Third-order cross-correlator

MODEL RINCON 1.053-4

INSTRUCTION MANUAL

Version 2.2   **July 2007**

Please take time to read and understand this Manual and familiarize yourself with the information that we have compiled for you before you use the product. This Manual should stay with the product to provide you and all future users and owners of the product with important operating, safety and other information.

GENERAL SAFETY INSTRUCTIONS

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

WARNING: Make sure this instrument is properly grounded through the protective conductor of the AC power cable. Any interruption of the protective grounding conductor from the protective earth terminal can result in personal injury.

CAUTION: Before supplying the power to the instrument, make sure that the correct voltage of the AC power source is used. Failure to use the correct voltage could cause damage to the instrument.

WARNING: If this instrument is used in a manner not specified in this document, the protection provided by the instrument may be impaired. This product must be used only in normal condition.

TABLE OF CONTENTS

1. ACCESSORIES

1. Opto-mechanical assembly -   1 unit
2. Electrical control unit   1 unit
3. Connection cables
     3.1) Cable DB9M (signal black cable)   1 unit
     3.2) Cable DB9F   2 units
     3.3) AC power cable 110/220 V   1 unit
     3.4) USB cable   1 unit
4. Table clamp   4 units

2. INTRODUCTION

2.1. General information

Third-order cross-correlator RINCON is a device developed for measuring and determining pulse pedestal, pre- and post-pulses and amplified spontaneous emission in a high dynamic range. It is based on third-order cross-correlation technique and provides information about the cross-correlation function of pulse intensity in *fs* scale.
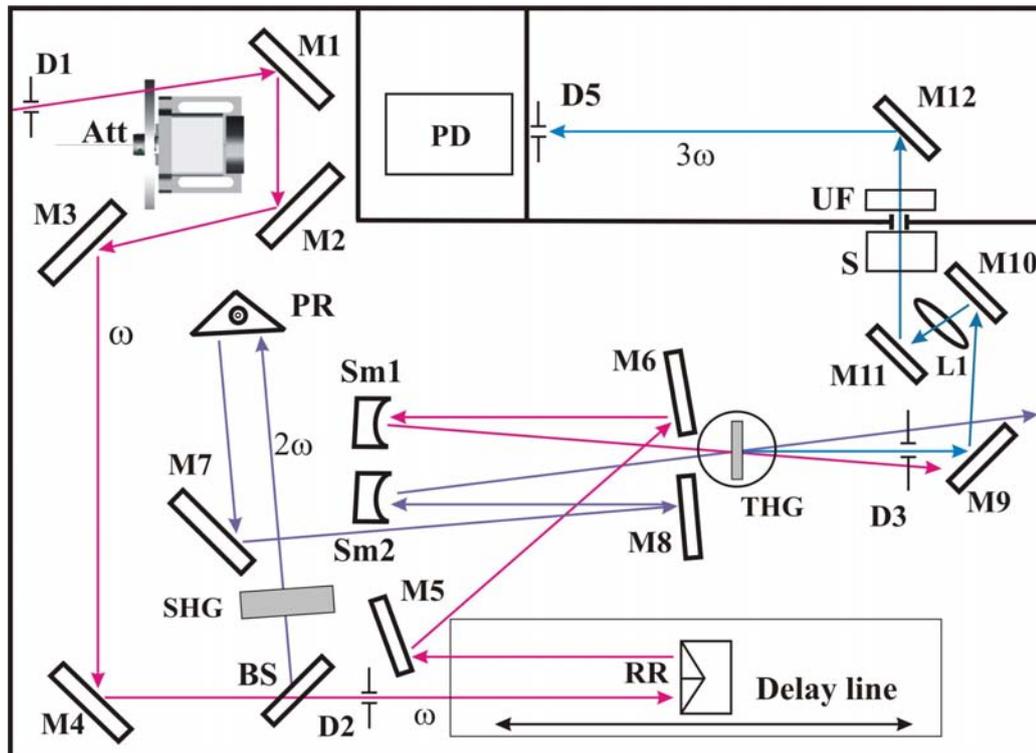
Fig.1. Optical arrangement of RINCON.

The basic optical arrangement of the correlator is depicted on Fig.1. An incoming pulse (λ=1053 nm) splits on two beams in ratio 1:9. The most intensive part reflecting from the beamsplitter BS generates a second harmonic (SH) signal (λ=527 nm) within the BBO crystal (SHG). An adjustable optical delay (RR) is placed into fundamental pulse arm. Polarization rotator (PR) that converts horizontal polarization of the fundamental beam to vertical one is inserted into SH pulse arm. Then two beams (fundamental and SH) are focused onto BBO crystal

for the sum frequency generation (SFG type I). TH beam is imaged on photodetector by lens L1 and it is separated from fundamental and SH ones by aperture D3, dichroic mirror S and UF filter. Dielectric mirrors M10, M11, M12, M13 that have very low transmittance for fundamental and SH beams give an additional selection. Then TH beam is incident on photodetector PD connected with the control unit. The attenuator wheel (Att) is used for attenuation of input fundamental beam.

