Laser Induced Damage of SiO_2 and CaF_2 under 263nm

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ABSTRACT

Laser damage performance of large aperture optical components has been study under fourth harmonic of 1053nm Nd:glass laser irradiation (263nm).The threshold of optical components is very low under 263nm laser irradiation ,due to conversion of beam to higher energy photons of the quadrupled frequency (4ω), and is relative to material characteristic. A preliminary test of laser induced damage in fused silica (SiO_2) and CaF_2under 263nm laser is reported in this article. Thresholds of these two materials are obtained. Laser damage threshold of SiO_2 is found about 2 J/cm^2 by 1-on-1 method using pulsed 263nm laser, lower than CaF_2 whose threshold.

Keywords: UV laser, laser damage, laser damage threshold, fused silica, CaF_2

1. INTRODUCTION

The problem of energy crisis has become a worldwide issue, inertial confinement fusion (ICF) might be a very promising way to solve this problem[1]. In ICF process, the collisional absorption of laser plasma absorption process occurs mainly nearby the critical surface[2]. High critical density would improve efficiency of laser plasma interaction, and the critical density is inversely proportional to wavelength, so short wavelength is needed. On the other hand, the instability of laser plasma interaction is an unavoidable question in ICF. when the plasma laser passed through the hohlraum plasma in direct driven ICF, stimulated Raman scatter and stimulated Brillouin scatter exists in this process, these two stimulated scatter decrease absorption efficiency of laser plasma, it is proved that gain coefficient of SRS and SBS is proportional to Square of wavelength. Short wavelength can be selected to suppress this two stimulated scatter. Fourth harmonic laser of Nd:glass laser whose wavelength is 263nm is a positive choice compared to fundamental laser and third harmonic laser.

The critical requires of materials at 263nm hinder the development of its application. The optical stability of fused silica and CaF_2 under ultraviolet radiation has increased people's attention in recent years due to its growing use as optical elements in a variety of deep-UV applications. For example, these two materials are made into optical widows used in laser system. However, laser-induced damage is a major potential factor that limits the lifetime of optical components[3], which results in losses in the transmission and additional damage to optics downstream due to beam modulation. The initial damage threshold and damage growth are typically used to estimate the optical damage characteristics[4]. The damage threshold is generally obtained by extrapolating the curve of damage possibility with energy density to zero-damage possibility.

This work focus on the initial damage of these two different materials after 263nm laser initiation, In particular, 263nm laser is obtained by noncritically phase-matched fourth harmonic generation of Nd:glass lasers in partially deuterated KDP crystals[5]. In addition, intensity-dependent transmissions through different samples have been measured, transmission of different materials changed with the increase of laser intensity.

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2. EXPERIMENT

2.1 Samples preparation

Four samples will be tested in our experiments, three samples of fused silica and one sample of calcium fluoride. They are different sizes or from different manufacturers, sample 1 ,2and 3 are fused silica, among them ,sample 1,2 is from the company of Corning, sample 3 is from the company of Heraeus which has a little difference to the fused silica from Corning, and sample 3 is side polished, Sample 4 is a calcium fluoride. All samples we use have been polished without acid pickling showed by fig.1 and their parameters are showed by Table 1.

