DEL MAR PHOTONICS

FEMTOSECOND MULTIPASS TI:SAPPHIRE AMPLIFIER

Wedge 50

User's Manual

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1. INTRODUCTION

This manual describes installation and operation of Wedge 50 titanium : sapphire (Ti : sapphire) amplifier system. The system is based on a femtosecond confocal multipass amplifier configuration and consists of parts, shown in the Figure 1:

1. Pulse stretcher
2. Multipass Ti : sapphire amplifier
3. Pulse compressor
4. Pulse picker and Pockels cell driver
5. Synchronization electronics

The seed pulses used in the system originate from a mode-locked Ti: sapphire seed oscillator, model Trestles 50 is recommended. Before amplification, femtosecond pulses are stretched in time to avoid effects of peak power damage in high energy ultrafast amplifiers. Femtosecond pulses with pulse duration ≤100 fs are stretched to several tens of picoseconds before pulse selection and amplification.

To decrease pulse repetition rate, a Pockels cell is placed between crossed polarizers. This pulse picker system permits transmission of a single pulse during a <6-ns window that is synchronized with a laser through the countdown and synchronization unit. The countdown electronics receives 80 – 90 MHz signal from the output pulses of the Ti : sapphire oscillator and divides this rate to 1000 Hz according to the pulse repetition rate of Nd:YAG laser pumping the multipass amplifier.

After the Pockels cell, the pulse is injected into a two-mirror confocal multipass amplifier (MPA) that is effective device for amplification of femtosecond pulses in a Ti: sapphire crystal. After six, eight, or ten passes the seed pulse is amplified by a factor up to 10^6 and leaves the amplifier through the aperture in the output mirror. The pump radiation is focused by the lens through the aperture in the input mirror.

After amplification, the picosecond pulses are temporally compressed to 50 - 100 fs pulses (depending on the input pulse duration) by one-grating pulse compressor. At the pumping with a frequency doubled Nd: YLF pumping laser (1000 Hz, 20 mJ/ pulse), the compressor gives 1.0 mJ pulses at 800 ± 20 nm.

Wedge 50 femtosecond amplifier system comprises:
1) Optical unit of two-mirror confocal multipass amplifier with installed inside stretcher, pulse picker with HV Pockels cell driver, and pulse compressor.
2) Synchronization electronics unit.

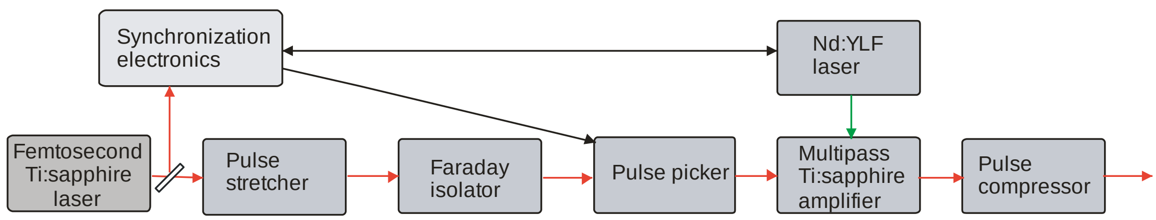


Figure 1. Wedge 50 femtosecond multipass amplifier system

2. PRINCIPLES OF OPERATION

Femtosecond Pulse Stretcher

Temporal pulse stretching is required in avoiding the effects of peak power damage in high energy ultrafast amplifiers. This peak power damage is due to the tendency of bright beams to self focusing (a result of non-linearity in the index of refraction), which makes it necessary to limit the intensity present in amplifiers. The technique of chirped pulse amplification (CPA) gives a possibility to avoid this obstacle. The idea of CPA is to stretch femtosecond pulse duration reducing peak power before amplification and to compress pulse duration back to femtoseconds after the amplification. A principal scheme of femtosecond pulse stretcher is shown in the Figure 2. This is purely optical device containing diffraction grating, spherical mirror and plane mirrors. Femtosecond pulse going into pulse stretcher has a broad bandwidth. For a 100 fs Gaussian pulse the corresponding bandwidth is about 9 nm. A diffraction grating sends different frequencies in different directions at different angles of diffraction shown in the Figure 2 for long wavelength (shown as red) and short wavelength (shown as blue) spectral components of femtosecond pulse. After double pass, bluer and redder components exit the stretcher as shown in the Figure 2. One can see from the figure that bluer frequency components have to travel further through the stretcher than the redder frequency components. The result is that the redder frequency components exit the stretcher first, the pulse has been stretched.