Detection of TH signal as a function of optical delay between the interacting fields yields the cross-correlation function. High gain and low noise of electronic detector unit and attenuation of fundamental pulse energy provide high dynamic range in TH signal measurement.
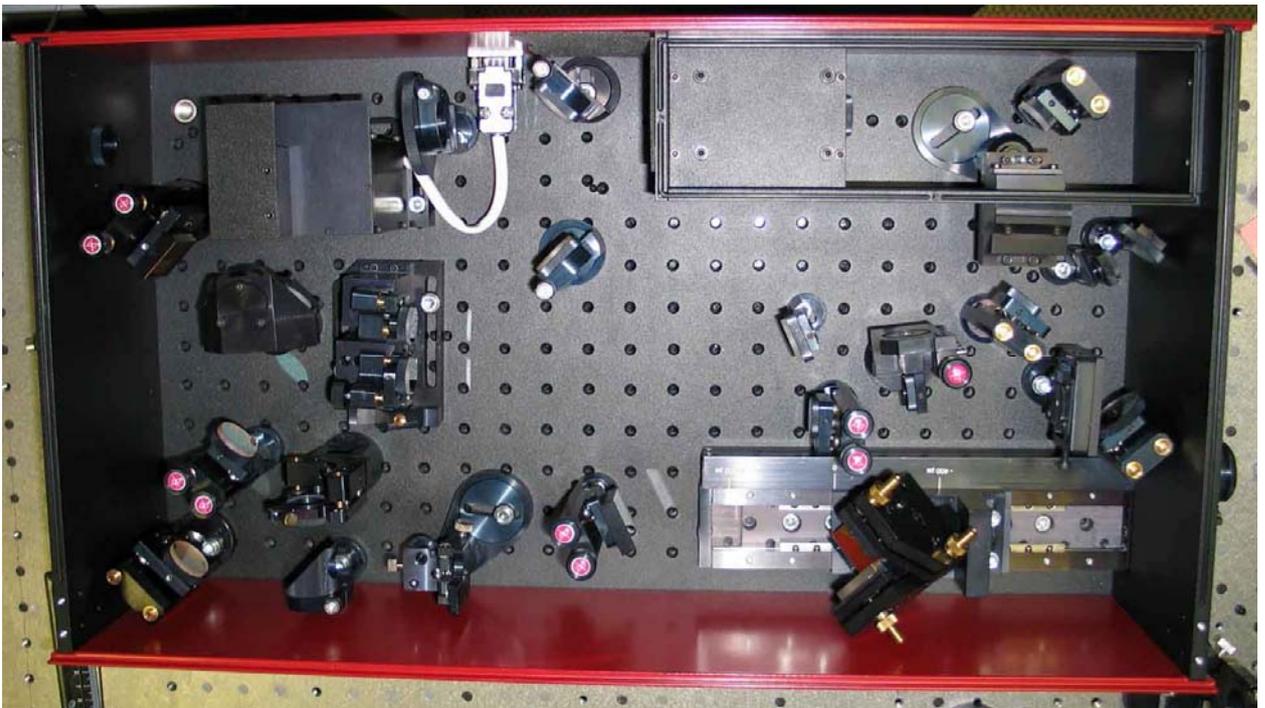
Fig.2. RINCON1.053-4

2.2. Key components

Optomechanical unit consists of the further components:

1) Crystal BBO, I type, θ=23°, d=1.5 мм,

2) Crystal BBO, I type, θ=31.7°, d=0.2 мм,

3) BS – beam splitter (R:S=1:9),

4) M1, M2, M4– dielectric mirrors for fundamental radiation (λ=1053 нм +/- 50 nm),

5) M3 - metal Au mirror,

6) M5, M6 – metal Ag mirrors,

7) PR – geometrical polarization rotator, consisted of three dielectric mirrors for SH (λ=527 nm),

8) M7 - dielectric mirror for SH radiation (λ=527 nm),

9) M8 – metal Al mirror,

10) SM1 and SM2 - Al spherical mirror for fundamental and SH beams mixing, R=250 mm.

11) RR – retroreflector, consisted of three Au mirrors,

12) L1 – lens (ARC 355 nm, f=120 mm) for TH imaging,

13) M9, M10, M11, M12 – dielectric mirror for UV radiation (λ=351 nm).

14) D1, D2, D3, D5 – apertures.

15) Att – attenuator for fundamental radiation with diffraction grating.

2.3. Theoretical background

We consider an interaction between the femtosecond pulse at λ=800 nm with duration τ=50 fs with the SH pulse (λ=400 nm), generated in BBO crystal. Interaction of these pulses in nonlinear crystal leads to sum frequency (specifically, third harmonic) generation at wavelength λ=267 нм. SH intensity as function of time delay between fundamental and SH pulses is third-order cross-correlation function.

$$\mathbf{I}_{3\omega}(\tau) = \int\limits_{-\infty}^{+\infty} \mathbf{I}_{\omega}(t+\tau)\mathbf{I}_{2\omega}^{2}(t)dt. \tag{1}$$

Generally, when dealing with the ultra-short laser pulse sources the effects of group velocity mismatch (GVM) and group velocity dispersion (GVD) have to be taken into account. In this case the effective mismatch:

$$\Delta k_{eff} = \Delta k + \Delta g_{31}\omega' + \Delta g_{12}\omega'' \tag{2}$$

consists of phase mismatch ($\Delta k = |k_3 - (k_1 + k_2)|$) and GVM ($\Delta g_{31} = 1/\upsilon_{g3} - 1/\upsilon_{g1}$ и $\Delta g_{12} = 1/\upsilon_{g1} - 1/\upsilon_{g2}$), where index 1 corresponds to fundamental pulse, indices 2 and 3 correspond to SH and TH harmonics, respectively.

Let us assume the τ_1, τ_2, τ_3 as durations of fundamental, SH and TH pulses, respectively and a τ_{cc} as a cross-correlation function width. Because the phase mismatch at τ_1=50 fs is much less than GV mismatch we can neglect it ($\Delta k \approx 0$). Now we consider two cases.

1) In the case of complete group velocity matching ($\Delta g_{31} = 0, \Delta g_{12} = 0$) the cross-correlation function width:

$$\tau_{cc} = (\tau_1^p + \tau_2^p)^{1/p}, \tag{3}$$

where *p*=2 and 1.65 for Gaussian pulse and *sech*^{2} pulse, respectively.

If the $\tau_1/\tau_2 > 6$ the function $\mathbf{I}_{2\omega}(t)$ can be substituted to function $\delta(t)$. In this case the cross-correlation function retrieves the fundamental pulse profile $\mathbf{I}_\omega(\tau)$:

$$\mathbf{I}_{3\omega}(\tau) \approx \mathbf{I}_{\omega}(\tau). \tag{4}$$

2) If the $\Delta g_{12} L \neq 0$, this is serious impact on the cross-correlation function width τ_{cc}. At the large group delay mismatch ($\Delta g_{31} L > \tau_1$) the cross-correlation function width tends to a limit:

$$\lim_{\Delta g_{12} L / \tau_1 \to \infty} \tau_{cc} = \Delta g_{12} L \tag{5}$$

where the L is a nonlinear crystal length. At a small group delay mismatch or a long pulse width τ_1 the cross-correlation function width tends to a limit:

