Third Harmonic Generator

MODEL ATsG800-7

S/N 00023

INSTRUCTION MANUAL

DEL MAR PHOTONICS

Del Mar Photonics, Inc
4119 Twilight Ridge
San Diego, CA 92130
tel: (858) 876-3133
fax: (858) 630-2376
support@dmphotonics.com
http://www.dmphotonics.com/

GENERAL SAFETY INFORMATION

In order to ensure the safe operation and optimal performance of the product, please follow these warnings in addition to the other information contained elsewhere in this document.

WARNING: If this instrument is used in a manner not specified in this document, the protection provided by the instrument may be impaired.

TABLE OF CONTENTS

1. ACCESSORIES

Part	Quantity	Note
Box	1	Opto-mechanical box
Table clamp	4	Clamps for securing the Optical Unit on optical table
Manual	1	This document

2. INTRODUCTION

2.1) Introducing device

Third harmonic generator (THG) is developed for frequency doubling and tripling of Ti-Sa amplifier radiation (λ=780-820 nm). Device is based on second harmonic generation (SHG) and sum-frequency generation (SFG) techniques and provides stable radiation in *fs* scale. TH generator is developed for high conversion efficiency.

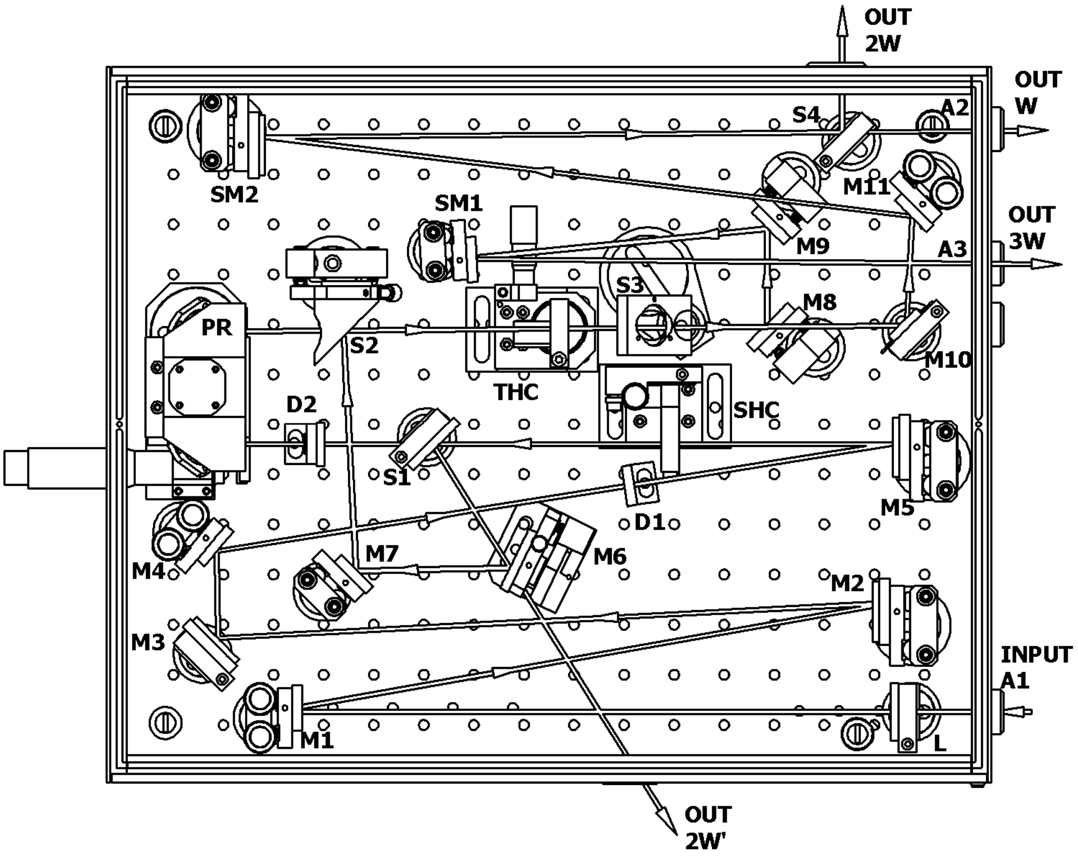

Fig.1. Scheme of TH generator.