In the Wedge 50 pulse stretcher the input pulse is dispersed in the horizontal plane. The stretched pulse is directed back to the stretcher with help of vertical retroreflector, and four passes through the stretcher are achieved. Four-pass configuration is necessary to ensure that the stretched beam is spatially reconstructed. Femtosecond pulses with pulse duration $\leq$100 fs are stretched to more than ten picoseconds pulses before amplification. High reflective gold coated holographic grating gives stretcher efficiency higher than 50% for specific wavelength regimes.

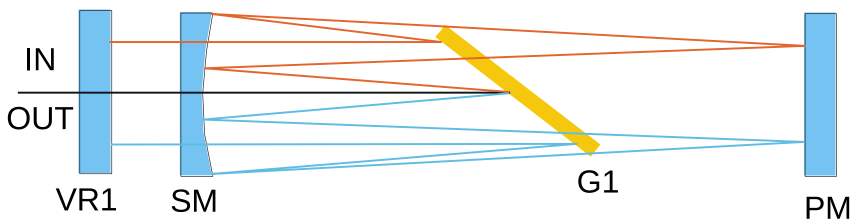


Figure 2. Femtosecond pulse stretcher

Femtosecond Pulse Compressor

The pulse compressor was designed for compression of picosecond pulses amplified by Wedge 50 multipass Ti: sapphire amplifier to pulses as short as 50-100 fs. The principle of pulse compressor operation is shown in the Figure 3. One can see that in contrast to the pulse stretcher, redder frequency components have to travel further through the compressor than the bluer frequency components. The result is that the pulse has been compressed. Varying distance between the gratings, the compression can compensate the stretching precisely giving almost the same pulse duration as obtained from the seed laser pulse. The Figure 3 shows a simplified pulse compressor. In the Wedge 50 pulse compressor some other optics are involved, i.e. horizontal and vertical retroreflectors give a possibility to use one grating and to achieve four-pass configuration. High reflective gold coated holographic grating gives stretcher efficiency higher than 50% for specific wavelength regimes.

Femtosecond Confocal Multipass Ti:sapphire Amplifier

The confocal multipass amplifier has been designed as an effective device for amplification of femtosecond pulses in different active media. Our unique design features two confocally placed concave mirrors of different radii of curvature (ROC) with central holes (Figure 4). This telescopic configuration provides six, eight, ten passes of the light beam through the common focus where Ti : sapphire crystal is placed. Due to different focal lengths of the mirrors, beam cross section is decreased after each pass and the beam waist diameter is increased accordingly. On the sixth pass the beam waist diameter is about four times more than on the first one. This is an important condition for getting the maximum gain, and one cannot find this feature in other multipass or regenerative amplifier systems. The pump radiation is focused by the lens through an aperture in the input mirror.