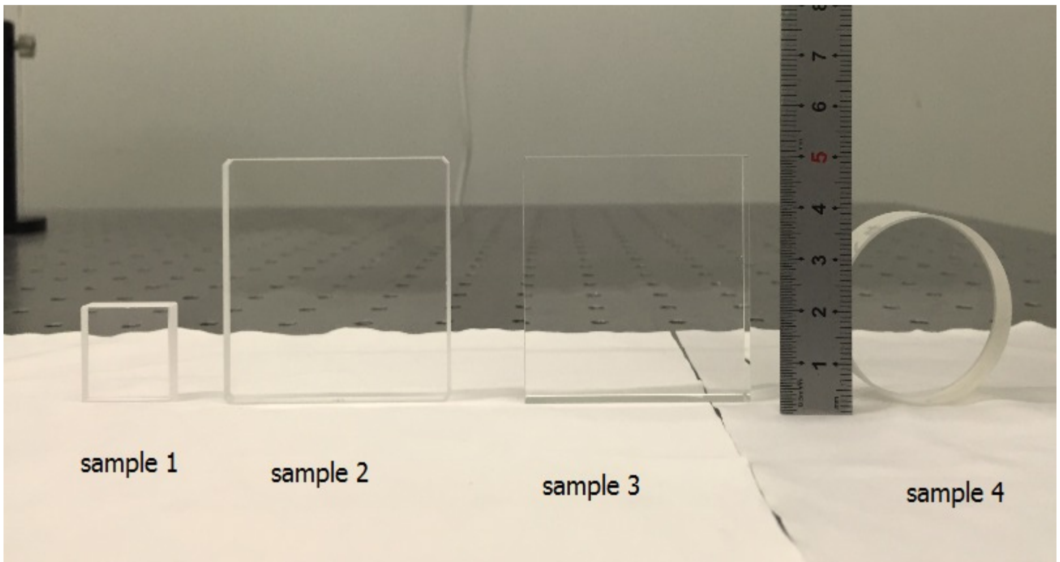

Fig.1 Four samples which would be test.

Table1. Parameters of different sample

Sample	Sample 1	Sample 2	Sample 3	Sample 4
Material	SiO_2	SiO_2	SiO_2	CaF_2
Model	Corning-7980	Corning-7980	Heraeus-suprasil 312	
Size	10*10*5(mm)	50*50*6(mm)	50*50*9(mm)	Φ40*11(mm)

2.2 Intensity-dependent transmissions of different samples

Before laser induced damage testing, intensity-dependent transmissions through samples have been measured. two-photon absorption(TPA) may exist in process of laser transmission.TPA studies has attract people's attention because of its scientific and technological feature[6]. Because the TPA selection rules are different in general from the linear spectroscopy selection rules, TPA data may provide new information about electronic wave functions and energy levels in the material, the TPA process has been used to excite bulk carriers in large semiconductor crystals and generate color centers in some alkali halides. These effects have been used for pumping semiconductor lasers and distributed feedback tunable lasers. The multi-photon absorption provides a damage mechanism, and thus it may determine the damage threshold of the material. This mechanism is especially important in UV windows. Phenomenon of TPA process can be obtained by measuring intensity-dependent transmission through samples. Fig.2 shows the layout of experiment which measures the transmission. The beam sampler is placed at 45 degree to the direction of laser propagation. Sample is placed after the beam sampler with one energy meter behind it. Two energy meters is used in this setup, the first energy meter(Cal.1) can meter the energy of initial laser the second energy meter(Cal.2) can meter the energy of the laser propagation through the sample. We can calculate the transmission while the laser energy of initial and through the sample is measured.

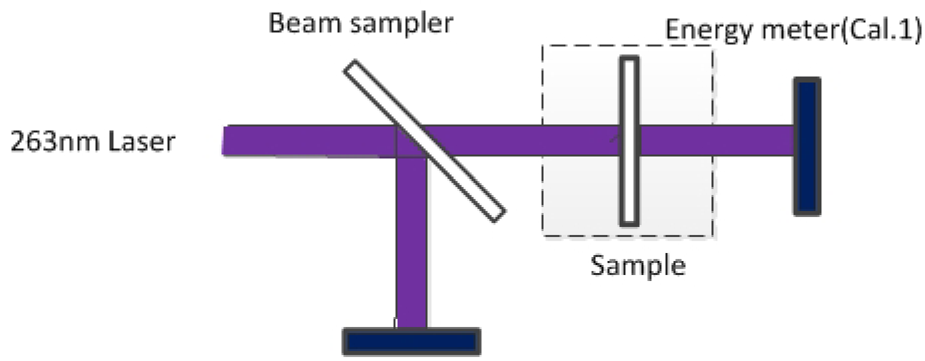

Fig.2 Set up for transmission measuring

2.3 Laser Induced Damage of $SiO_2$and CaF_2 under 263nm

After measuring the transmission, laser induced damage under 263nm is tested, Fig.3 is the layout of this experiment. Focus lens is used for gaining enough laser fluence, two beam samplers are used so that we can monitoring the energy and beam quality at the same time. A CCD microscope is placed behind the sample and it can observe the damage on the sample on real time, the light source was used to light the sample so that the microscope can monitor better. The laser radiation of 263nm is 5ns Gauss pulse whose waveform of this beam is showed by Fig.4. And the quality of this beam is showed by Fig.5. Energy of laser radiation can be varied from 1mJ to 4mJ. The samples can be exposed by different laser intensity. Method of finding damage thresholds we used in 1-on-1 test method[7]. And this method is that the samples were exposed to one same laser energy by N points , one point was exposed one time ,we calculate the damage probability of this sample under this energy. The energy was changed varied from all points are damaged to all points are undamaged.

