Efficient Third Harmonic Conversion of Ti:Sapphire Laser Radiation

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ABSTRACT

For the first time, to the best of our knowledge, we report the highest efficiency of 35% (overall efficiency) for frequency tripling of Ti:Sapphire laser radiation in LBO (Type I) crystal. TEM_{00} injection-seeded Ti:sapphire laser was operated in 920-960 nm range to provide 307-320-nm UV light for ozone LIDAR applications.

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SUMMARY

The primary objective of this work was the development of an all-solid-state laser source that provides nominal 100 mJ pulses in 300-320 nm range at the required on-line and off-line wavelengths for ozone differential absorption lidar (DIAL)

The study of ozone is significant because ozone has such a profound impact on life on earth, being a threat to life when present in the troposphere and a protector of life (via UV absorption) when present in the stratosphere. These atmospheric studies have been conducted successfully from both ground-based and aircraft-based systems employing a variety of laser sources that emit in the 285- to 315-nm region. While the studies have been successful, they have always been limited by the availability of suitable laser sources. It would greatly benefit future DIAL research to have new laser transmitters that are more compact, robust, reliable, and low-maintenance than those currently available.

The laser sources used to date for ozone DIAL work have included Nd:YAG-pumped, organic dye lasers; Raman-shifted Nd:YAG lasers; excimer lasers; and Raman-shifted excimer lasers which are either toxic, or bulky, or require high maintenance.

Here we describe a robust, packaged, all-solid-state laser transmitter, based on a frequency tripled titanium-sapphire laser, that provides ≤35 mJ output pulses with 500 μs temporal separation in 307-320 nm wavelength range for ozone DIAL.

As a master tunable oscillator, we used the breadboard version of our patented high-energy Ti:sapphire laser design [1]. The Ti:sapphire laser was pumped by a high-energy, flashlamp-pumped, frequency-doubled, Nd:YLF laser configured for a 5-Hz, double-pulsed format. Dual-wavelength operation of a high-energy titanium-sapphire laser was achieved by incorporating a mirror mounted on a magnetic scanner which can rapidly tune the titanium-sapphire laser in 920-960 nm range with a temporal separation of 500 μs.

As it was shown previously [2] injection-seeding of Ti:Sapphire lasers allows for significant increase in THG conversion efficiency. In our experiments Ti:sapphire laser was injection-seeded using two external grating laser diodes (EOSI, Inc) tuned to 925 nm and 945 nm, respectively.

The main parameters of the pump Nd:YLF laser and unseeded Ti:sapphire tunable oscillator are given in Table 1. (When Ti:sapphire laser was seeded the output energies were ~10-15% smaller).

	Wavelength, nm	Beam Quality	Beam Diameter, mm	Min. Pulsewidth, ns	Max. Energy per pulse, mJ
Nd:YLF pump laser	527	Multimode, M^2 ~10	~8	~10	~525
Ti:Sapphire laser	925	TEM_{00} M^2 ~ 1.3	~2	~20	155
	945	TEM_{00} M^2 ~ 1.3	~2	~30	125

In order to achieve efficient frequency tripling of Ti:sapphire laser we performed theoretical evaluation of a number of nonlinear materials suitable for tripling of 920-960 nm range. The results for calculation of "power threshold" NLO figure-of-merit [1] for BBO (Type I and II), LBO (Type I and II) and CLBO (Type I) are presented in Fig.1.