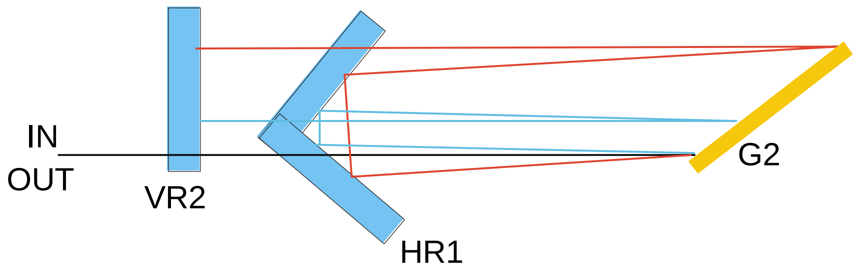


Figure 3. Femtosecond pulse compressor

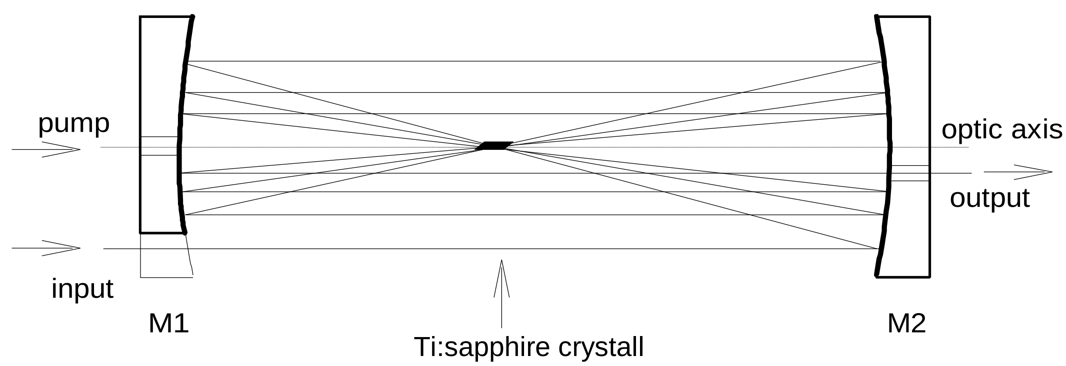


Figure 4. Optical schematic of two-mirror confocal multipass Ti : sapphire amplifier

Pulse Picker

A pulse picker installed in the Wedge 50 femtosecond amplifier system is used for one pulse selection from a train of stretched pulses. As a result, seed pulses are formed for the amplification. The pulse picker utilizes well known electrooptical Pockels effect. Pulse train having horizontal polarization goes through the Pockels cell. Without applied voltage pulses do not change polarization and exit pulse picker with help of polarizers as shown in the Figure 5. When half wave voltage is applied to the Pockels cell, an input pulse changes its polarization from horizontal to vertical, goes through polarizer and is used as a seed pulse for the amplifier. Applied voltage is synchronized with femtosecond pulse train and Nd:YLF pump pulses, and seed pulses have pulse repetition rate equal to the repetition rate of Nd:YLF pump pulses. Input polarizer is used to increase polarization ratio for input pulses.

Synchronization Electronics

The unit is designed to trig high voltage window applied to the Pockels cell and to synchronize this window with pump pulse and femtosecond pulse train. The aim of synchronization is to select one femtosecond pulse from train and to amplify it at the maximum pump efficiency. The schematic diagram is shown in the Figure 5 and the unit description is in the Section 5.

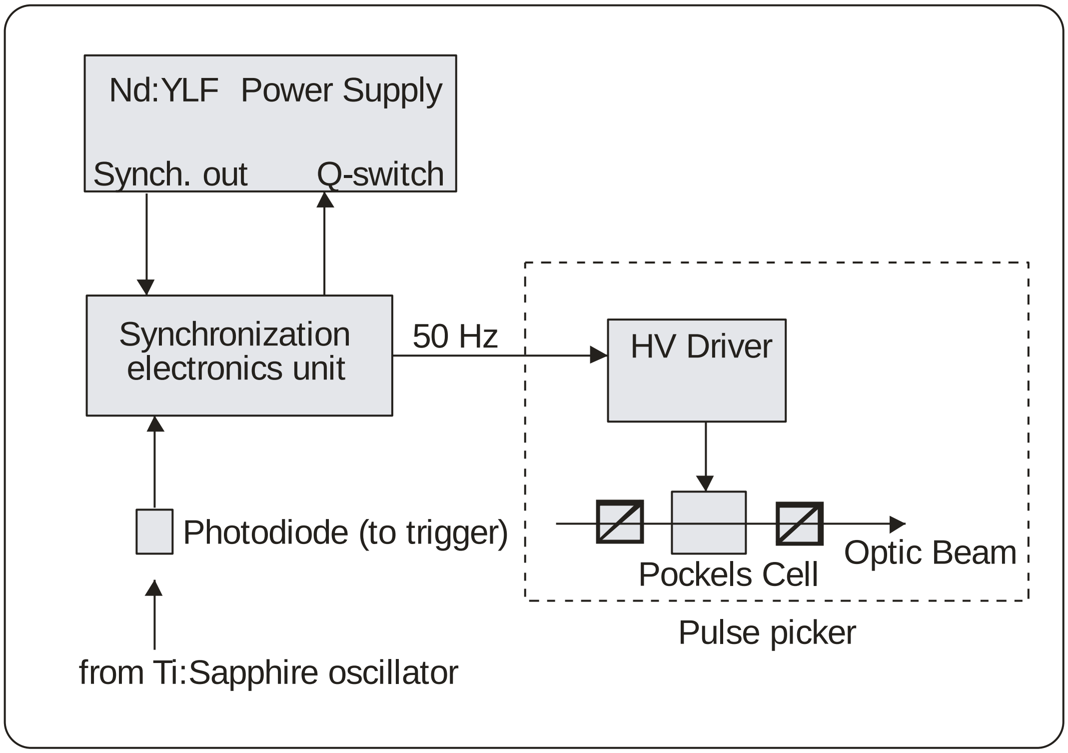


Figure 5. Pulse picker and synchronization electronics.