The basic scheme of generator is depicted on Fig.1.

An incoming fundamental (F) beam passes through the lens L. Slightly focused beam reflecting from the mirrors M1, M2, M3, M4 and M5 passes through the crystal SHC (BBO, type I) and generates SH signal. Then F and SH beams are separated into two different paths by separator S1 that has a high transmittance for F beam and high reflectance for SH beam.

Polarization rotator (PR) consisted of three mirrors is placed into F beam arm to convert horizontal polarization of the fundamental beam to vertical one. An adjustable optical delay with PR is used to make F and SH pulses coincident in time for SFG. The flip-mirror M6 in “up-state” acts like a mirror. In “down-state” it is used for emanating of the full SH radiation (just after the SHC crystal). After meeting each other at separator S2 two beams interact in THC crystal (BBO, type I) producing third harmonic. TH signal is separated from fundamental and SH ones by two-mirrors separator S3. Then TH beam reflects from dielectric mirrors M8 and M9 and then it is recollimated by spherical mirror SM1. F and SH beams reflect from mirrors M10 and M11 and then they are recollimated by spherical mirror SM2. SH beam is separated from F one by separator S4.

TH generator consists of the following optical elements:

1. SHC crystal - BBO (type I) 0.5 mm thick crystal;
2. THC crystal - BBO (type I) 0.5 mm thick crystal;
3. M1, M2, M3, M4, M5 – dielectric mirrors (λ=780-820 nm);
4. M6, M7 – dielectric mirrors (λ=380-420 nm);
5. Separators (S1, S2, S4)- high transparent for F radiation and high reflective for SH radiation;
6. PR – polarization rotator (consisted of three dielectric mirrors for λ=780-820 nm);
7. Separator S3 - high reflective for TH radiation (λ=250-280 nm) and high transparent for F and SH radiation;
8. M8, M9 – dielectric mirrors for TH radiation (λ=250-280 nm);
9. M10, M11 – Al mirrors;
10. L – lens, (f=1333 mm, ARC 800 nm);
11. SM1 – Al concave mirror (f=600 mm);
12. SM2 – Al concave mirror (f=1000 mm).

2.2) General information

If the matter interacts with the high power laser radiation the material properties are changed by the incident field. In this case the induced polarization has the high components depending on the electrical field:

$$P = \chi^{(1)}(\omega)E(\omega) + \chi^{(2)}(2\omega)E(\omega)E(\omega) + \chi^{(3)}(3\omega)E(\omega)E(\omega)E(\omega) + ... \tag{1}$$

The $\chi^{(2)}$ is the tensor of second-order nonlinear optical susceptibility and it is responsible for second-harmonic generation (SHG) and sum-frequency generation (SFG). Let's consider the generation of *Ti-Sa* second ($\omega_2 = 2\omega_1$) and third harmonic ($\omega_3 = 3\omega_1$) obtained by fundamental and SH radiation mixing ($\omega_1 + \omega_2 = \omega_3$). Assuming the plane wave front and neglecting group velocity dispersion (GVD) and group velocity mismatch (GVM), the SH conversion efficiency can be written as:

$$\frac{I_2}{I_1} = \frac{2\pi^2 d^2 L^2 I_1}{\varepsilon_0 c n_1^2 n_2 \lambda_2^2} Sinc^2\left(\frac{|\Delta k| L}{2}\right), \tag{2}$$

where I_1 and I_2 are the fundamental and SH intensities, respectively, L – the length of the crystal, *d*- the dipole moment of the interaction, $|\Delta k| = 2k_1 - k_2$ is a phase mismatch. In the case of type-I *oo-e* interaction in which the fundamental ordinary (*o*) wave produces extraordinary (*e*) wave, respectively, the phase-matching angle θ of birefringent crystal can be easily derived from the equation:

$$|\Delta k| = 2\frac{\omega}{c}(n_e(\omega) - n_o(2\omega, \theta)) = 0. \tag{3}$$

