Application of plasma shutter in second harmonic generation of $AgGaSe_2$ crystal

Jinzhe Huang (黄金哲)[1,2], Xiaoyong Hu (胡孝勇)[1], Deming Ren (任德明)[1], and Yanchen Qu (曲彦臣)[1]

[1] *Institute of Optoelectronics, Harbin Institute of Technology, Harbin 150001*

[2] *Department of Electronic Science and Technology, Harbin University of Science and Technology, Harbin 150080*

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A reliable target-triggering plasma shutter was applied to second harmonic generation (SHG) of $AgGaSe_2$ crystal with a TEA CO_2 laser. Under normal air pressure, argon charged plasma shutter was triggered by focusing beam companying with a pair of adjustable metal targets. Conversion efficiency was enhanced by 3.3 times and the maximal efficiency 9.3%, with 1.4-mJ second harmonic energy was obtained. Finally, crystal damage was discussed together with previous work.

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Mid-infrared coherent light, due to its good atmospheric transmitting properties, is mostly used in some applications such as ecological monitoring of the atmosphere, remote sensing and other military operations in infrared (IR) countermeasures. And that is usually available through frequency conversion of radiations in CO_2 laser with a suitable nonlinear crystal. In spite of the emergence of some promising crystals[1,2], $AgGaSe_2$ crystal pumped by TEA CO_2 laser still presents good realization of mid-infrared radiation with high energy efficiency and maturity in growth technology[3-5]. However, conversion efficiency is usually restricted by poor pulse shape containing low intensity tail and by crystals' damage threshold in case of high power pumping. Shaping original pulse into peaked one to form high power intensity is practically obtainable. In this way, the lower intensity part of a pulse, "tail", which is much less contributed to energy conversion and more to crystal heating, will be cut off. An electronic-optic switch, typically employed by D. A. Russell and R. Ebert[5], and plasma shutter, which is concerned in this paper by its convenience in operation, can both complete the pulse-shaping task. Adopting laser trigged spark gap (LTSG) technology with pulse forming network (PFN) circuit plasma shutter can also be capable of exact time control and much shorter (ps level) cut off[6-9]. Recently, that was used in frequency doubling of CO_2 laser in IR crystal for higher efficiency[10]. In the present work, a plasma shutter without LTSG (passive) is used for second harmonic generation (SHG) (type I ooe matching) in $AgGaSe_2$ crystal. Schematic diagram of this experiment is shown in Fig. 1.

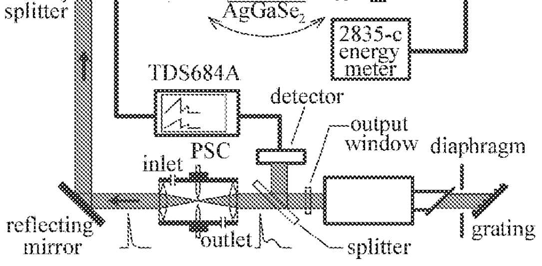

Fig. 1. Experimental arrangement of SHG with plasma shutter.

The TEA CO_2 laser resonator is an open-cavity in which a diffraction grating (300 line/mm) of reflection type takes the place of reflecting mirror[11]. Internal gas mixture is located at $CO_2 : N_2 : He = 1 : 1 : 3$. And to achieve relative stable radiation, we lower repetition frequency to 1 Hz. The 100-ns FWHM main peak hauling 400-ns low energy tail containing about 50% of total pulse is measured in TDS684A oscilloscope (using HgCdTe detector). The optical system of plasma shutter is a 1:1 Keplerian telescope formed by two identical lenses with 50 mm focal length each. And the lens mounts sealed by O-rings can be screwed into precise position along optic axis to exactly collimate output beam. The plasma shutter cell (PSC) is designed as a sealed cell (1Cr18Ni9Ti material) with an observation window. Symmetrically arranged metal rods (impurities of iron and Mo) with cone-shaped tip, are intended for targets to promote self-breakdown (also acting as electrodes of LTSG in future use), and the tips are arranged to penetrate into centered focal point vertical to beam axis. Truncated laser pulses are focused by a lens of 30 cm focal length into a 12-mm-thick, 55° cut $AgGaSe_2$ crystal coated on incident and output surfaces accounting for 80% transmittance at 10.59-μm wavelength. Original pulse directly out of TEA CO_2 laser and truncated pulse from PSC are shown in Fig. 2. The PSC extracts peaked pulse about average 45-ns FWHM with $\sim$ 22% energy efficiency (ED500 energy meter is arranged to replace HgCdTe detector) with over 15% energy instability due to jitter up to 13 ns and unstable radiation of TEA CO_2 laser. The pulse duration is a little wider than that (within 40 ns) presented by A. K. Nayak *et al.*[9]. Under 10 P(20) spectral line of TEA CO_2 laser operating in multiple mode, we inflate the PSC with flowing argon under air pressure, where the targets are carefully adjusted for stable gas breakdown occurrence. In the experiment, we find that several small burnout spots have been appeared on the tips of targets. With respect to the Ref. [12], we attribute to the reason that lower intensity pulses cause surface evaporation near focus region. In this case, SHG is demonstrated with and without PSC, and results are illustrated in Fig. 3.