4. LASER SAFETY

Please read next page carefully before you start an installation

WARNING ! LASER SAFETY

Be very careful executing any step of alignment. Avoid any exposure to the directed and reflected laser beams. Direct and reflected laser radiation from pump lasers and Ti: sapphire amplifier can cause serious eye damage. Remember, that Ti: sapphire radiation is invisible or looks like as red radiation of small intensity. However, it is dangerous even at lowest intensity. Even diffuse reflections are hazardous. Check all reflections during alignment procedure and provide enclosures for beam paths whenever possible. Intense incoherent luminescence is emitted from the Ti: sapphire rod also.

Many reflections are from pump laser. Please use safety instructions of your pump laser and use their recommendations in your work.

Wear protective goggles whenever possible.

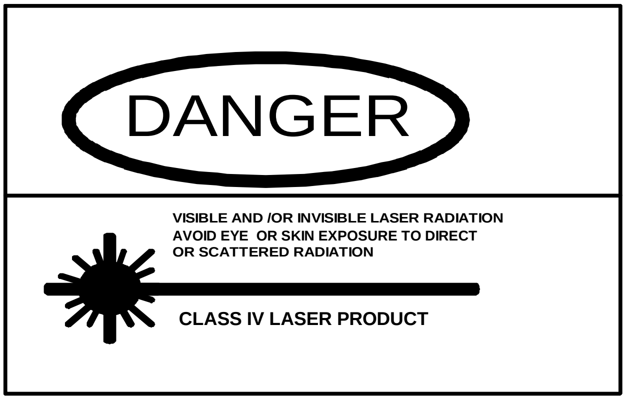
Keep all beams below eye level always. Never look in the plane of propagation of the beams.

When possible, maintain a high ambient light level in the laser operation area.

Provide enclosures for beam paths whenever possible.

Establish a controlled access area for laser operation.

Post prominent warning signs near the laser operation area:


DANGER
VISIBLE AND /OR INVISIBLE LASER RADIATION
AVOID EYE OR SKIN EXPOSURE TO DIRECT
OR SCATTERED RADIATION
CLASS IV LASER PRODUCT

4. OPTICAL ALIGNMENT

Figure 6 shows optical layout of the Wedge 50 amplifier system. Below you will find legends for all optical elements shown in the figure. These conventional signs will be used through the Chapter:

TIS – Ti : sapphire crystal
AM1 - spherical amplifier mirror
AM2 - spherical amplifier mirror
G1 - G2 - stretcher and compressor gratings, respectively
L1 - lens
SM - stretcher spherical mirror
PM - stretcher plane mirror
VR1- stretcher vertical retroreflector
VR2- compressor vertical retroreflector
HR1- compressor horizontal retroreflector
P1, P2, P0 - polarizers
PC - Pockels cell
M1 – M9 - mirrors, high reflectors at 800 nm
Y1 – Y3 – mirrors, high reflectors at 532 nm
A1 – A5 - apertures
BS1 – BS2 – beamsplitters
R – half wave plate
F – Faraday rotator

INPUT BEAM ALIGNMENT

1. Remove the rotation stages with gratings from the breadboard.
2. Operate the Ti : sapphire seed oscillator in continuous wave regime at 800 nm.
3. Input beam should be aligned through apertures A1, A2 and A3 at a beam height of 120 mm above the breadboard.