The sum-frequency (SF) conversion efficiency can be written as

$$\frac{I_2}{I_1} = \frac{8\pi^2 d^2 L^2 I_2}{\varepsilon_0 c n_1 n_2 n_3 \lambda_3^2} Sinc^2\left(\frac{|\Delta k| L}{2}\right) \tag{4}$$

where I_3- SF intensity, I_1 and I_2 are the fundamental and SH intensities, respectively, L – the length of the crystal, $|\Delta k| = k_1 + k_2 - k_3$ is a phase mismatch. In the case of type-I *oo-e* interaction phase-matching angle θ of birefringent THC crystal can be obtained:

$$\left|\Delta k\right| = \frac{\omega}{c}(n_o(\omega) + 2n_o(2\omega) - 3n_e(3\omega,\theta)) = 0. \tag{3}$$

For example, the phase-matching angle for SF in BBO-type-I crystal is θ=44° at $\lambda_\omega = 0.8\mu m$.

If the ultra-short laser pulse sources are used the effects of group velocity mismatch (GVM) and group velocity dispersion (GVD) can seriously effect on SH pulse propagation. In case of exact phase matching fundamental pulse does not suffer losses and the SH electrical field at the end of crystal of the length L can be written as:

$$E_2(2\omega, t - \frac{L}{\upsilon_2}, L) = -i\chi^{(2)}\frac{\omega_2^2}{4c^2k_2}\int_0^L E_1^2\left[t - \frac{L}{\upsilon_2} + z\left(\frac{1}{\upsilon_2} - \frac{1}{\upsilon_1}\right)\right]dz. \tag{4}$$

The term $z\left(\upsilon_2^{-1} - \upsilon_1^{-1}\right)$ describes the longitudinal walk-off between the SH pulse and the F pulse owing to the different group velocities. The result is a broadening of the second harmonic pulse. Only for crystal lengths

$$L << L_D = \frac{\tau_p}{\upsilon_2^{-1} - \upsilon_1^{-1}}, \tag{5}$$

an influence of GV mismatch can be neglected.

The case of SFG is more complicated. If the thick crystals are used the duration of TH pulse generated in SF crystal can be written as:

$$\tau_3 = (\tau_1 + \tau_2)\frac{\upsilon_3^{-1} - \upsilon_1^{-1}}{\upsilon_2^{-1} - \upsilon_1^{-1}}. \tag{6}$$

For instance, for the BBO type-I crystal $\left(\upsilon_2^{-1} - \upsilon_1^{-1}\right)$=317fs/mm, $\left(\upsilon_3^{-1} - \upsilon_1^{-1}\right)$= 725 fs/mm and assuming $\tau_1 \approx \tau_2 \approx 50$ fs we obtain τ_3=220 fs for sufficiently long crystal. It means that the TH must be broadened in 4 times compare with the fundamental pulse duration. But using thinner crystals is not so attractive because of the small conversion efficiencies.

However the focusing femtosecond pulses with lenses can reduce the effect of GVM due to the angular dispersion. When achromatic phase matching is considered, an angular dispersion of the pulse allows phase matching and GVM simultaneously. In this case the generation of SH and TH pulses as short as fundamental pulses is available.

