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Investigation of laser induced air breakdown thresholds at 1064, 532, 355, 266 and 248nm

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ABSTRACT

Laboratory air is one most popular transparent medium for high power laser beam propagation. Its threshold of laser induced breakdown is one of the key characters for the high power laser system. The thresholds of laser induced air breakdown under laboratory condition were measured using 1064, 532, 355, 266 and 248nm short pulse laser. The focal spot varies from 50μ m to 150μ m which achieved using a lens with 117mm focal length. The measured breakdown thresholds range from 3.2×10^{10}W/cm^2 to 5.1×10^{11}W/cm^2, depending on the wavelength. It is confirmed that the KrF laser induced air breakdown threshold should be 3.2×10^{10}W/cm^2, which is almost 1 order of magnitude higher than the reported value of 2.7×10^{9}W/cm^2 .The measurements indicate multi-photon ionization is the dominant mechanism since the air breakdown thresholds at 1064, 532, 355, 266 and 248nm seemed well-agreed with the scale law of λ^2.

Keywords: threshold, Laser induced breakdown, air

1. INTRODUCTION

Laboratory air is one most popular transparent medium for high power laser beam propagation. The phenomenon of laser induced air breakdown has been observed and attracted great interests soon after the Ruby laser was invented [1-5]. Therefore, the threshold of laser induced air breakdown is one most important character to avoid and make use of this phenomenon. The measured thresholds of laser induced air breakdown have been widely reported in the literatures[6-12].It is found that the measured value Varies at a wide range. As we known, the results of the measurements are influenced by a large number of factors in the experimental conditions, such as laser wavelength, pulse width and optical arrangement to focus the laser. However, it is noteworthy that the presence of particles would lowered the threshold about the 2-3 orders of clean air, which is similar with the effect of impurity in the transparent optical material like quartz. So it is believed that the investigation of laser induced air breakdown could give some clues on the laser induced damage of transparent materials.

Although many measurements have been carried out with the Nd:Yag Glass laser. As the KrF laser was concerned, there are only few works reported[10-12].The measured KrF laser induced breakdown threshold of Gower[10] is close to 8.2×10^{10}W/cm^2 for the air under the atmosphere press, while the value given by Turcu's work[11] is above 2×10^{11}W/cm^2.However, Chen dezhang[12] gave the threshold as low as 2.66×10^{9}W/cm^2. To make a confirmation, we measured the KrF laser induced air breakdown threshold under our laboratory condition. It is found that the KrF laser induced breakdown threshold of open air is 3.24×10^{10}W/cm^2, which is much closer to the value give by Gower. Meanwhile, the thresholds at 1064, 532, 355, 266nm were measured under the same condition with a Nd:YAG laser. Similar with wavelength dependence of quartz damage, our measurements also showed the breakdown threshold decreases with decreasing wavelength, which are well-agreed with the scaled as λ^2.

2. EXPERIMENTAL SETUP AND MEASUREMENT PROCEDURE

The experimental arrangement was conventional and shown in fig 1.The laser beam was focused in air with convex lens with focal distance f =117mm. A set of neutral attenuators was inserted in the beam path before focusing to adjust the laser energy. The pre-focal energy of laser pulse was sampled with a fused silica plate between the attenuators and the

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convex lens. The plate was orientated 45° to the beam and reflected about 10 percent laser into the energy meter. The laser pulse duration was monitored with a photo diode behind the high reflective mirror with silica base with 0.05% transmission. The air spark induced by the laser was observed in side-view with a CCD camera (SP503U, Ophir-Spiricon Inc) and another UV-VIS sensitive photodiode. Both the laser pulse and spark emission from photo diodes were recorded using a Tektronix TDS 340 oscilloscope. The post focal energy through the spark was measured with another energy meter.

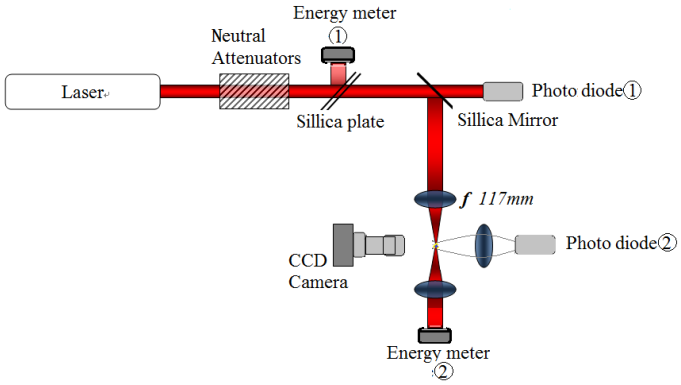

Figure 1. Experimental arrangement for threshold measurement of laser induced air breakdown

The KrF laser used in the experiment is a discharge pumped excimer laser which operated in unstable resonator mode. The laser pulse energy is 200mJ and the duration is 20ns. The beam profile is about 21mm×7mm with the divergence of 1.58×0.72mrad. Therefore, a focal spot of 185μ m×85um(fig 2a) could be produced with the *f*=117mm lens and the intensity at the focal spot was up to 8.1×10^{10}W/cm^2.