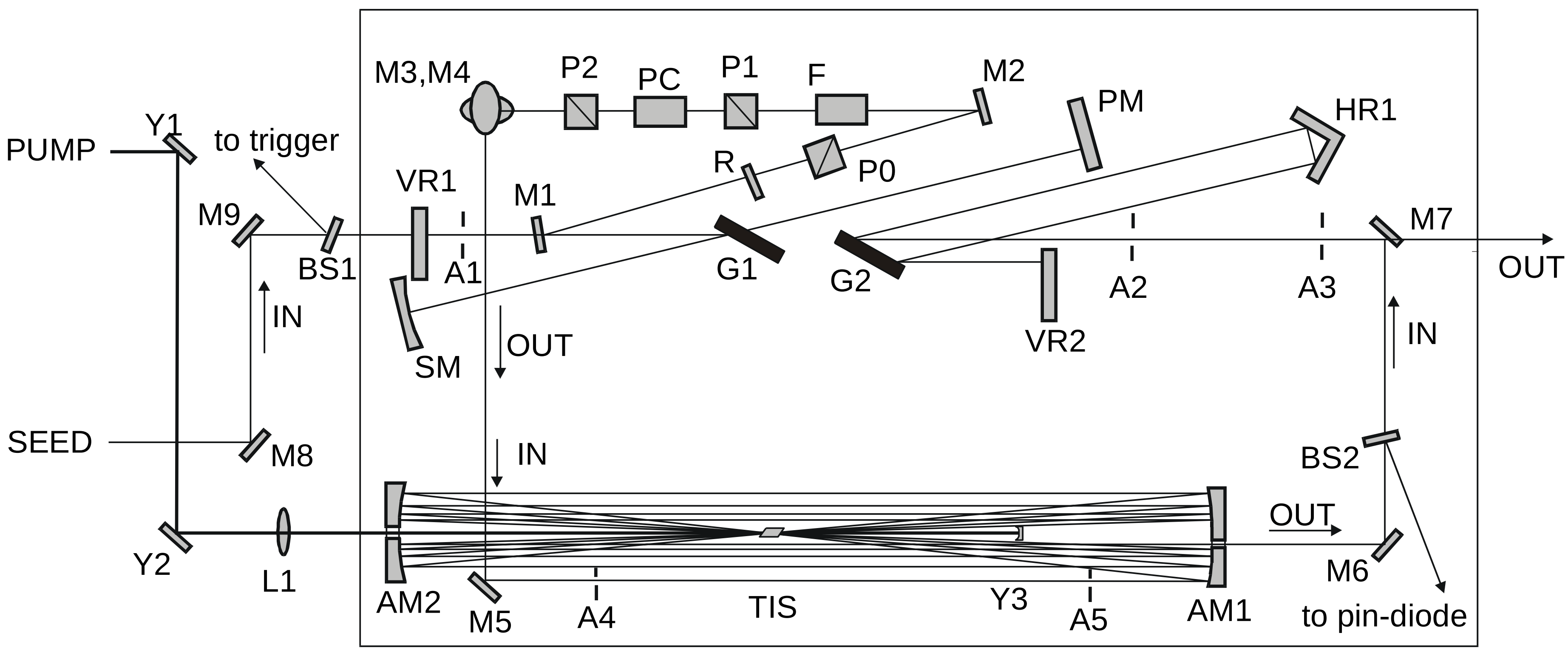


Figure 6. Schematic layout of multipass amplifier, pulse stretcher, pulse picker, and pulse compressor

STRETCHER GRATING ALIGNMENT.

1. Replace the rotation stage with the grating G1. Set position of rotation stage to “0”.

2. With rotation stage set so that the zero order beam from the stretcher grating goes back through aperture A1, adjust the vertical and horizontal tilts of the grating mount for best alignment to aperture A1.

3. Set rotation stage at 14 degrees for 800 nm. Littrow (auto collimated) diffracted beam should go back through A1.

4. If not, adjust rotation of the grating about it’s face for best vertical alignment to the A1. These is done by carefully loosening the retaining screw in the grating mount so that the grating holder can be rotated in the mount . **Caution: grating holder can fall from tilt stage if this step is not performed carefully or if retaining screw is too loose.**.

5. Reiterate between step 2 (adjust only the vertical tilt of the mount) and step 3 (adjust only the rotation of the grating) until no further adjustment is necessary.

STRETCHER MIRROR ALIGNMENT

1. Operate the Ti : sapphire laser in continuous wave regime at 800 nm.

2. Rotate stretcher grating angle so that first order diffracted beam hits the center of mirror SM. The beam height must be maintained at 120 mm. The distance from SM to the center of stretcher grating G1 should be 35 cm. The angle between input and diffracted beams is equal 14 degrees (rotation stage position should be approximately at 21 degrees).

3. Adjust mirror SM, so that reflected beam hits the center of mirror PM. The distance from the mirror SM to the mirror PM should be 70 cm.