$$\lim_{\tau_1 / \tau_2 \to \infty} \tau_{cc} = \tau_1. \tag{6}$$

2.4. Artifacts in cross-correlation measurements

The problem in measuring of post- and pre-pulses is the artifacts originated from multiple reflections inside the cross-correlator. The common cross-correlation trace obtained with RINCON800 is depicted on Fig.3. We have found **4** artifact peaks. **3** peaks – at +27,210 ps (on level $\sim 3 \times 10^{-4}$), at +33,000 ps (on level $\sim 2 \times 10^{-4}$) and at +54,420 ps (on level $\sim 5 \times 10^{-7}$) are identified with double and quadruple reflections of fundamental beam in attenuator. **Peak** at -17,240 fs (on level $\sim 1.5 \times 10^{-3}$) is attributed to the double reflection of SH beam in SH crystal (d~1.5mm).You should take them into account in your measurement.
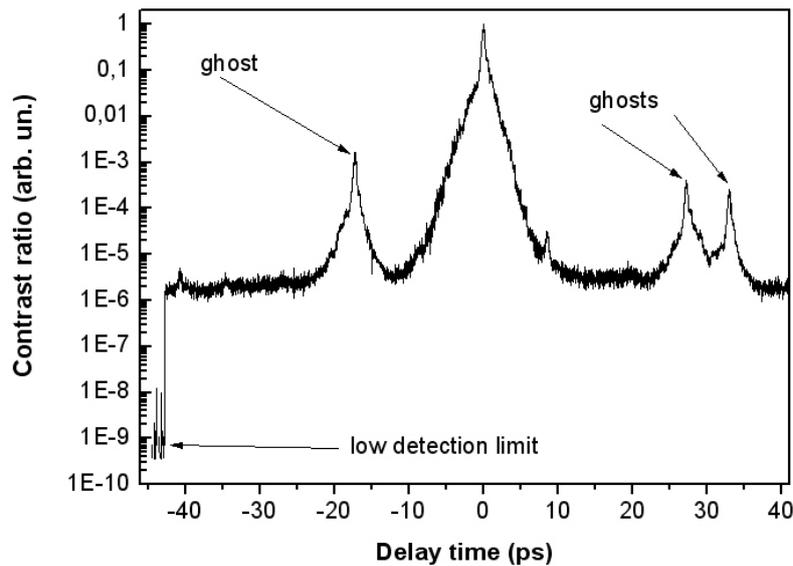
Fig.3. Cross-correlation trace.

3. SPECIFICATIONS

- Input wavelength   -   1040- 1064 nm
- Pulse width   -   600 fs < > 300 fs *
- Input pulse repetition rate -   < 3 kHz

- Dynamic range   - 10^9 *
- Temporal range   -   990 ps
- Input energy (at 350-500 fs input pulse duration) - ≤ 100 μJ

- Beam diameter (full)   < 8 mm
- Input polarization   -   Linear- horizontal
- Resolution   -   400 fs
- Electric power   -   110/220 V AC, 50/60 Hz ± 10%
- Dimensions   -
        - optical unit   657mm x 339mm x 210mm
        - control unit   255мм x 200мм x 80мм

* - assuming that input pulse is spectrum bandwidth limited.

4. INSTALLATION AND ALIGNMENT OF RINCON

RINCON was packed with great care and all containers were inspected prior to shipment: the correlator 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 Del Mar Photonics Sales representative.

Open the cover of the box head and remove the bags that cover the elements of RINCON. **Just cut elastic bands that fasten the bags and pull the bags!** Otherwise you can misalign the device and even damage optical elements. After that remove the residue from the elastic bands.

Especially take care of attenuator because it might be damaged easily!
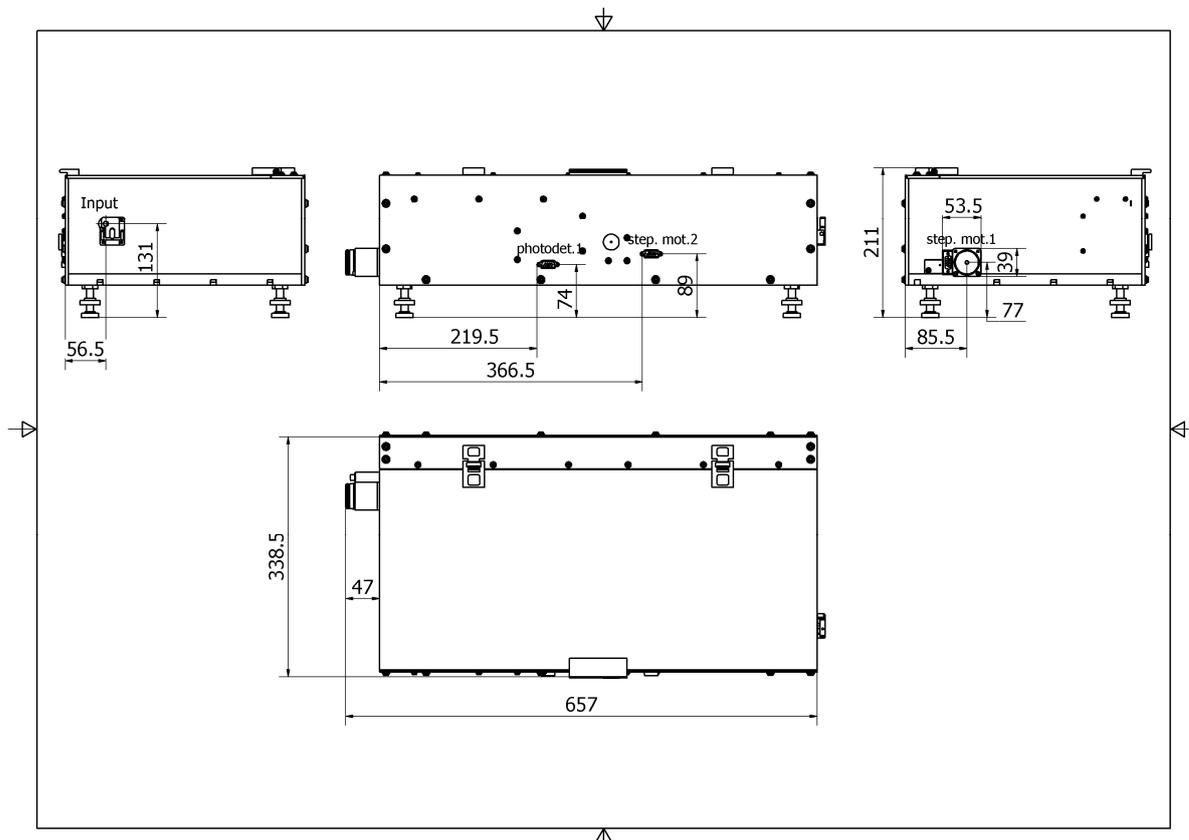
. Outline drawing of RINCON1.053-4.

     RINCON consists of opto-mechanical box, control unit and connection cables. Box has two outlets for stepping motors of delay line and filter wheel (st.mot.1 and st.mot.2, respectively) and one outlet for photodetector (photodet.1) (Fig.4).

1)   Install control unit near the main box.

2)   Connect them via two connection cables. Connector with "Step.mot.1" mark should be connected to connector "Step.mot.1" on the side of the opto-mechanical box and connector "Step.mot.2" must be connected to "Step.mot.2" connector on another side of the box, respectively.