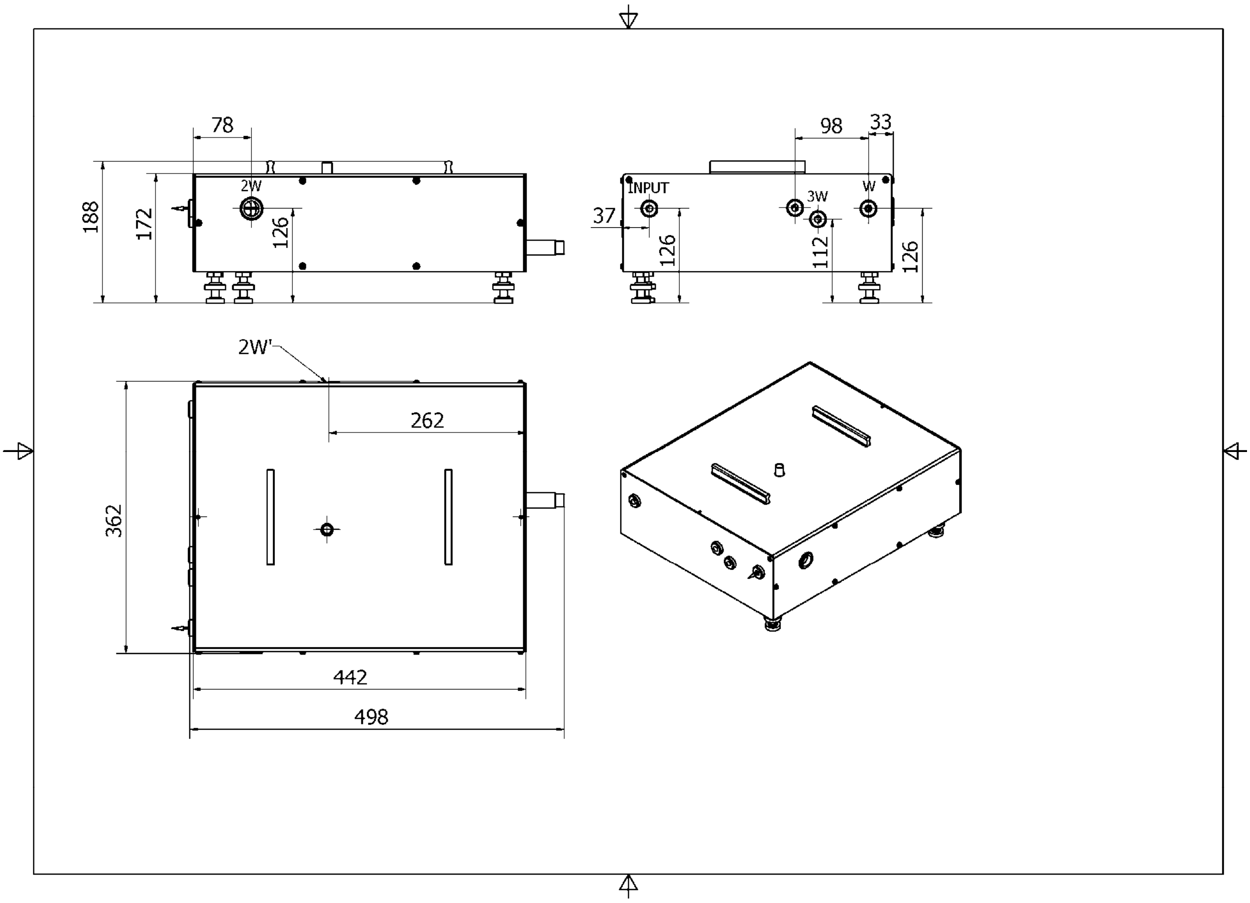

Fig.2. Outline drawings

3. SPECIFICATIONS

- Pulse width - 40-60 fs
- TH efficiency - > 7 %*
- SH efficiency - >25 % (full output**)
- Input beam size (FWHM) - 2.7 mm ***
- Input energy in pulse > 8 μJ
- Temporal broadening - For TH pulse< 250 fs
  For SH pulse <100 fs
- Input polarization - Linear- horizontal
- Output TH polarization - Linear- horizontal
- Output SH polarization - linear- vertical
- Output fundamental beam polarization - linear- vertical
- Input wavelength - 780 – 820 nm
- Output TH wavelength - 260 – 274 nm
- Output SH wavelength - 390 – 410 nm
- Dimensions - 500mm x 362mm x 188mm

* - assuming that pulse is compressed;

** - just after the flip-mirror M7;

*** - assuming that $1.5<M^2<2$.

4. INSTALLATIONS AND ALIGNMENT

4.1) Unpacking the generator

Your generator was packed with great care and all containers were inspected prior to shipment: the generator left Del Mar Photonics in good condition. Upon receipt of your laser, immediately inspect the outside of the shipping containers. If there is any major damage, such as holes in the box or cracked wooden frame members, insist on that a representative of the carrier should be present when you unpack the contents.

Carefully inspect generator box as you unpack it. If you notice any damage, such as dents, scratches or broken knobs immediately notify the carrier and your Delmar Photonics Ltd Sales representative.

Open the cover of the box head and remove the bags which covering the elements of generator and fixing elements which are used for transport. Do it very carefully, try not to misalign the generator, and damage optical elements during this procedure. We strongly recommend you to cut elastic bands that fasten the bags before removing.