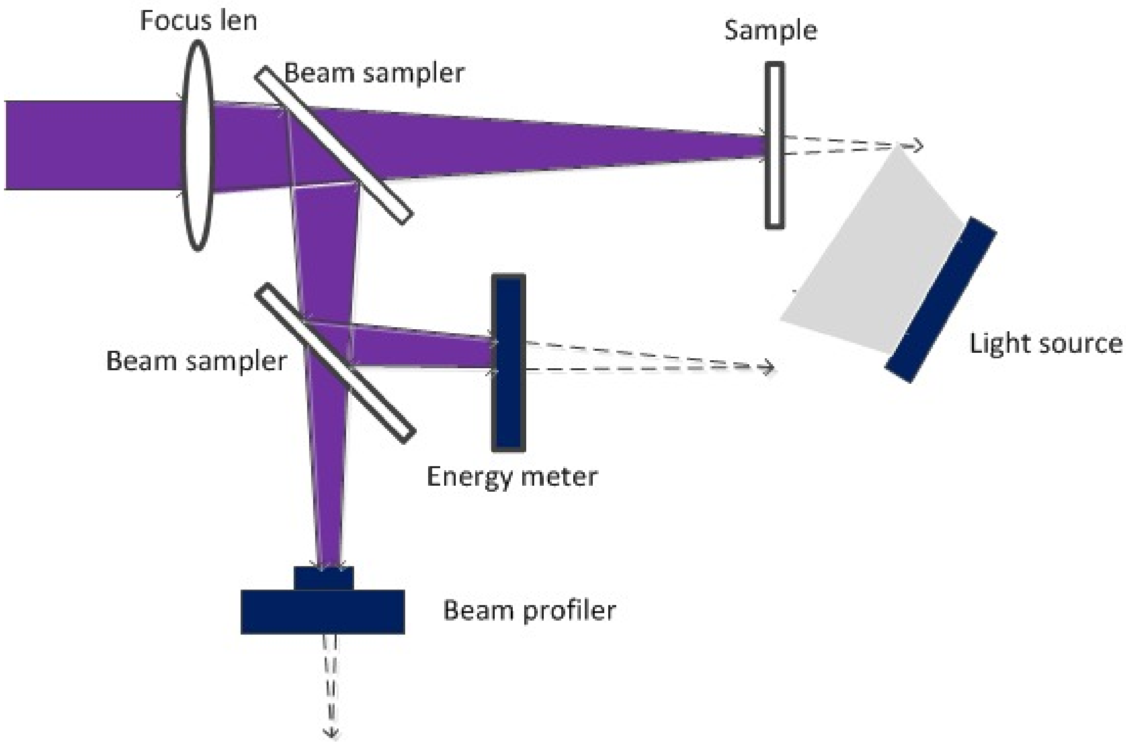

Fig. 3 layout of laser induced damage test

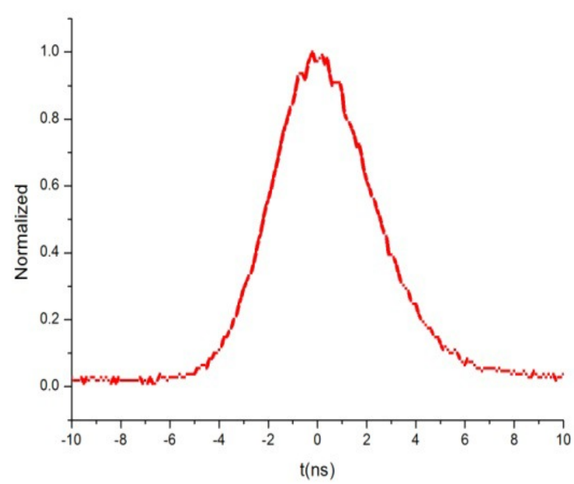

Fig.4 Waveform of 263nm laser

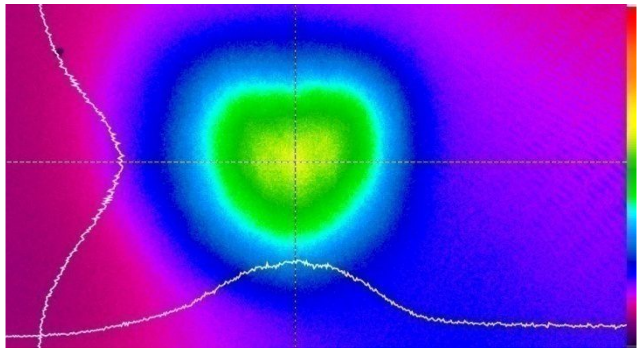

Fig.5 Quality of 263nm beam

3. EXPERIMENT RESULT

3.1 result of intensity-dependent transmissions of different samples

At first, the sample is not placed in this set up, the energy of these two beam are measured by two energy meter. The energy is measured by Cal.1 is Ein0 and the energy is measure by Cal.2 is Eout0. Then sample is placed in this set up as fig.2. The energy is measured by Cal.1 is Ein and the energy is measure by Cal.2 is Eout. T is transmission. So T can be calculated by this equation:

$$T = \frac{E_{out}}{E_{in}} \cdot \frac{E_{in0}}{E_{out0}} \quad (1).$$

Two samples in this experiment are test independently, sample three and sample 4 which is fused silica from Heraeus and CaF_2. Fig.6 shows the This figure shows intensity dependence of transmission through these two different material. We can observe that the transmissions of these two materials are all less than 96%, and the transmission of CaF_2 is bigger than SiO_2. Transmission decreases slightly with the increase of intensity. The reason cause this phenomenon is two-photons absorption in these samples while ultraviolet laser passed through them.