3)   Black DB9M cable connects two outlets "Photodet.1" of the opto-mechanical box and control unit.

4)   Connect the control unit and computer via USB cable applied.

5)   Apply a positive synchronous signal with amplitude of 4-5 V and duration not shorter than 300 ns in the BNS outlet "Trigger" of control unit. The repetition rate must be the same as repetition rate of laser source. Before starting a work you need to adjust the synchronous signal with laser pulse using the oscilloscope and avalanche diode. **The leading edge of synchro-signal must be in advance before the leading edge of laser pulse on 100-150 ns.**

6)   Install optical unit of RINCON on the optical table horizontally approximately at the same height as the pump beam. Use low screws to adjust a level. The level of input beam outlet is 135+/- 5 mm (Fig.4).

7)   Before you get started you need to set the input radiation power. You should have a possibility to change the input power gradually. We recommend you to start with input radiation energy **60 – 70 μJ** .

8)   Remove the protective gag from the input hole inside the box (Fig.5).

9)   Direct the beam through the apertures D1 and D2 (see. Fig.1). Flip the diaphragms D1 and D2 to "down" state. Insert a visualization IR card after

the D2 (Fig.6). Let the beam pass through the D2 so that a dark dot (from a beam diffraction on D1) must be on the center of the beam spot after D2.

10) Turn on control unit and set the filter wheel in position №3 (See 6) Measurement procedure).

Fig.5. Protective gag on the input hole.

Fig.6. Diaphragm D2.

11) Insert the piece of white paper before the separator S2.

12) The delay line must be in "0" position (far edge of carriage should point on the mark "0").

13) Move RR (**turn off the control unit before**) rotating the stepping motor1 handle in clockwise and anti-clockwise directions approximately on ±5 mm.

14) If the TH doesn't appear then turn on the control unit. The filter wheel will be set in position № 1.

15) Try to detect TH signal by eye moving the delay line handle. *If you still have a problem with TH signal detection contact us for further help instructions.*

16) Check that the TH beam reflects from the mirrors M9 and M10 and passes through the lens L1 freely.

17) Be sure that the TH spot is not cut off on the aperture D3. Shift the D3 if it necessary (Fig.7). At the same time check that the SH signal doesn't propagate through the D3 at all.

18) Open the small black box and check that TH beam passes through the S2 freely, reflects from a mirror M12 and then check that it is incident on the center of the aperture D4. Adjust the M12 if it is necessary.

19) Now the box is installed and you can go to signal measurement with the knowledge of software description.
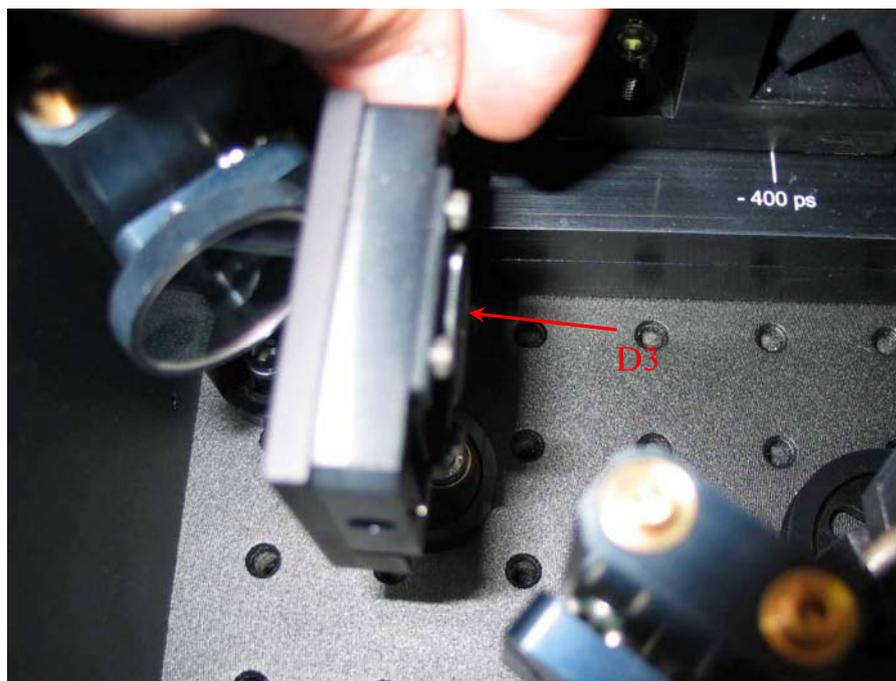
Fig.7. D3 aperture.

5. WORKING WITH SOFTWARE AND HARDWARE

5.1. Software installation

Device software consists of Contrastmeter software and drivers. Electronic control unit connects with the computer via USB 1.1 interface. For proper work of software we recommend you to install it on a computer with the configuration not worse than following:

CPU	Intel Pentium III $\geq$500 MHz
RAM	$\geq$256 Mb
Video buffer	$\geq$16 Mb
Free space on hard disk	$\geq$5 Mb
Operating system	Microsoft Windows XP
Video mode	1024x768x24 , Small Fonts.

1)   There are two parts of software on the CD: drivers and main program. Copy directory \Drivers\ to your directory on a hard disk.

2)   Connect the control unit with your computer via a USB cable. Turn on the control unit.

3)   When the computer indicates that it finds a *New Hardware*, point path to a directory with drivers and follow the installation instructions.

4)   Launch *Setupe.exe* (main software) and follow installation instructions.

If the software is installed successfully, it will find the hardware automatically.

5.2. Settings

Main menu contains all functional potentialities of the hardware. It contains four sub-menus (Fig.8).

The sub-menu "File" can be used for saving and opening project files and for exporting and printing the data.

Sub-menu "Device" contains commands calling settings dialog frames including: 1) settings and 2) adjustment.

All commands in sub-menus are duplicated on "Control panels".
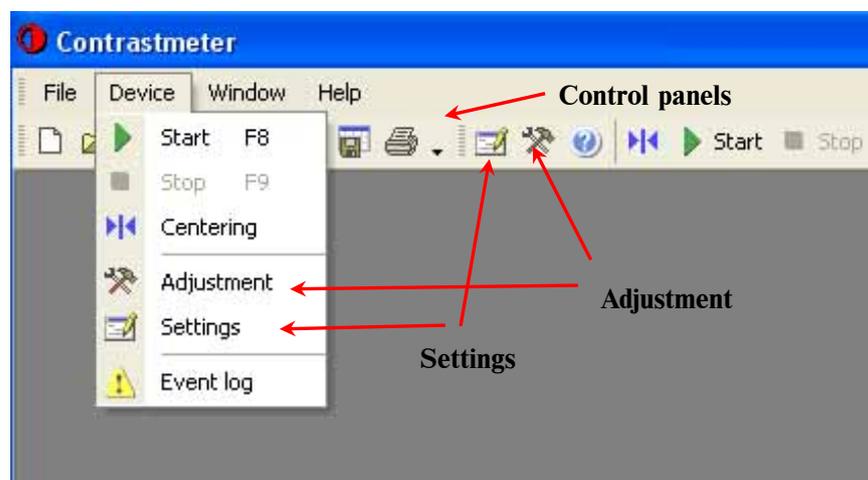
Fig.8. Main software frame.