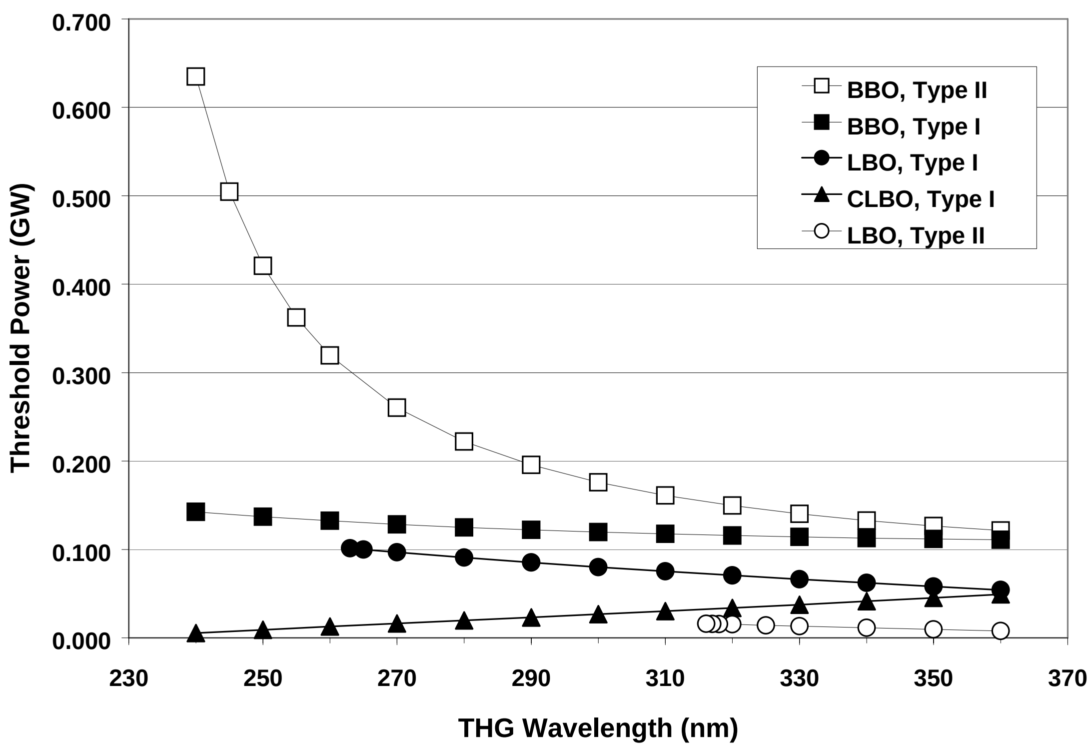

Figure 1 THG NLO "power threshold" versus THG wavelength in borate materials

It follows from calculations, that CLBO (Type I) and LBO (Type II) feature the "lowest power" threshold. However, LBO (Type II) does not have phase matching for fundamental wavelengths shorter than 945 nm and CLBO is still on the stage of development. Therefore LBO (Type I) seems to be the best practical material for frequency tripling of Ti:Sapphire radiation (shorter than 945 nm) and it was chosen for our experiments.

Schematic of the set-up for THG experiments is shown in Fig.2. LBO (Type I), 20-mm long, AR coated crystal was used for second harmonic generation Ti:sapphire laser. The efficiency of second harmonic generation was ~50% in seeded or unseeded regime of operation.

We evaluated performance of LBO (Type I) crystal with and without a 2.5X telescope, which was used to reduce the diameter of the first and second harmonic beams. The energy per pulse (1ω) was set to ~ 100 mJ in seeded regime of operation what

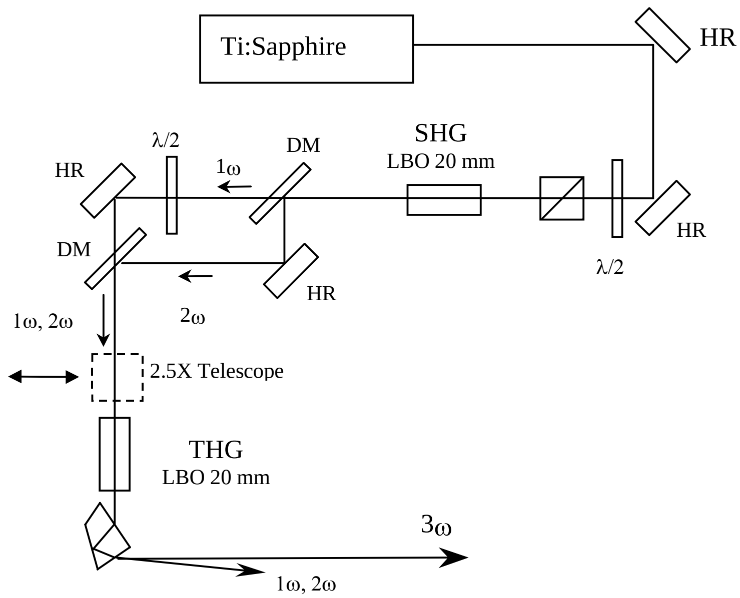

Figure 2 Schematic of the set-up for THG in LBO (Type I) crystal.

corresponds to ~0.1 GW/cm^2.