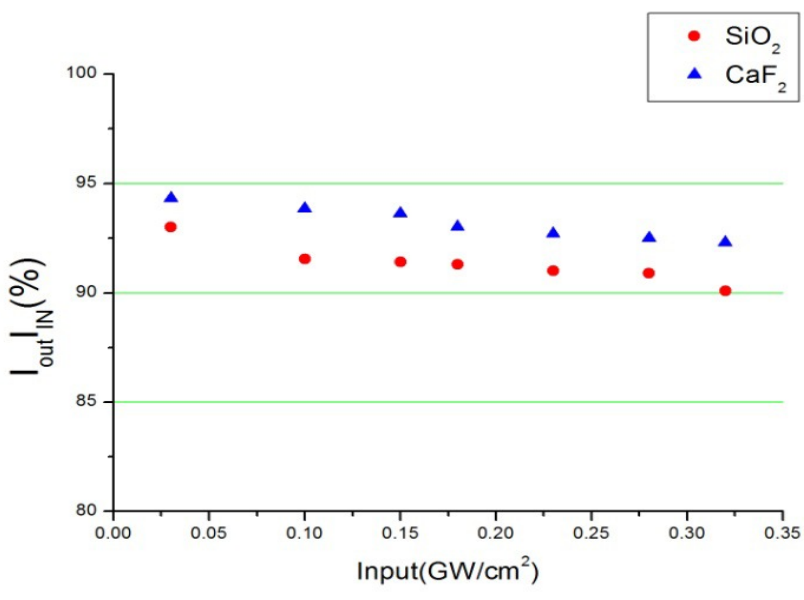

Fig.6 Intensity-dependent transmissions of different samples

3.2 Initial damage thresholds of different material

Five different samples showed by Fig.1were placed in the layout of laser induced damage test. All of them were test respectively. At first sample 1(SiO_2) was exposed to one same laser energy by 10 points , one point was exposed one time ,we calculate the damage probability of this sample under this energy. The energy was changed varied from all points are damaged to all points are undamaged. Then we linear fit this experiments data. The thresholds of samples are calculated. Then the rest samples were also been done the same test, and all their damage threshold were calculated. Fig.7 (a) shows the liner fit of fused silica and Fig.7(b) shows the liner fit of CaF_2. The threshold were gained from these liner fit. And table 2 presents damage thresholds of these samples. In addition, threshold of SiO_2 under 351nm was also present in this table so that the data can be compared apparently[8].