Before getting started you need to specify hardware preferences that given in "Settings" (see Fig.9).

Length is a total range of delay line given in the motor steps. It equals to a total number of the motor steps from initial limit switch to final limit switch. It is obtained from calibration (see 6 "Measurement procedure").

Zero position is a number of motor steps from initial switch to position where the maximum of signal is achieved.

Step motor period, ms, is a time between driving pulses applied to stepping motor in delay line. **Strongly recommended value is 2 or 3 ms.**
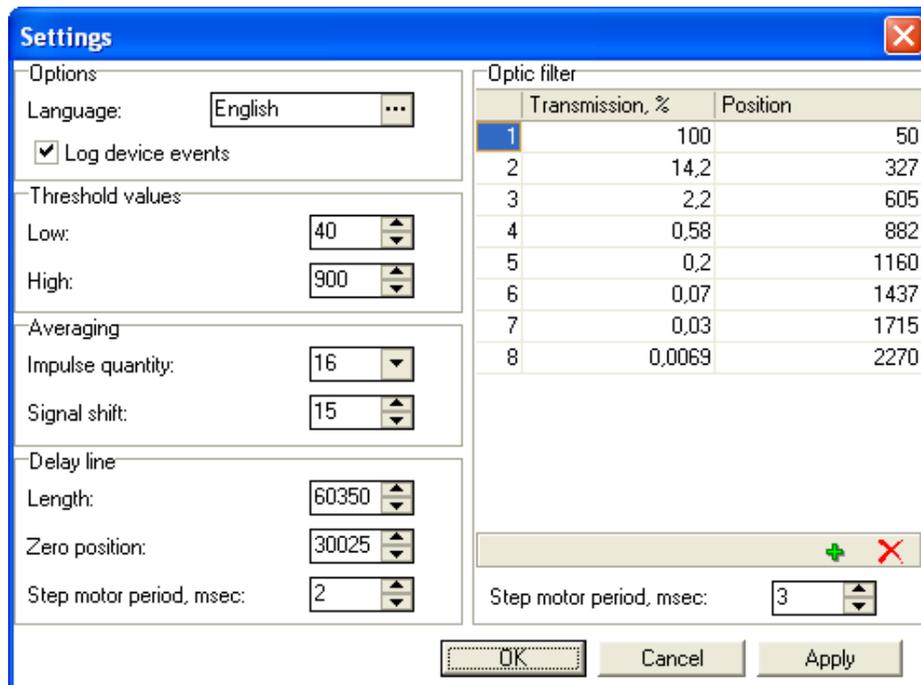
Fig.9. Settings.

Transmission of optical filter, (%) are attenuator transmittance values for each position in the set. Each position is given in steps from initial limit switch.

You need to make calibration each time when you are going to test another system or the wavelength of you system changes. **See Appendix A for calibration procedure description.**

Step motor period of optic filter, ms, is a time between driving pulses applied to stepping motor in filter wheel. **Strongly recommended value is 3 ms.**

Low threshold and high threshold are the values that limit real signal. Recommended values are **40** and **900-920**, respectively.

Averaging impulse quantity. The number of measurements made on each step of delay line. It is determined by the repetition rate of your laser system and the scale of laser fluctuations.

Signal shift is a positive shift of delivered signal. It is property of electronics and it is should be maintained as **15**.

Log device events, allows the log read in file.

English (Russian) you can choose appropriate language.