The THG conversion was characterized by two numbers: (1) overall efficiency defined as the ratio of the pulse energy (1ω) at the input of the SHG crystal to the THG pulse energy (3ω) at the output from the THG crystal, and (2) THG crystal efficiency defined as the ratio of the pulse energy at the input of the THG crystal (1ω+2ω) to the THG pulse energy (3ω) at the output from the THG crystal. Fresnel reflection from the THG crystal faces where not taken into account for efficiency calculation.

The following efficiencies were measured:

Efficiency	No telescope	With telescope
THG Crystal	~40	~45
Overall	~30	~35

The dependencies of THG output energy and THG crystal efficiency versus the input pulse energy in seeded and unseeded regimes of operation are shown in Fig. 3. THG conversion efficiency was ~ 3 times larger for seeded regime than for unseeded. Record conversion efficiency of ~ 45 % (~35% overall) was measured.

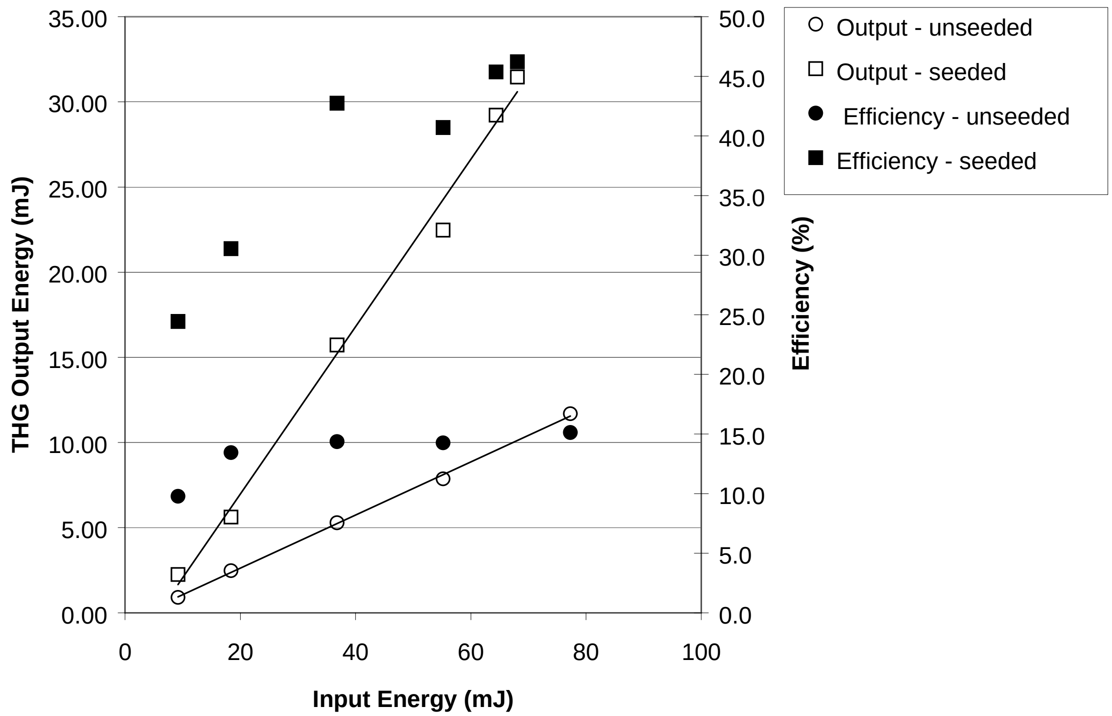

Figure 3 **THG output energy and THG efficiency versus the combined input energy at the THG crystal (fundamental wavelength – 925 nm)**

Conversion efficiency stayed approximately the same when the wavelength was tuned in 925 – 945 nm range.

In conclusion, we demonstrated highly efficient frequency tripling of TEM_{00} injection-seeded Ti:sappphire laser operated in 925-945 nm range using LBO (Type I) crystal. Injection seeding allows to narrow the spectral bandwidth of laser emission and increase the tripling efficiency by ~ times.

Efficient schemes to generate light in 308-320 nm range significantly benefit the atmospheric sciences studies. While this effort emphasizes the ozone application with operation in the 308- to 320-nm region, the same system could easily be modified to produce outputs around 300 nm for SO_2 detection, 450 nm for NO_2 detection, and 226 nm for NO detection.

References:

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