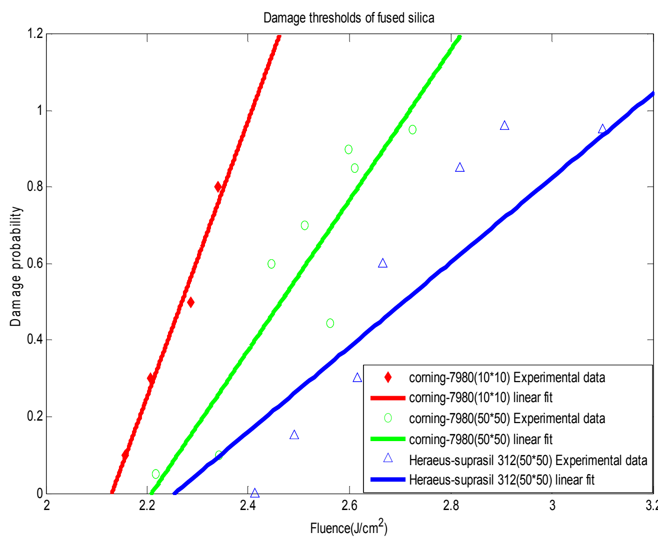

Fig.7(a) Linear fit of SiO_2

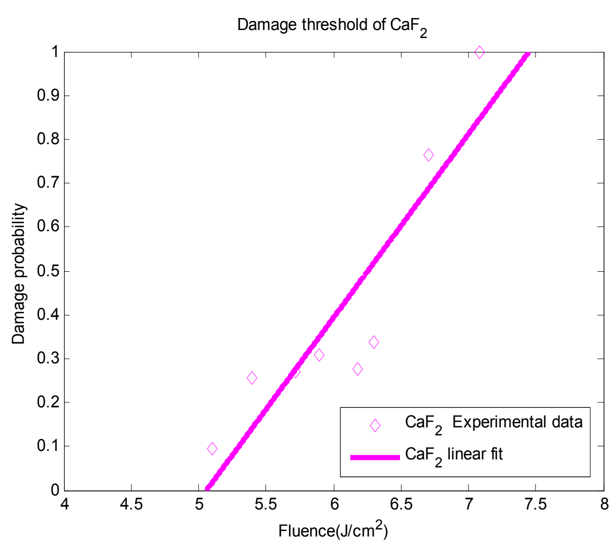

Fig.7(b) Linear fit of CaF_2

Table 2. Threshold of samples under different laser

Sample	Sample 1	Sample 2	Sample 3	Sample 4
Material	SiO_2	SiO_2	SiO_2	CaF_2
Model	Corning-7980 (10*10*5)	Corning-7980 (50*50*5)	Heraeus-suprasil 312 (50*50*10)	Φ40(mm)
Threshold(J/cm^2) under263nm at 5ns	2.1	2.2	2.3	5.1
Threshold(J/cm^2) Under355nm at 3ns	5~10			

We found that, damage threshold of fused silica are similar although they were from different manufacturers and the threshold is 2~2.5 J/cm^2. Damage threshold under 263nm is much lower than damage threshold under 351nm. One reason of this phenomenon is that the wavelength of 263nm is short than 351nm, the photon energy is bigger. Optical materials under 263nm laser are much easier to be damaged than them under 355nm. The other reason is much more nonlinear phenomenon exist after samples are exposed to laser of shorter wavelength. Additional, damage threshold of CaF_2 is higher than SiO_2, which is 5 J/cm^2. One reason leads to this result is that refractive index is changed and color-center is formed when fused silica is exposed to ultraviolet light irradiation. And SiO_2 is easier to be damaged than CaF_2.

4. CONCLUSION AND DISCUSSION

Samples of different material were exposed to 263nm laser. Intensity-dependent transmissions and laser induced damage of them were got in our experiment. And this conclusion can be easily found that transmission of CaF_2 is higher than SiO_2, Transmission decreases slightly with the increase of intensity. Damage threshold under 263nm is much lower than damage threshold under 351nm of SiO_2. And damage threshold of CaF_2 is higher than SiO_2. We can find that the performance of CaF_2 is better than fused silica. However CaF_2 cost more than fused silica. And the material of CaF_2 is easy deliquescence. In conclusion, the material for the output window, as well as for any subsequent windows (such as a target chamber window) should be carefully chosen, CaF_2 is a good choice.

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