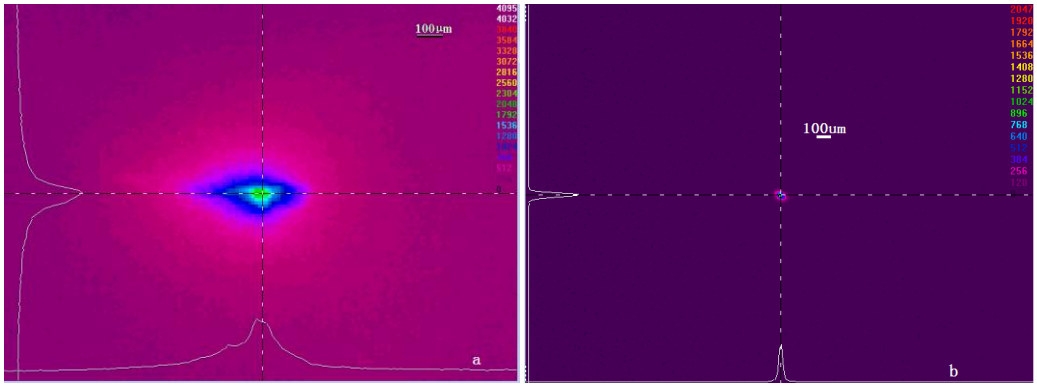

Figure 2. The focal spot of KrF laser (a)and Nd:Yag laser(b) recorded with the Spiricon Laser Beam Analyzer .

The Nd:YAG laser(Q-smart 450, Quantel) used in the experiment outputs 450mJ laser pulse with 10ns duration at fundamental wavelength(1064nm). The laser also can be used to produce 200mJ pulse at 532nnm and 80mJ pulse at 355nm. When it operates with the quadruples, the pulse energy is about 60mJ at 266nm. The beam divergence is about 0.5mrad. Accordingly, it can produce a focal spot with 58.5um diameter and the intensity is up to 1.6×10^{12}W/cm^2 at fundamental wavelength.

The threshold of air breakdown have different definitions depended on the purpose of the study. For the interest of LID, it is general accepted as the intensity of 50% probability to observe the spark. According to Stefan Brieschenk [13], the portion of the laser pulse that goes through the focal waist represents the early portion of the pulse before process initiates the plasma formation and is therefore equal to the threshold energy. So, it is attempted to recognize the laser induced air breakdown both with the spark observation and laser energy decreased through the focal spot.

As the effect of particles was concerned, the laboratory air was purified with air cleaner. The index of particle matter in air kept below 50ug/m^3 in the experiment which satisfied the good standard of air quality index.

3. EXPERIMENTAL RESULTS

The experimental result of KrF laser induced air breakdown is shown in fig 3.The spark started with 60 mJ per pulse irradiation. Then, the probability to observe spark increased quickly with the pulse energy increasing from 60mJ to 100mJ. There was a nearly stable spark generated when the energy rose up to 98mJ and the breakdown probability is close to 100%.

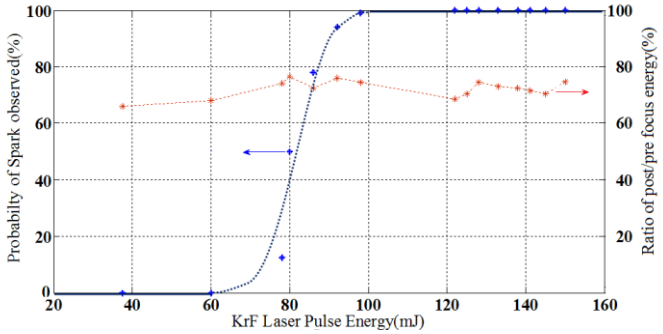

Figure 3 Probability of air spark induced by KrF laser with different pulse energy.

The measurement indicated that there should be 50% probability to observe the spark under 80mJ laser irradiation, i.e. the threshold of open air threshold induced by KrF laser should be 3.24×10^{10}W/cm^2 and close to the value give by Gower. For the purpose to make laser propagation safety, the laser intensity should keeps below 2.4×10^{10}W/cm^2. On the other hand, it is suggested to keep the intensity above 4.0×10^{10}W/cm^2 if one want to make use of Air LIBS with KrF laser.

