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# 基于光克尔门空间扫描单次激光信噪比测量

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**摘　要**：提出一种基于光克尔门空间扫描的单次激光信噪比测量方法. 在该方法中，门光和探测光在光克尔介质中正交传输，通过光克尔门对探测光的空间扫描实现激光信噪比测量. 采用该测量方法进行了单次激光信噪比测量的实验研究，测得时间窗口和分辨率分别为 88.2ps、2.7ps. 由于取样门是由光克尔效应来控制，因此该激光信噪比测量方法对于待测激光的波长没有限制.

**关键词**：单次激光；光克尔效应；光克尔门；激光信噪比

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# Signal-noise Ratio Measurement Based on Space Scanning of Optical Kerr Gate for Single Shot Laser

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**Abstract**: A measurement method of signal-noise ratio for the single shot laser based on space scanning of optical Kerr gate was presented. In this method, the gate light and probe light transmit orthogonally in optical Kerr medium, the measurement of signal-noise ratio for the single shot laser was achieved by using an optical Kerr gate to make a space scanning for the probe light. With this approach, a single shot laser signal-noise ratio measurement was realized experimentally with a temporal window of 88.2 ps and a resolution of 2.7 ps. This method has no limitation on spectral range because of the gate is controlled by optical Kerr effect.

**Key words**: Single-shot laser; Optical Kerr effect; Optical Kerr gate; Laser signal-noise ratio

**OCIS Codes**: 120.0120; 140.3538;170.7160;320.7100

## 0 Introduction

With the remarkable development of laser technology, the peak intensity of optical pulses produced in high-power laser systems has been able to reach $10^{20}$ W · cm$^{-2}$[1-3]. At such a high peak intensity, the Signal-Noise Ratio (SNR) of laser pulses is of fundamental interest and yet of particular importance in many research and application fields, such as plasma physics, high-order harmonic generation, inertial

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confinement fusion, and quantum electrodynamics[4-6]. In general, laser systems generating optical pulses of high peak intensity operate at extremely low repetition rates, where pre-pulses or noises have strong impacts on the interaction of a main pulse with a target. Precisely obtaining detailed information of pre-pulses with picosecond time resolution in a large time range, *e.g.*, about one hundred picoseconds, prior and posterior to the main pulse and, eventually, completely eliminating the pre-pulses are of fundamental significance in processing experimental data and explaining experimental results. Therefore, it is imperative to develop a device capable of measuring SNR of single shot laser pulses with wide dynamic range and large temporal window.

So far, a great deal of endeavor has been dedicated to the SNR measurements of optical pulses and, consequently, several single shot pulse measurement techniques[7-13] have been developed based on second-order and third-order correlation. The basic idea of the aforementioned techniques is to transform temporal shape of a pulse into spatial profile that can be analyzed with a plane array detector. The application of the second-order and the third-order correlation techniques, however, is limited to a relatively fixed spectral range because of the requirement for phase matching in nonlinear crystals, causing an urgent requirement for SNR measurement techniques of single shot pulses without spectral limitation. Fortunately, Mayer and Gires firstly observed the optical Kerr effect in 1964[14]. Duguay and Hansen devised an optical Kerr gate driven by ultrashort optical pulses in 1969 [15]. Till now, optical Kerr gate has been widely used in investigation of various ultrafast optics phenomena such as transient luminescence[16-20], light absorption, photoconductivity, photoimaging[21-23]. Moreover, Albrecht *et al*. detected femtosecond pulses by using optical Kerr gate technology in several picoseconds window[24]. One of the most distinct features of optical Kerr effect is that it occurs in all materials and has no limitation on spectral range. Bearing this in mind, we proposed a single shot laser SNR measurement based on Optical Kerr Gate (OKG) using a step grating[25]. In this paper, we proposed another SNR measurement for single shot laser based on OKG without the step grating.

## 1 Experiment and results

In a typical Optical Kerr Gate (OKG) configuration[26], an intensive pulse used to switch on the OKG is referred to as the gate light, and the other light controlled by the OKG is referred to as the probe light. In our configuration, the gate light and the probe light are set to propagate in perpendicular directions and cross inside the optical Kerr material. In order to get the maximum value of the probe light after OKG, the polarization of the gate light is tuned to be vertical, and the probe light is polarized at an angle of 45° with respect to the polarization of the gate light.

The experimental setup is schematically shown in Fig. 1. Beam Splitter (BS) is to separate the single pulse into signal pulse and gating pulse. $W_1$, $W_2$ are $\lambda/2$ wave plate and $\lambda/4$ wave plate. D is a delay line made of double wedges. E is beam expander. OKM is Optical Kerr Material. $P_1$, $P_2$, $P_3$ are polarizers. $M_1$, $M_2$ are HR mirrors. Laser pulses are generated from a Ti: sapphire regenerative amplifier (Spitfire, Spectra Physics Co.), with wavelength centererd at 800 nm, duration of 250 fs and single pulse energy of 200 J.