4. Adjust mirror PM, so that reflected beam hits the mirror SM at the height of approximately 114 mm. The second reflected from SM beam will hit the stretcher grating at the height of 114 mm. The second reflected from G1 beam hits the lower mirror of the stretcher vertical retroreflector VR1. Exiting retroreflector, the beam hits the G1 at the height of 126 mm and reflected beam hits the SM at the height of 126 mm, too. The

third reflected from the SM beam hits the PM. The reflected from the PM beam hits the SM at the height of 108 cm. The fourth reflected from the SM beam hits the G1 at the height of 108 cm, too. The fourth reflected from the G1 beam hits the mirror M1. Radiation pattern on the stretcher grating G1 is shown in the Figure 7:

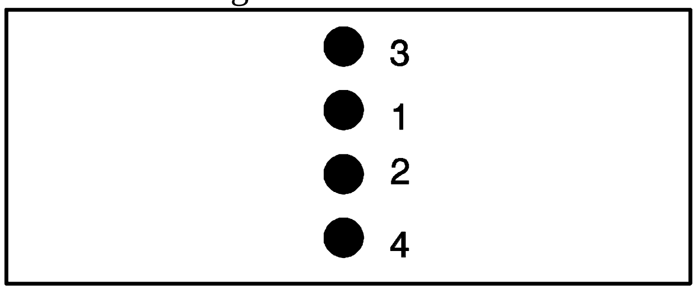


Figure 7. CW radiation pattern on the stretcher grating

If the spot No 3 is not aligned vertically with one another, a small horizontal rotation of the VR1 should be done. When the Ti:Sa laser is mode-locked, pattern seen on the G1 is shown in the Figure 8:

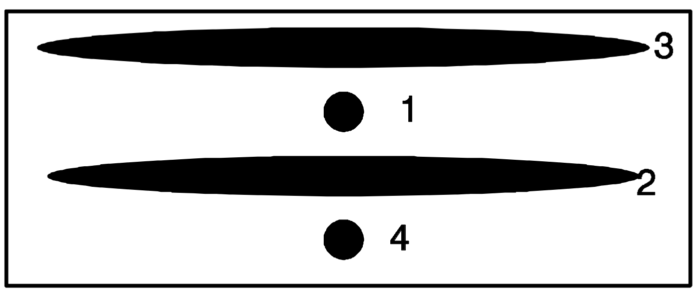


Figure 8. Femtosecond radiation pattern on the stretcher grating

PLANE MIRROR (PM) ALIGNMENT

You must check a view of the reflected from M1 beam on a distance about 3 m. If you moved the PM translation stage, the shape of the beam is changed. You must find the position of the PM when the beam spot is round. Two spots observed on the PM should coincide in case of perfect stretcher alignment. The stretcher alignment is finished with this procedure.

FARADAY ASSEMBLY ALIGNMENT

1. Direct the beam through R, PO. Do the clamp of R more weaker. Rotating R measure the average power behind PO

(PO has been installed at 45^o position). Get maximum of the average power. Press the clamp of R.

2. Direct the through F with help of M2.

PULSE PICKER ALIGNMENT

1. Remove Pockels cell PC and polarizers P1 and P2.

2. Adjusting M1, direct beam reflected by M1 to the center of M2.

3. Adjusting M2, direct beam reflected by M2 to the center of M3 and M4. Mirrors M3 and M4 serve for 90^o polarization rotation.

4. Replace P1 and adjust it. The input beam should hit the center of P1. P1 should be oriented for transmission of light having horizontal polarization.

5. Replace P2 and adjust it. The input beam should hit the center of P2.

6. Place white screen (white paper sheet) after P2 and observe transmitted by P2 light with IR viewer. Mark spot position by a pencil.

7. Rotating P2 find minimum transmutation.

8. Replace PC and adjust it. The input beam should hit the center of PC.

9. Place a sheet of scattering paper (for example, a sheet of optical cleaning paper) between P1 and PC.

10. With help of IR viewer observe on the screen a spot of the transmitted light. The spot looks like dark cross. Adjusting PC, coincide the center of the cross with the mark on the screen.