4.2) Aligning the generator

1) Install optical unit of the generator on the optical table horizontally.
2) Adjust the height of the generator using the leg-screws so that the box will be parallel to the table surface. The height of input outlet is **126±10** mm.
3) Attach the optical unit to the table using clamps.
4) Lead the pump beam F into the generator following three steps:
5) *1st step*. Make the pump beam passing through the aperture A1 and diaphragm D1 (Fig.3) (installed by default). Remove the diaphragm A1 (Fig.3).

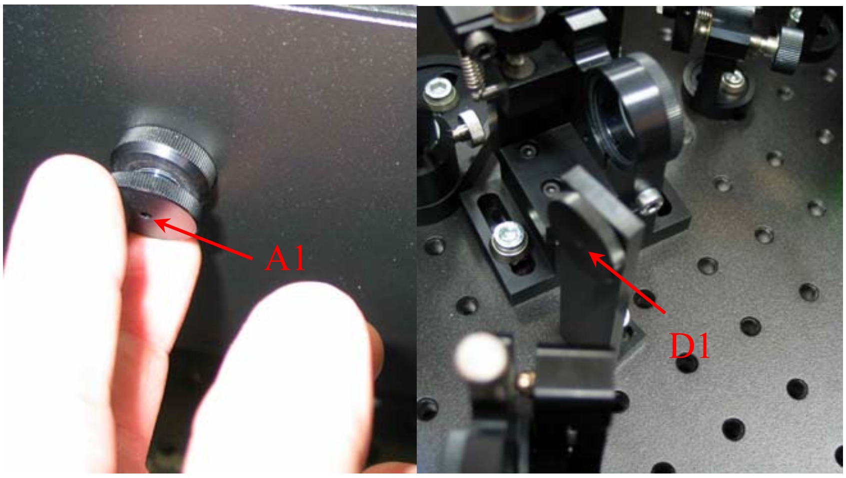

Fig.3.

6) *2nd step*. Lead the F beam through the diaphragm D1 and diaphragm D2. Try to lead the focusing beam into the center of D2. The generator left Del Mar aligned at the fundamental wavelength λ=0.8 μm so first you don't need to align the SH and TH crystals. Remove the D1 and D2.

7) Check that position of PR screw is 6.9 mm (6 big graduation marks and 40 small marks) (Fig.4). Insert straight behind output of 3ω (A3) the white piece of paper. TH signal must appear.

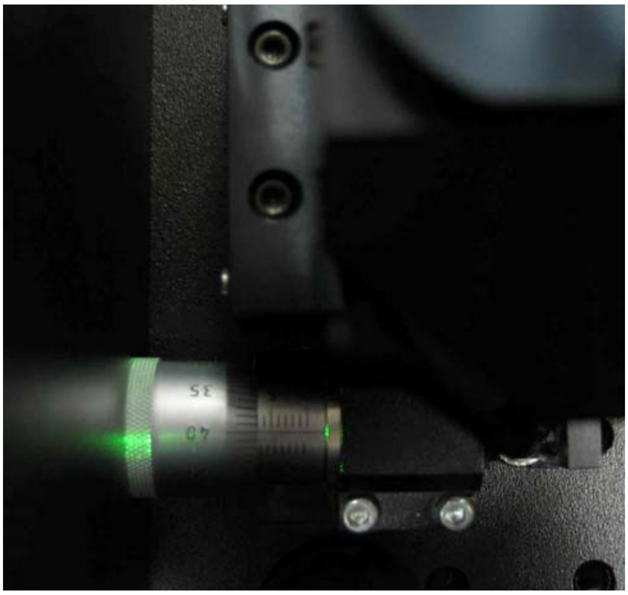

Fig.4.

8) *3rd step.* Install a power meter in TH beam. Measure the TH power. Try to maximize TH signal slightly adjusting your mirrors that lead F beam into the generator.

9) Check that the residual F beam incident onto the center of gag A2. To use F beam you need to remove gag.

10) Flip the mirror M6 so that it will be in “down-state” (parallel to the table) (Fig.5). Remove the gag. Install a power meter in SH beam.

11) Adjust a screw on SH holder to get the maximal SH intensity (Fig.6).