18
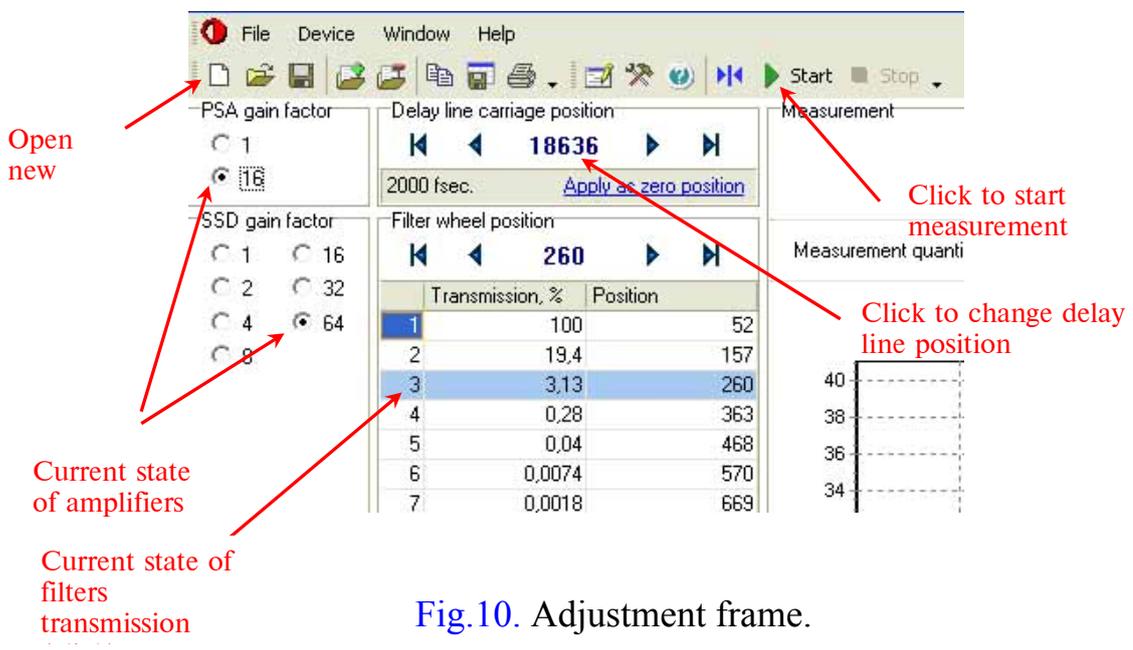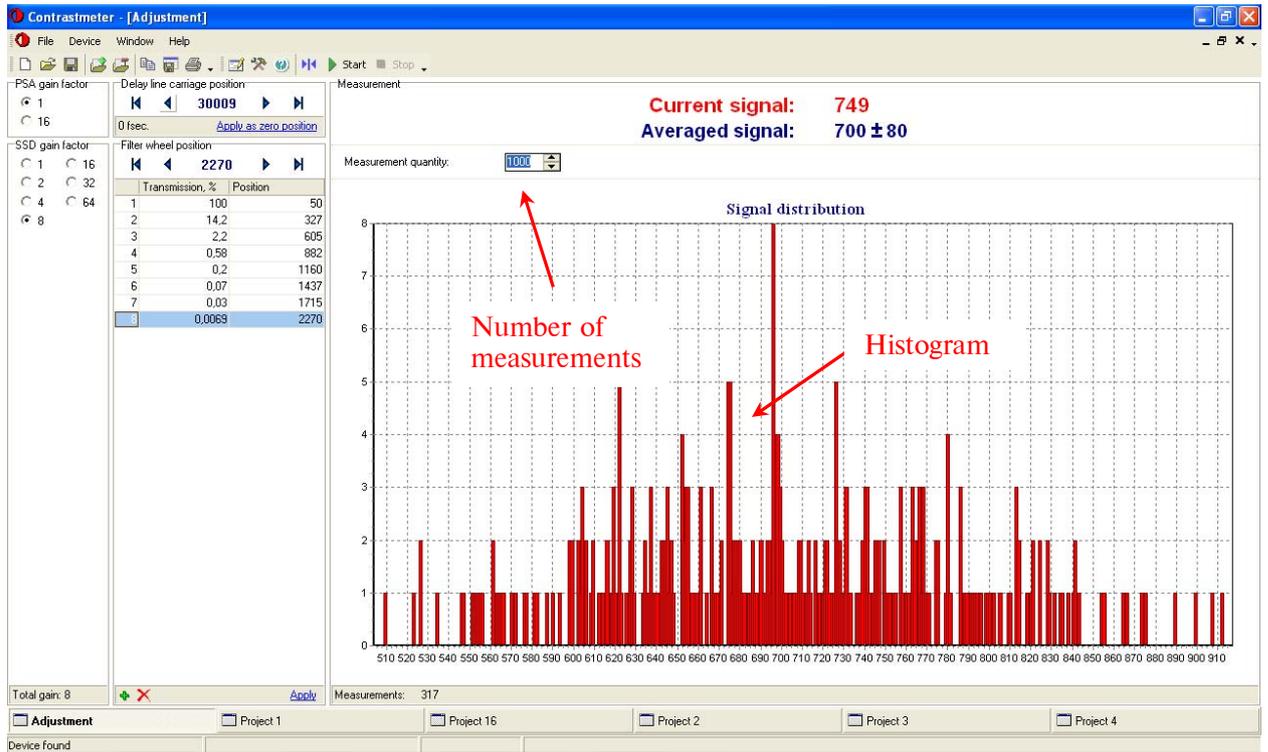
5.3. Adjustment

Fig.10. Adjustment frame.

This mode should be used for alignment. Its panel contains further options:

Signal level is delivered from the output of analog-digital converter (ADC) in the range from 12 to 1000 units. There are two amplifiers -- photosensor array (PSA) amplifier and storage-selection device (SSD) amplifier – and attenuator

wheel with 7 positions of attenuation. PSA gain has two discrete values (1 and 16); SSD gain has 7 discrete values (1, 2, 4, 8, 16, 32, 64). So total gain varies from 1 to 1024.

You can measure signal at any delay line position. Click on the central bar at the carriage position panel (see Fig.10) and set the number of delay line steps or value in *fs* where you want to move delay line. The button ▶ moves delay line on one step and the buttons ◀ and ▶ move the carriage to initial or final limit switch, respectively.

Button "Start" start measuring the signal level. You can see histogram of signal (dependence of measurements number on signal level) on the screen. Button "Stop" stops the measurement.

5.4. Scanning

Scanning mode is a main mode of the software (Fig.11). In this regime dependence of the contrast ratio on the delay time between fundamental and second harmonic pulses is obtained. To start measuring open a new project. *Initial shift, Final shift* (delay) are set in *fs*. *Step* is set in units of motor steps. Motor step is equal to 16.6667 fs and is fixed (Fig.12). Press button "Start" to make a contrast measurement. Software will start the scan. It will automatically change the amplifiers gain or attenuator wheel transmittance when the signal goes beyond thresholds. Contrast ratio is shown in dB. During the measurement, step by step, the signal is normalizing on the local maximal value of signal. Generally speaking, each local maximum will be normalized on unit 1.
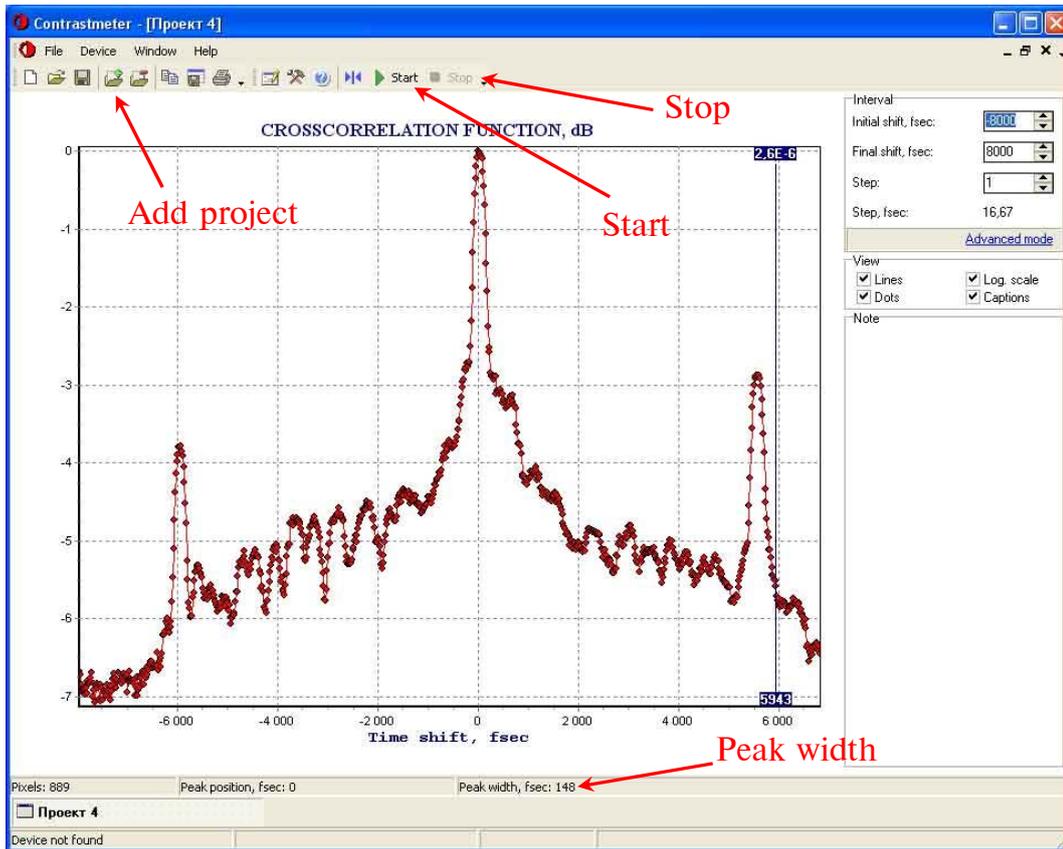
Fig.11. Scanning mode.
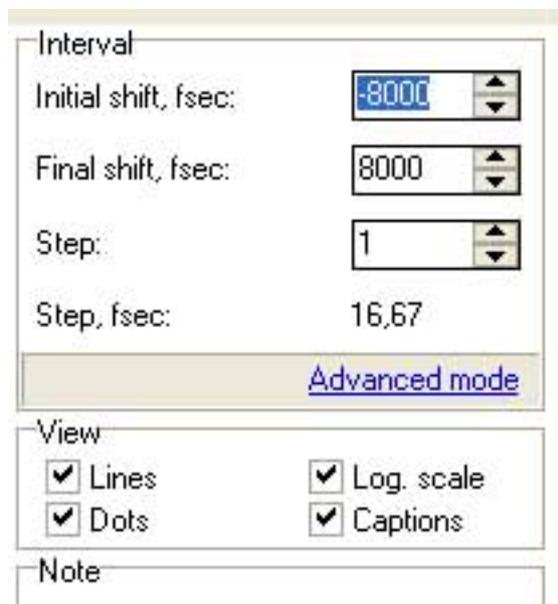
Fig.12. Simple sequence of delay shifts.