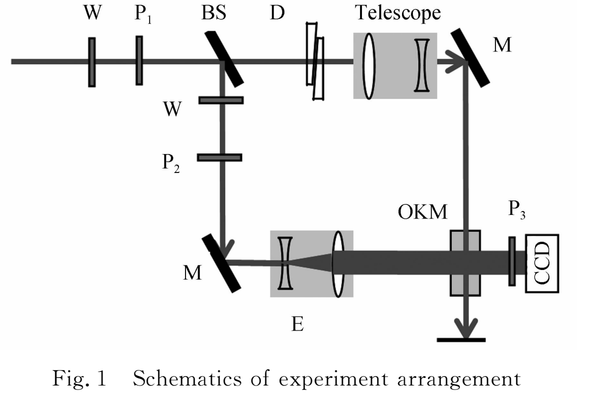

Fig. 1 Schematics of experiment arrangement

One single shot laser pulse propagated through $a/2$ wave plate $W_1$ and a polarizer $P_1$ and, then, is split into two beams by the BS, referred to as probe light and gate light, respectively. Optical anisotropy in the optical Kerr material is created by the gate light.

The probe intensity is typically 10 times lower than the gate light. $P_1$ is a vertical polarizer. The probe light is expanded by a beam expander. At the same time, the spatial intensity distribution of the probe light is smoothed. In the path of probe light, two crossed polarizers, $P_2$ and $P_3$, are placed before and behind the Kerr material, respectively, forming an OKG. The probe light is expanded to about 16 mm in diameter by a beam expander E. The gate light, after propagating through an optical delay line D, which made of double wedges (quartz glass), is narrowed to 0.5mm diameter by a telescope and input into the optical Kerr material, $CS_2$. The gate light and the probe light cross perpendicularly inside the Kerr material. When the gate light propagates through the optical Kerr material, the OKG is opened continuously along the path of the gate light. In this case, the probe light crossed with the gate light is sampled at different time position and recorded in space by CCD. The polarizers $P_1$, $P_2$ and $P_3$ are Glan-Taylor prisms with extinction ratio of $10^6$.

The relationship between the gating efficiency of OKG and the gate intensity is described in Ref. [26]. When the gate energy exceeds 55 J, due to high order nonlinear effect, white light will be generated in Kerr material $CS_2$. In order to avoid the white light disturbing, the energy of the gate light before reaching to OKG is attenuated to 40 J.

The principle of measurement was shown in Fig. 2. The expanded probe light and the narrowed gate light are crossed perpendicularly in $CS_2$ cell of OKG. The probe light is considered as $N$ light pulses. When the gate light propagates through the $CS_2$ cell, the $N$ probe light pulses were sampled at different times. On the one hand, the time resolution of the setup is determined by the laser pulse width (250 fs in our case), the diameter 0.5 mm of gate light (corresponding to about 2.7 ps calculated by $0.5 \cdot n/c$, $n=1.63$ is the refractive index of $CS_2$, $c$ is the light speed in air) and the opening duration of the OKG (570 fs)[25]. Therefore, the time resolution of the setup was limited to be 2.7 ps. On the other hand, the detection time range is determined by the size of the cross section of the gate light and the probe light. The time window could be tuned by adjusting the time delay line D (shown in Fig. 1). The main pulse of the probe light is shifting along time axis as adjusting the time delay line. And the time distance of the main pulse shifting is corresponding to the change of the delay time. In this case, the time range is detected to be 88.2 ps by tuning the main pulse shifting from the most left to the right side of the time window.

A single shot laser is detected with the experimental setup. The result is shown in Fig. 3. The SNR is about $3\times10^2$. In order to confirm the reliability of the detected result, some verification experiments are made.