11. Remove the scattering paper.

12. Achieve minimum light transmutation through P2 by fine adjustment of PC.

AMPLIFIER ALIGNMENT

1. Place a half wave plate between P1 and PC or between PC and P2.

2. With help of M4 and M5 direct the beam into apertures A4, A5. Remove A4, A5. In case of aligned amplifier go to step 16. Go to step 4 if it is necessary to make amplifier alignment.
3. With help of M3 and M4 direct beam onto left side of M5.
4. With help of M4 and M5 direct beam parallel to the breadboard at the level 132 mm above the breadboard.
5. Place amplifier mirror AM1 (R=1000 mm) and AM2 (R=830 mm) at the distance 915 mm between metal clamps. The distance between AM2 and M5 should be 10 cm.
6. Set AM1 hole centers at the same level above the breadboard as the beam level. AM2 hole center is at 142 mm.
7. With help of M5 direct the beam onto AM1 to a distance 18 mm from the edge of the AM1 hole to the center of the spot.
8. With help of AM1 direct reflected beam to the right side of AM2 to a distance 17 - 18 mm from the symmetry center of the AM2 to the center of the spot.
9. With help of AM2 direct reflected from AM2 beam parallel to the M5-AM1 beam (47 mm distance between beams). After this step, multipass beam configuration will be aligned automatically. Six-, eight-, or ten-pass amplifier configuration is determined by the distance from the center of the M5-AM1 beam spot to the edge of the AM1 hole.
10. With IR viewer watch six (eight) beam spots on mirrors AM1 and AM2 (Figure 9).

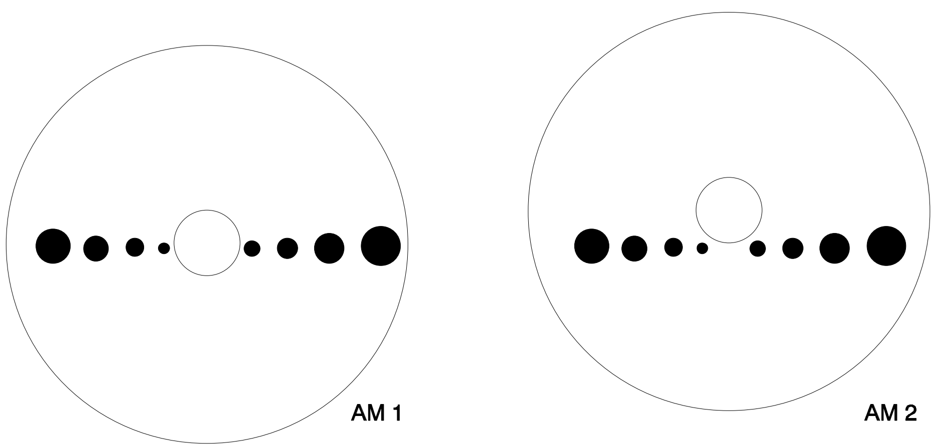


Figure 9. Radiation pattern on mirrors AM1 and AM2

11. Moving narrow paper strip through beams between AM1 and AM2 find common for AM1 and AM2 focal point.

12. With horizontal control of AM2 tune the beams configuration to get 40-41 cm distance between AM2 and common focal point.

13. Place the titanium : sapphire crystal assembly to the common for AM1 and AM2 focal point. A movement of the lowest translation stage should be parallel to the M5-AM1 beam.

14. Aligned multipass configuration will be broken after the step. By horizontal control of M5 take all beams to one spot on the left surface of the titanium : sapphire crystal. After that, restore eight passes configuration slightly moving AM1 translation stage in a direction "to the user", and simultaneously adjusting horizontal control of AM1.

15. Using controls of Ti:sapphire assembly and controls of AM1 and AM2 get that:

a) Going to the crystal input beams should intersect in one and the same point on the crystal surface (use microscope).

b) Going through the AM1 hole output beam should not touch the edge of the AM1 hole.

16. With help of M6 and M7 direct the output beam to the pulse compressor.

17. Place substrate beamsplitter anywhere between M6 and M7 and direct reflected beam to *pin*-photodiode connected with oscilloscope for amplification control. Watch unamplified pulses.

COMPRESSOR GRATING ALIGNMENT.

1. Use mirrors M6 and M7 to align the beam though the apertures A3 and A2.

2. Replace the rotation stage with the grating G2. Set position of rotation stage to "0".

3. With rotation stage set so that the zero order beam from the stretcher grating goes back through aperture A3, adjust the vertical and horizontal tilts of the grating mount for best alignment to aperture A3.

4. Set rotation stage at 14 degrees for 800 nm. Littrow (auto collimated) diffracted beam should go back through A3.

5. If not, adjust rotation of the grating about it's face for best vertical alignment to the A3 by carefully loosening the retaining screw in the grating mount so that the grating holder can be rotated in the mount. **Caution: grating holder can fall from tilt stage if this step is not performed carefully or if retaining screw is too loose.**.

