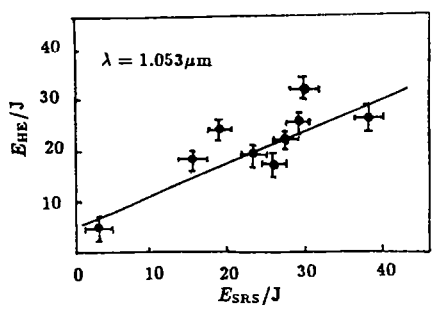

Fig.7 Correlation between E_{SRS} and E_{HE}

3.4 SRS and hot electrons both have a close relation with laser parameters as well as the scale length of plasma (see Table 1, Figs.8,9).

Table 1 Hot electrons and SRS from targets irradiated with 0.53 and 1.053μm light

Targets	λ/μm	E_{SRS}/E_L	E_{HE}/E_L	T_e/keV	T_h/keV
Au disk target	1.053	$\sim 4\times10^{-3}$	2.8×10^{-2}	3.72	13.6
	0.53	2×10^{-5}	3.1×10^{-3}	1.50	8.5
Cylindrical target	1.053	$1\sim1.5\times10^{-1}$	1.8×10^{-1}	–	27~35
	0.53	2×10^{-2}	3.5×10^{-3}	–	15~20

Table 1 shows that the total energy of hot electrons produced by laser of 0.53μm wavelength is about one to two order of magnitude less than that of 1.053μm; fraction of SRS energy decreases about two order of magnitude, T_h and T_e reduce about one half. Shorter wavelength laser can be used to suppress SRS because of increasing electron-ion collision. At

the same conditions, E_{SRS} of cavity target ($\phi 400\mu m \times 200\mu$m) and planar target($\phi 210\,\mu$m) are 200 times and 20 times larger than that of planar target($\phi 60\mu$m), respectively. Fig.9 shows that SRS energy dramatically increases as the laser energy increases.

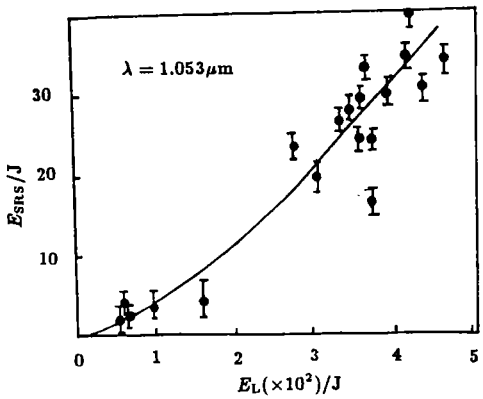

Fig.8 SRS energy vs incident laser light energy

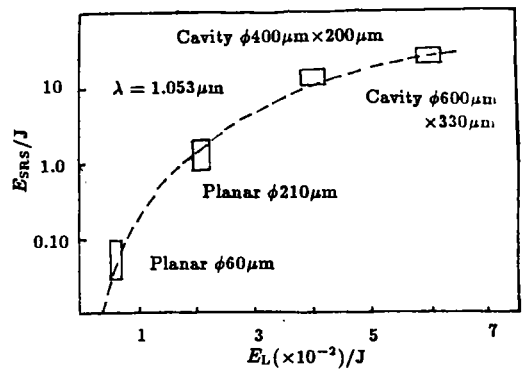

Fig.9 The dependence of SRS energy on the scale length of plasmas

4 Conclusion

In the nonlinear laser-plasma interaction experiments we can draw the following conclusions:

a) We have obviously observed the big enhancement of SRS light by two order in cavity targets because of the cavity confinement for the plasmas. SRS and SBS are main nonlinear processes, TPD is the third nonlinear processes, the weakest are RA and IAD, they can scatter about 0.25, 0.15, 0.006 and 0.003 of laser light energy fraction, respectively.

b) There is a linear correlation between the SRS light energy and hot electron energy, it indicates that hot electrons of cavity target are mainly generated by SRS.

c) SRS is a sensitive functuon of laser parameters, target size, structure.

d) Shorter wavelength laser can be used to suppress SRS and hot electrons because of increasing electron-ion collision.

e) Hot electrons mostly travel along the direction of laser beam. Hard X-rays are generated at gold wall of cavity target.

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