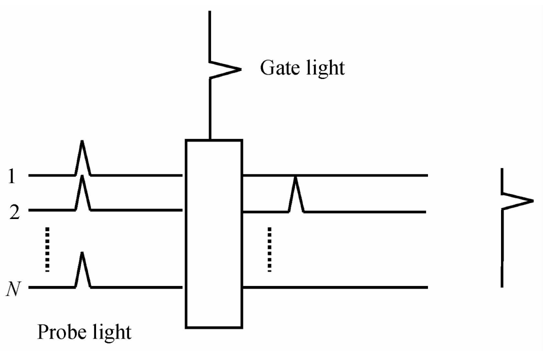


Fig. 2 Principle diagram of SNR measurement for a single shot laser

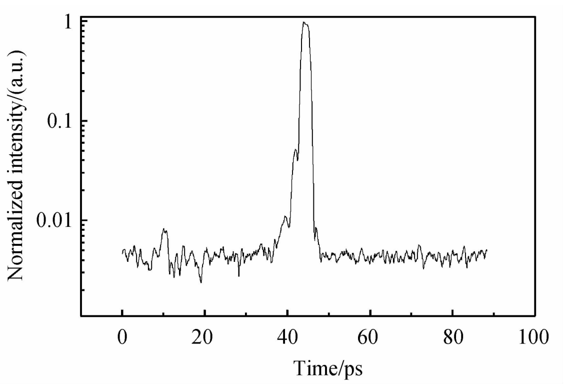


Fig. 3 Detection result for a single shot laser

According to the experiment setup, for a single shot laser pulse, once a noise pulse appears before or after the main pulse of laser, it should be captured and recorded by the CCD. In order to confirm this point, an artificial noise pulses are generated by an etalon made of two partially reflecting mirrors. Two different time interval (13.2 ps and 26.4 ps, calculated by $2d/c$, $d$ is the distance between the two mirrors) pulse series are generated by tuning the distance $d$ of the two mirrors as 2 mm and 4 mm, respectively. According to the reflectivity $R=35\%$ of the mirrors, the intensity ratio between the two adjacent pulses is calculated to be 12.2% (calculated by $R^2:1$).

The two pulse series are captured by the experiment setup. Fig. 4 shows the detection results for the two pulse series. The intensity ratio of two adjacent pulses is about 12.8%, and the time interval between these pulses are about 13.1 ps, 26.1 ps, respectively, indicating that the experimental results are in agreement with the theoretical prediction.

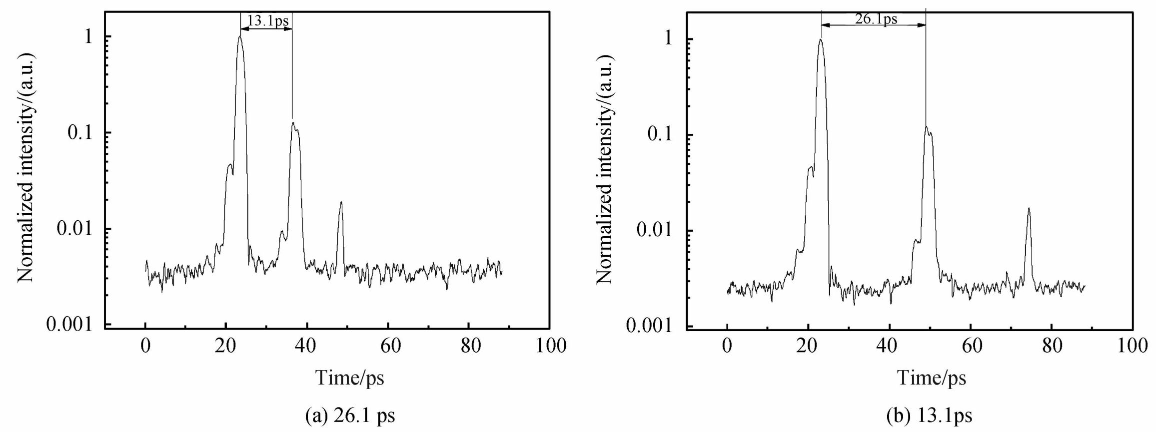


Fig. 4 Detection results of two different time interval pulse series

## 2 Conclusion

In conclusion, based on a perpendicular gate-probe OKG configuration, a SNR measurement for a single shot laser has been demonstrated. As the gate light propagates through the Kerr material, the OKG is opened continuously along the path of the gate light and the probe light is sampled continuously at different times. As a consequence, time resolution of 2.7 ps and detection time range of 88.2 ps have been obtained, respectively.

**References**

[1] BROMAGE J, BAHK S W, IRWIN D, *et al*. A focal-spot diagnostic for on-shot characterization of high-energy petawatt lasers[J]. *Optics Express*, 2008, **16**(21): 16561-16572.

[2] YANOVSKY V, CHVYKOV V, KALINCHENKO G, *et al*. Ultra-high intensity- 300-TW laser at 0.1 Hz repetition rate[J]. *Optics Express*, 2008, **16**(3): 2109-2114 .

[3] BAHK S W, ROUSSEAU P, PLANCHON T A, *et al*. Characterization of focal field formed by a large numerical aperture paraboloidal mirror and generation of ultra-high intensity ($10^{22}$ W/cm$^2$)[J]. *Applied Physics B*, 2005, **80**(7): 823-832.

[4] MOUROU G A, BARRY C P J, PERRY M D. Ultrahigh-intensity lasers: physics of the extreme on a tabletop[J]. *Physics Today*, 1998, **51**(1): 22-28 .

[5] KUKULIN V I, VORONCHEV V T. Pinch-based thermonuclear D3He fusion driven by a femtosecond laser[J]. *Physics of Atomic Nuclei*, 2010, **73**(8): 1376-1383.