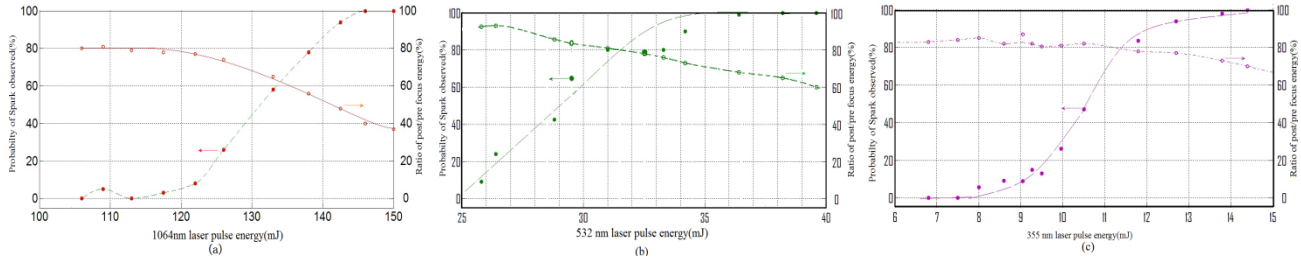

Figure 4 Probability of air spark induced by Nd:YAG laser at 1064(a),532(b)and355nm(c) with different pulse energy

The experimental results of the air breakdown induced Nd:YAG laser were shown in fig 4. As shown in fig 4a, the laser at fundamental wavelength started to trigger air spark when the pulse energy rose up to 113.0mJ while triggered stable air spark with the energy above 145.0mJ.The energy to induced air breakdown at 50% probability is 131.6mJ.It means the measured threshold of laser induced air breakdown in our laboratory should be 4.90×10^{11}W/cm^2.For the 2ω laser, the pulse energy to induced air breakdown at 50% probability is 29.0mJ(fig 4b), i.e. the measured threshold of 532nm laser induced air breakdown in our laboratory should be 1.08×10^{11}W/cm^2. As shown in fig 4c, the 3ω laser induced air spark started when the pulse energy rose up to 7.5mJ, and it was stably triggered when pulse energy rose to more than 14.5mJ. It was found that the energy of 50% probability air spark is 10.5mJ.Therefore,the threshold of air breakdown induced by 355nm laser should be 3.91×10^{10}W/cm^2.

As the luminance of spark induced by 4ω laser was too weak to trigger our CCD camera, it is hard for us to plot the air spark probability at different energy. But the sight observation of the spark indicated that the laser of 10mJ could make stable sparking and the threshold of 50% probability air breakdown might close to 3.35×10^{10}W/cm^2.

4. SUMMARY AND DISCUSSION

The thresholds of laser induced air breakdown under our laboratory condition were measured using 1064, 532, 355, 266 and 248nm short pulse laser. The focal spot varies from 50μ m to 150μ m which achieved using a lens with 117mm

focal length, and the measured breakdown thresholds range from 3.2×10^{10}W/cm^2 to 5.1×10^{11}W/cm^2 , depending on the wavelength. It is confirmed that the threshold of KrF laser induced air breakdown is about 3.2×10^{10}W/cm^2,which is about ten times of Chen's work and closer to the value give by Gower. It might come from the clean air condition in different laboratories.

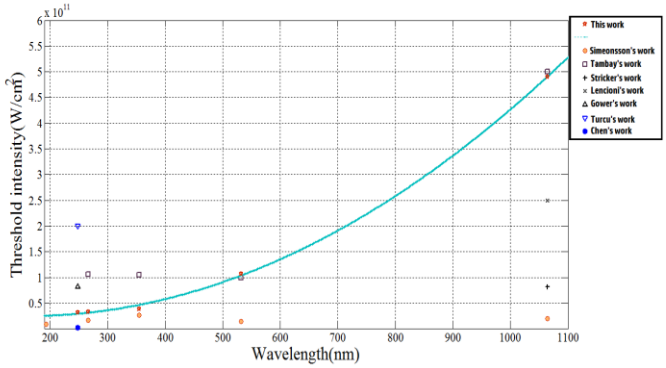

Figure 5 Measured and reported thresholds of laser induced air breakdown at different wavelength

The measured thresholds of laser induced air breakdown at different wavelength were plotted in fig 5 and compared with those from literatures [6-12]. It is found our results are more close to the Simeonsson's work in UV bands. While the 532nm and 1064nm laser was concerned, our results are well-agreed with Tambay's work. From our experimental results, As fig 5 shown, the air breakdown thresholds increase with increasing wavelength and are well-agreed with the scaled as λ^2. It might indicate that multi-photon ionization is the dominant mechanism of air breakdown from UV to NIR band.

According to our measurement of pre/post focal spot energy, there are no evident that the UV laser induced breakdown could be recognized with the laser energy loss through the focal spot(fig3 and fig 4c).Although ratio of the laser energy post focal spot decreased with the increasing pre focal energy(fig 4a and fig 4b), it was still hard to identify the threshold of 50% probability of air breakdown by measuring pre- and post-focal energies. One possible reason is likely that the energy absorbed and reflected by the laser induce plasma depends on both the laser wavelength and the characters of LIP such as temperature and density.

5. ACKNOWLEDEGMENTS

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