Under the identical laser radiation, the conversion

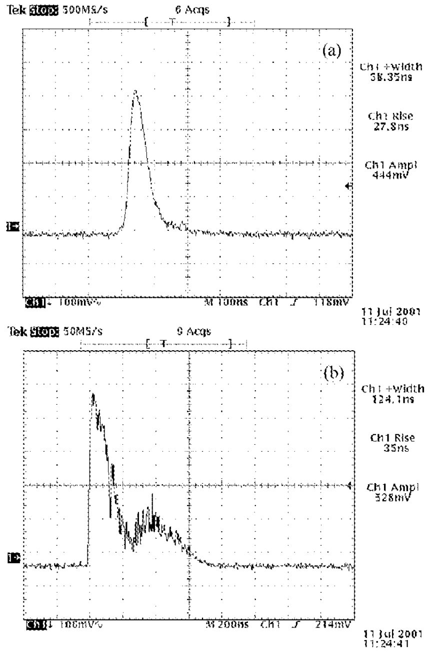

Fig. 2. Truncated (a) and untruncated (b) pulses.

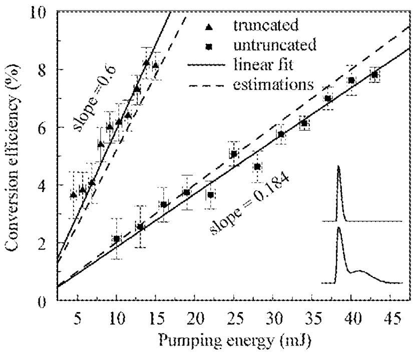

Fig. 3. Conversion efficiencies under the truncated and untruncated radiations with the fit lines and estimated ones. The assumed pulse shapes are depicted as insets.

efficiency of SHG in truncation case is about 3.3 times higher than that of untruncation, as illustrated in Fig. 3. For further corroboration, we simulate the results on the assumption that the truncated pulse is a Gaussian pulse with 45-ns FWHM and the original one is a combination of 100- and 300-ns (400 ns in total) Gaussian pulses at 1:1 energy ratio. And enhancement of factor 2.6 is estimated in our simulation. The high dependence of the conversion on pulse width results in intensified fluctuating, which together with instability of radiations from cavity increase the discrepancy. It should be noted that though the total system conversion efficiency do not change by pulse shortening, damage threshold is indeed lowered and that makes higher energy pumping possible. It will advance system's capability competing with multi-pass OPG/A pumped by TEA CO_2 laser.

With pumping energy being gradually increased to a maximum, measurements covering 50 pulses at each energy level are compared with the previous result of the same crystal that now has been polished and coated. Figure 4 demonstrates the result appending four data of former experiment[13] without PSC. There is no damage spot to be observed on the output surface through this experiment even for the maximal pumping, in which 200 repetitious 15-mJ pulses with estimated $16-20$ MW/cm^2 peak power intensity focused on the output surface continue to be detected. And up to 9.3% conversion with 1.4-mJ second harmonic (SH) energy is achieved finally. By the smooth distribution of SH energy, no damage even inside crystal is confirmed. While, in the former experiment, damages were observed under 60-mJ pumping ($18-25$ MW/cm^2 in total was estimated in crystal). SH energy was seen to decrease to less then 0.7 mJ during the fixed pumping, shown in Fig. 4.

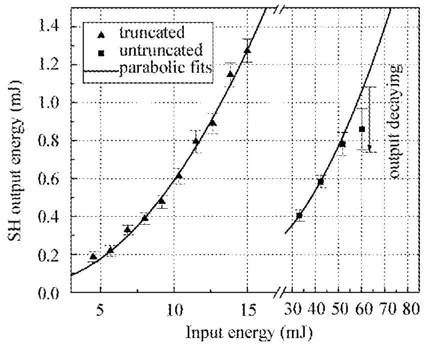

Fig. 4. SH outputs with and without plasma shutter versus input pulse energies.

In conclusion, a domestic passive plasma shutter with triggering targets is successfully applied to shaping TEA CO_2 laser pulse. And SHG conversion efficiency is enhanced nearly to tri-fold due to peak pulse's forming. It will be worthwhile to further apply LTSG for precisely timed pulse generation to optimize truncation.

J. Huang's e-mail address is co2@hope.hit.edu.cn.

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