Fig.13. Advanced mode of delay shifts.

Advanced delay line sequence is switched when you click "Advanced mode".

The values for advanced delay line sequence consist of initial delay time and group of simple delay line sequences that are defined by their own delay step and final delay time (Fig.13). Initial delay time for *i* sequence is a final delay time for *i-1* sequence. Delay line sequences must be specified in ascending order. To add or delete sequence you should click on green or red cross, respectively.

Advanced mode can be useful for detailing some regions in intensity-delay time distribution when the measurement takes a long time.

6. MEASUREMENT PROCEDURE

Before starting measurements you need to optimize TH energy.

1) If you detect TH signal by eye launch the "Contrastmeter.exe". Try to maximize TH signal with software.

2) Set all parameters in "Settings". You need calibrate a filter wheel (see **Appendix A**).

3) Switch to "Adjustment" mode. Set filter wheel in position №**8** (minimal transmittance) and set total gain factor as **8** or **16**.

4) Measure the signal. If it is lower than low threshold increase the gain factor. If it is higher than upper threshold decrease the gain.

5) Adjust vertical and horizontal screws of mirror M8 to achieve the maximum of the TH intensity (see Fig.14). **Do it very carefully!** Look at the current signal in an "Adjustment" mode frame.
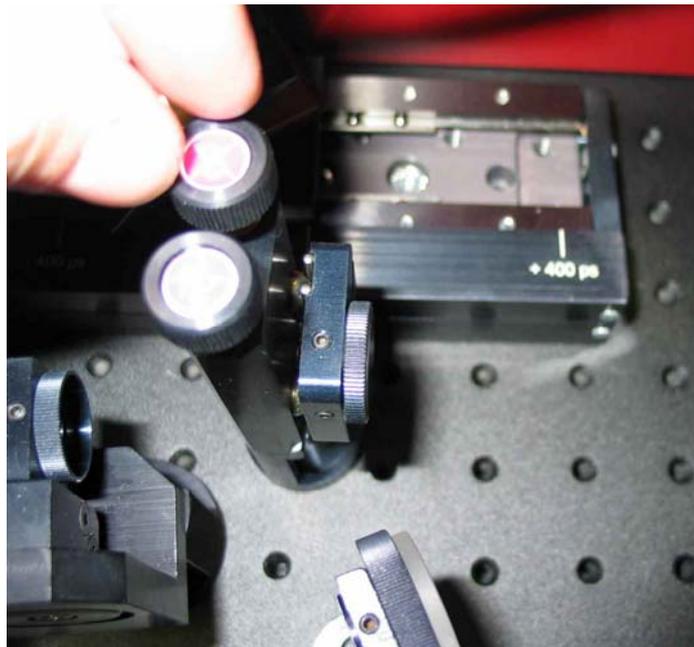
Fig.14. M8 mirror.

6) Adjust the screw of the THC mount to achieve the maximum of the TH intensity (see Fig.15).
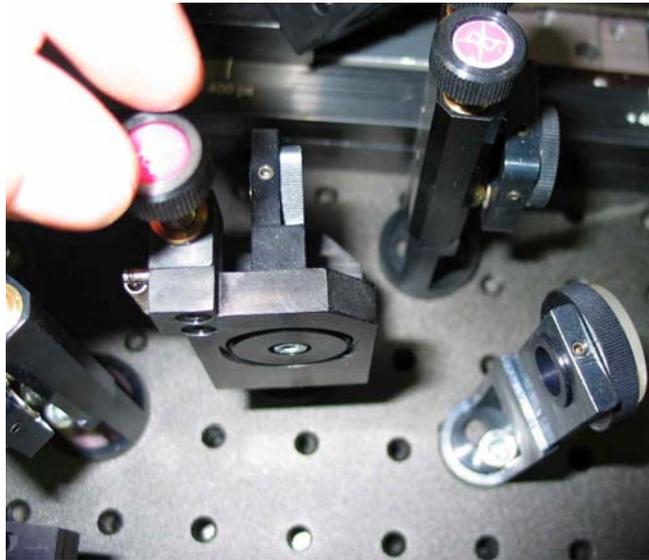
Fig.15. TH crystal.

7) Move delay line on several steps back or forward to get the maximal TH signal.