6. Reiterate between step 3 (adjust only the vertical tilt of the mount) and step 4 (adjust only the rotation of the grating) until no further adjustment is necessary.

COMPRESSOR ALIGNMENT

1. Use mirrors M6 and M7 to align the beam through the apertures A3 and A2.

2. Rotate compressor grating angle so the angle between input and diffracted beams is equal 22 degrees (rotation stage position should be approximately at 25 degrees). The input beam entering the compressor should be reflecting off the lower right corner of the compressor grating G2 before entering the horizontal retroreflector HR1, as shown in the Figure 10:

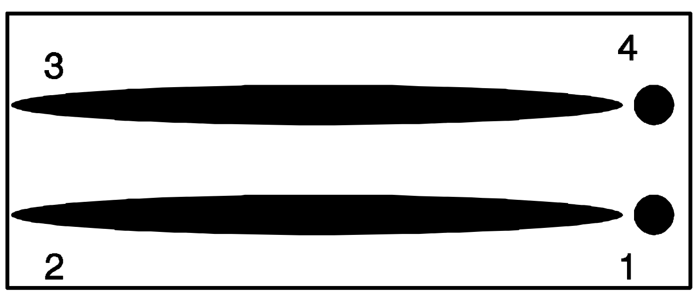


Figure 10. Femtosecond radiation pattern on the compressor grating

3. The HR1 should be reflecting the stripe onto the lower left side of the grating. If the side to side position is off, the lateral position of the HR1 can be adjusted by loosening bolts holding the HR1 assembly to the translation stage.

4. The first stripe should now reflect off the vertical retroreflector VR2 before reflecting off the grating G2 a third time. The third reflection on the grating should be a stripe on the upper left side of the grating directly above the first stripe. If the

height of this stripe requires adjustment, move VR2 in vertical direction by loosening two bolts.

5. The beam should now reflect off the HR1 a final time before reflecting off the upper right corner of the grating in the form of a spot. The beam should now be exiting the amplifier optical unit above the mirror M7 and through the output port. The height of the final compressed beam is adjusted with HR1 assembly.

6. The length of the compressor should be set by adjusting the horizontal retroreflector HR1 to be 30-32 cm from the grating to the apex. This should be adjusted further by minimizing the pulse width as measured by autocorrelator.By changing the angle of grating and adjusting the horizontal HR1, you can minimize the pulse width.

PULSE AMPLIFICATION

1. Place neutral filters before *pin*-diode to detect amplified pulses.

2. Switch-on pump Nd:YLF pump[laser for attenuated "free generation" operation (see Operation Manual for the pump laser).

2. With help of two external mirrors Y1, Y2 direct attenuated pump beam into amplifier through the center of the AM2 hole onto the Ti:sapphire crystal surface (to the point where amplified beams are intersected).

3. Place lens L1 into the pump beam maintaining the direction of the pump beam. A distance from L1 to the TIS (approximately 680 mm) is determined by an initial diameter and divergence of the pump beam. To find this distance watch with microscope a diameter of the pump beam on the crystal surface. It should be about 750 μ.

4. Set up concave mirror Y3, reflecting pumping beam back to the Ti:sapphire crystal. A distance between the mirror and Ti: sapphire crystal (approximately 205 mm) should be adjusted to give reflected pump beam waist diameter about 750 μ inside the crystal.

5. Switch-on 'Q-switch" operation of the pump laser. Set pump energy E_{pump} = 20 mJ.

6. Watch amplification with *pin*-diode and oscilloscope, slightly moving pump beam with external mirror.
7. Get maximum amplification slightly adjusting AM1, L1, Y3, and M5.
8. Pulse amplification is determined by amplification saturation level. An amplification saturation is highest when only 3-4 amplified pulses are detected with oscilloscope.
9. Check energy of amplified pulses at 8-pass amplifier configuration, E_{pump} = 20 mJ, and 750 μ pump beam diameter inside the TIS. Average power of a train containing 3-4 pulses should be not less than 70 – 80 mW after pulse compressor when 50 Hz pump laser is used.
10. Remove half wave plate.
11. Switch on the electronics unit.
12. With controls of the synchronization unit change a delay of the selected femtosecond pulse and achieve maximum amplification for the selected pulse. Average power of amplified pulses should be 50 – 55 mW when 50 Hz pump laser is used, and spontaneous emission should not be more than 8 – 10 mW at closed input for seed femtosecond pulses.