[6] McKENTY P M, GONCHAROV V N, TOWN R P J, *et al*. Analysis of a direct-drive ignition capsule designed for the national ignition facility[J]. *Physics of Plasmas*, 2001, **8**(5): 2315-2322.

[7] DORRER C, BROMAGE J, ZUEGEL J D, High-dynamic-range single-shot cross-correlator based on an optical pulse replicator[J]. *Optics Express*, 2008, **16**(18): 13534-13544.

[8] BRUN A, GEORGES P, SAUXG L, *et al*. Single-shot characterization of ultrashort light pulses[J]. *Journal of Physics D: Applied Physics*, 1991, **24**(8): 1225-1233.

[9] COLLIER J, HERNANDEZ-GOMEZ C, ALLOTT R, *et al*. A single-shot third-order autocorrelator for pulse contrast and pulse shape measurements[J]. *Laser Part Beams*, 2001, **19**(2): 231-235 .

[10] ZHANG D, QIAN L, YUAN P, *et al*. Fiber-array-based detection scheme for single-shot pulse contrast characterization[J]. *Optics Letters* 2008, **33**(17): 1969-1971 .

[11] SHAH R C, JOHNSON R P, SHIMADA T, *et al*. Large temporal window contrast measurement using optical parametric amplification and low-sensitivity detectors[J]. *The European Physical Journal D*, 2009, **55**(2): 305-309.

[12] DIVALL E J, ROSS I N. High dynamic range contrast measurements by use of an optical parametric amplifier correlator[J]. *Optics Letters*, 2004, **29**(19): 2273-2275.

[13] TAVELLA F, SCHMID K, ISHII N, *et al*. High-dynamic range pulse-contrast measurements of a broadband optical parametric chirped-pulse amplifier[J]. *Applied Physics B*, 2005, **81**(6): 753-756.

[14] MAYER G, GIRES F. Action dune onde lumineuse intense sur l′indice de refraction des liquids[J]. *Comptes Rendus de l'Académie des Sciences (Paris)*, 1964, **258**: 2039-2042.

[15] DUGUAY M A, HANSEN J W. An ultrafast light gate[J]. *Applied Physics Letters*, 1969, **15**(6): 192-194.

[16] YAN L H, YUE J J, SI J H, *et al*. Influence of self-diffraction effect on femtosecond pump-probe optical Kerr measurements[J]. *Optics Express*, 2008, **16**(16): 12069-12074 .

[17] KINOSHITA S, OZAWA H, KANEMATSU Y, *et al*. Efficient optical Kerr shutter for femtosecond time-resolved luminescence spectroscopy[J]. *Review of Scientific Instruments*, 2000, **71**(9): 3317-3322.

[18] NAKAMURA R, KANEMATSU Y. Femtosecond spectral snapshots based on electronic optical Kerr effect[J]. *Review of Scientific Instruments*, 2004, **75**(3): 636-644.

[19] TAKEDA J, NAKAJIMA K, KURITA S, *et al*. Suemoto, femtosecond optical Kerr gate fluorescence spectroscopy for ultrafast relaxation processes[J]. *Journal of Luminescence*, 2000, **87-89**: 927-929 .

[20] TAKEDA J, NAKAJIMA K, KURITA S, *et al*. Time-resolved luminescence spectroscopy by the optical Kerr-gate method applicable to ultrafast relaxation processes[J]. *Physical Review B*, 2000, **62**(15): 10083-10087.

[21] MINOSHIMA K, YASUI T, ABRAHAM E, *et al*. Three-dimensional imaging using a femtosecond amplifying optical Kerr gate[J]. *Optical Engineering*, 1999, **38**(10): 1758-1762.

[22] WANG L, HO P P, ALFANO R R. Time-resolved Fourier spectrum and imaging in highly scattering media[J]. *Applied Optics*, 1993, **32**(26): 5043-5048.

[23] WANG L, HO P P, LIU C, *et al*. Ballistic 2-d imaging through scattering walls using an ultrafast optical kerr gate[J]. *Science*, 1991, **253**(5021): 769-771.

[24] ALBRECHT H S, HEIST P, KLEINSCHMIDT J, *et al*. Single-shot measurement of ultraviolet and visible femtosecond pulses using the optical Kerr effect[J]. *Applied Optics*, 1993, **32**(33): 6659-6663.

[25] HE J, ZHU C, WANG Y, *et al*. A signal to noise ratio measurement for single shot laser pulses by use of an optical Kerr gate[J]. *Optics Express*, 2011, **19**(5): 4438-4443.

[26] HE Jun-fang, WU Deng-ke, WANG Yi-shan, *et al*. Improvement of laser pulse contrast by optical Kerr shutter[J]. *Optics and Precision Engineering*, 2011, **19**(2): 470-474.