8) Adjust vertical angle of SH crystal to get the maximum of TH signal (see Fig.16).
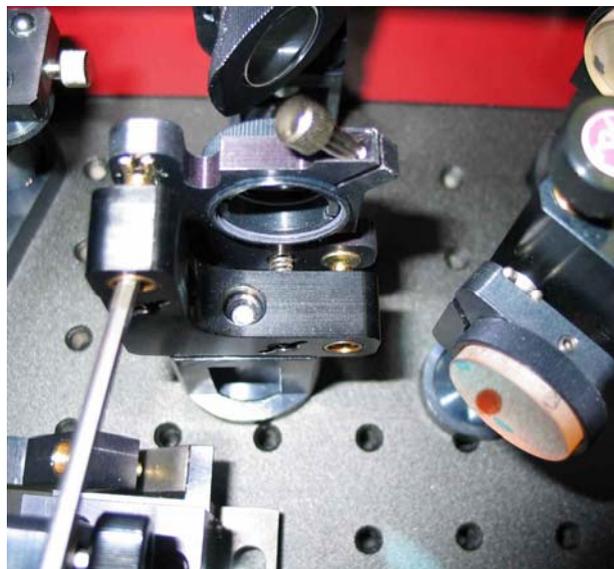
Fig.16. SH crystal.

9) Repeat steps 5), 6) and 7) until the maximum of TH is achieved.

10) Increase gradually the input energy of fundamental pulse till the signal achieve approximately 300-400 units (at filter wheel position № 8 and total gain factor - 4). **Don't increase the energy higher than 120 μJ!**

11) Click on "Apply as zero position" in the delay line frame.

12) *You don't need to make a delay line calibration because it was already done in Avesta Project*.

13) Now you can switch to the contrast measurements.

14) Open a new project. Set appropriate *Initial shift, Final shift* and *Step* or a sequence of delay line shifts (See 5.4) Scanning). We recommend setting the *Step* **2-3** for detailed scanning and **5-10** for rapid one.

15) Press the button ("Start"). Process can be interrupted if you press the right button "Stop". To continue the measurement press ("Start") again.

16) If the measurement finish save the file and/or export a data to *.dat* file.

17) Software remembers the delay line position when you turned off the control unit. So when you turns it on the next time the software will show you delay line position in which you left it.

Appendix A

Calibration of attenuator wheel.

1) **The value of filter positions must be maintained the same as on Fig.9.**

2) Shift delay line stage from "Zero position'' approximately on 2-4 ps.

3) Switch to "Adjustment mode". Set PSA gain factor as **1**, SSD gain factor as **8** (or **16**) and switch the filter wheel on the **1st** filter position. Set the attenuator positions as in "Settings" on Fig.9. **Don't modify them!** Set the **1st** transmission value as 100 %.

4) Measure the signal. The signal value must be approximately 300-600 units. If the signal is higher than high threshold, shift the delay line carriage away from "Zero position". If the signal is lower than low threshold then shift the delay line carriage closer to "Zero position".

5) Measure the signal again. Remember its value.

6) Switch the filter wheel on the **2nd** position (for instance, unknown xx% of transmittance). Then raise the SSD gain factor to **16 (or 32)** (if it is necessary) so that the signal value will be in the range from 200 to 600 units.

Transmittance of **2nd** filter can be calculated according to equation:

$$XX(\%) = \frac{S_2 G_1^{SSD} G_1^{PSA}}{S_1 G_2^{SSD} G_2^{PSA}} \times 100\%,$$

where S_1 – the signal at the **1st** filter, S_2 – the signal at the **2nd** filter, G_1^{SSD} G_1^{PSA} - SSD and PSA gain factor, respectively, at the **1st** filter, G_2^{SSD} and G_2^{PSA} - SSD and PSA gain factor, respectively, at the **2nd** filter.

7) Shift the delay line carriage closer to "Zero position" so that the signal at the **2nd** filter will be 300-600 units at SSD gain factor **8** (or **16**) and calibrate **3nd** filter according to **2nd** one.

8) Calibrate the other filters in the same way.

9) Write the attenuator transmittance values down to "Settings".

7. REFERENCES

1. J. Janszky, G. Corradi, R.N. Gyuzalian, *Opt. Comm* 23 (3), 293 (1977).

2. G. Albrecht, A. Antonetti, G. Mourou, *Optics Comm*. 40, 59 (1981).

3. H.Roskos, A.Seilmeir, W.Kaiser, and J.D. Harvey, *Opt. comm.*. 61, 81 (1987).

4. Y.Yamakawa, H.Shiraga, Y.Kato and C.P.J.Barty, *Opt. Lett*., V.15, 1593, (1991).

5. C. Danson et. al., *Opt. Comm*. 103, 392-397 (1993).

6. P.F.Curley, G.Carpentigny, G.Cheriaux, J.P. Chambaret, A. Antonetti, *Optics Comm*. 120, 71-77 (1995).

7. A. Braun, J.V. Rudd, G.Mourou at. al., *Opt. Lett*. V.20, No.18, 1889 (1995).

8. J.C.Diels, W.Rudolph, Ultrashort Laser Pulse Phenomena, *Academic Press*, Printed in U.S.A. (1996).

9. J.F. Ripoche, B. Prade, M. Franco et. al., *Opt. Comm*. 134, 165-170 (1997).

10. A. Kasper and K.J.Witte, *JOSA B*, v.15 No. 9, 2490 (1998).

11. J.Itatani, J.Faure et al., *Optics Comm*., 148, 70-74 (1998).

12. M.Nantel, J.Itatani et al., *IEEE Journal Sel. Topics Quant. Electr*., v.4,No2, 449-458 (1998).

13. J.Collier, C. Danson, C. Jonson, C.Mistry, *Rev. Sci. Instr*. 70 (3), 1599-1602 (1999).

14. M.Hentschel, S.Uemura, Ch.Spielman, F,Crausz et al, *Appl. Phys. B* 68, 145-148 (1999).

15. K.Osvay, I.N. Ross, J.M.D. Lister, C.J. Hooker, *Appl. Phys. B* 69, 19-23 (1999).

16. M. Aoyama, A. Sagisaka, S. Matsuoka, Y. Akahane, F. Nakano, K. Yamakawa, *Appl. Phys. B* 70, S149-153 (2000).

17. J.Collier, A.Hall er al, *Laser and Particle Beams* 19, 231-235 (2001)

18. M.Akiba, M.Fujiwara, *Opt. Letters* v.28, No 12, 1010 (2003).

19. F.Tavella, K.Schmid, N.Ishii, et al, *Appl. Phys. B* 81, 753-756 (2005).

20. K.-H. Hong, B.Hou, J.A.Nees. E.Power, F. Tavella, G.A. Mourou, *Appl. Phys. B* 00, 1-11 (2005).