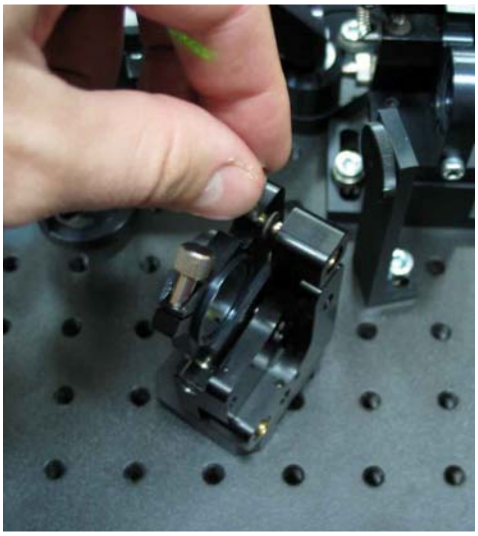

Fig.5.

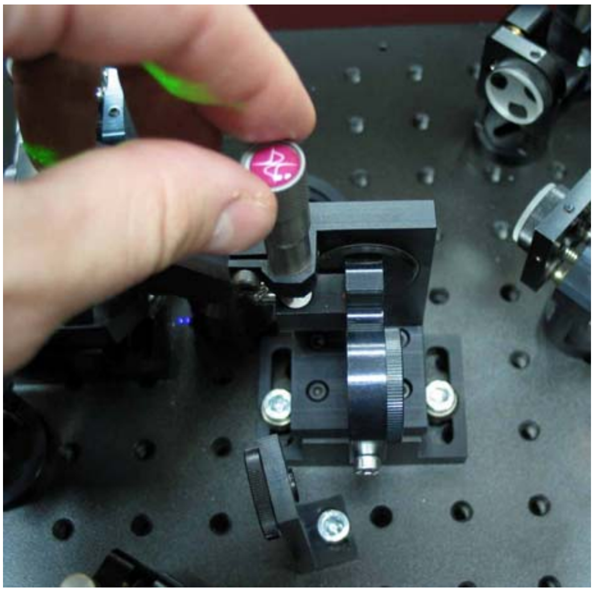

Fig.6.

12) Set the flip M6 into the "up-state".

13) Install a power meter in TH beam. First try to maximize TH signal adjusting mirror M7 in horizontal and vertical directions (Fig.7). Use screw-knob that is applied to holder.

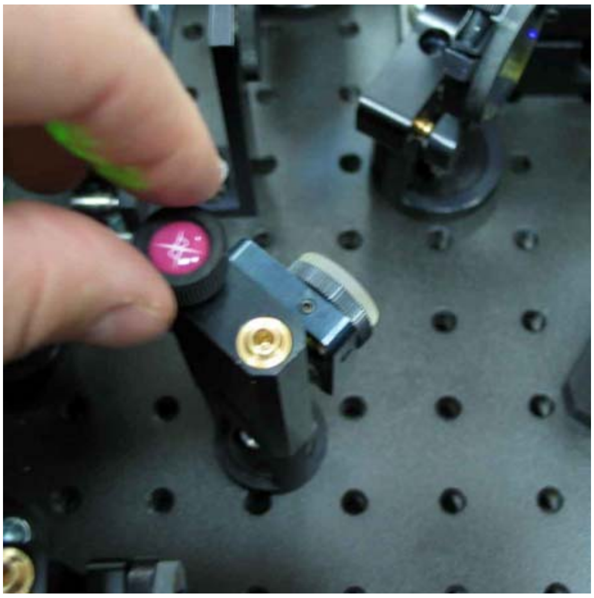

Fig.7.

14) Adjust the S2 to get more TH intensity. Use the screw-knob (Fig.8).

15) Maximize TH signal rotating the PR screw slightly (Fig.4).

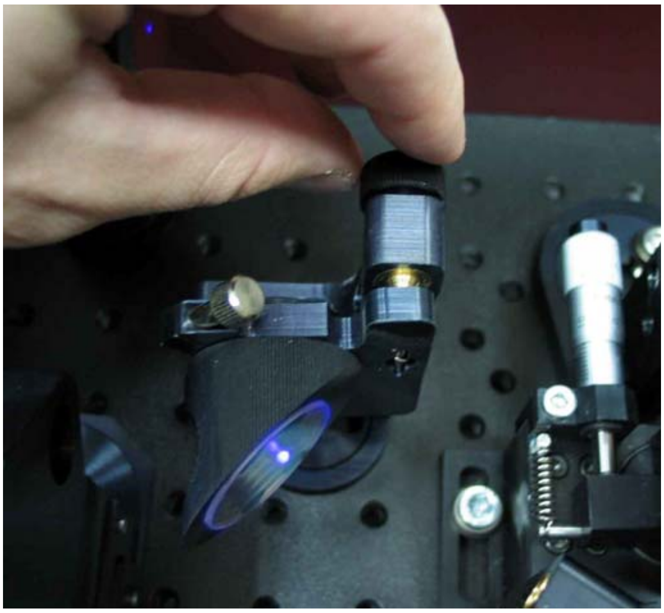

Fig.8.

16) Check that TH beam goes through the A3 properly. You can align the SM1 mirror to direct TH to the center of A3.

17) Adjust a small micrometer knob on TH table to get the maximal TH intensity (Fig.9).

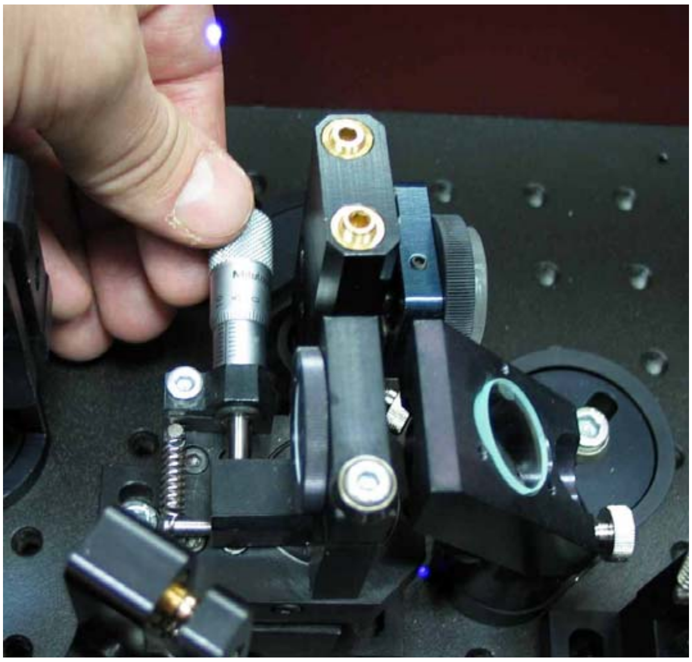

Fig.9.

18) Repeat steps 13,14,15.

19) Now the generator is ready for operating.

NOTE: Occasionally, it may be necessary to clean the optics of TH generator. The best method to clean surfaces is to first block the pump beam and then blow excess particles from the surface. If the mirrors are severely contaminated you may clean it with acetone and very soft tissue.

WARNING: Don’t clean the BBO crystal with acetone or alcohol. Use only blowing to clean the surface of crystal.

REFERENCES

1. J.-C. Diels and W. Rudolph, *Ultrashort Laser Pulse Phenomena: Fundamentals, Techniques, and Applications on a Femtosecond Time Scale* (Academic, San Diego, Calif., 1996),pp. 365-399.
2. R. C. Miller, Phys. Lett., **26**: 177-178 (1968).
3. S.A. Akhmanov, A.S. Chirkin, and A.P. Sukhorukov, Sov. J. Quantum Electron., **28**, 748-759 (1968).
4. W.H. Glenn, IEEE J. Quantum Electron., QE-**5**, 281-290 (1969).
5. R.C. Eckardt and J. Reintjes, IEEE J. Quantum Electron., QE-**20**, 1178-1187 (1984).
6. N.C. Kothari and X. Carlotti, J. Opt, Soc. Am. B, **5**, 756-764 (1988).
7. D. Kuehlke and U. Herpers, Opt. Commun, **69**, 75-80 (1988).
8. G. Szabo and Z. Bor, Appl. Phys. B, **50**, 51-54 (1990).
9. A. Stabinis, G. Valiulis, and E.A. Ibragimov, Optics Comm., **86**, 301-306 (1991).
10. S.H. Ashworth, M. Joschko, M. Woerner, E. Riedle, and T. Elsaesser, Opt. Lett. Vol. **20**, No. 20, 2120 (1995)
11. A. Furbach, T. Le, C.Spielmann, F.Krausz, Appl. Phys. B **70**, S37 (2000).

NOTES