DESY SUMMER STUDENT'S PROJECT

Measurement of pulse front tilt.

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Contents.

Introduction.

Pulse front tilt is a phenomenon which is often connected with ultra fast lasers physics, particularly in the context of very broadband ultrashort laser pulses. Essential it means that the arrival time of an ultrashort laser pulses varies across the beam profile. (see Figure 1). In other words, there is a tilt between the pulse front and direction perpendicular to the beam [1].

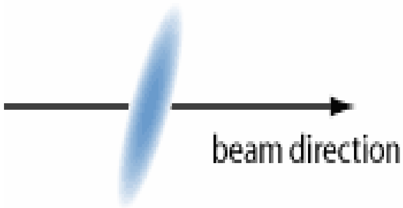


Figure 1. Schematic of an ultrashort laser pulse with a puls front tilt. The upper part arrives earlier than the lower part.

A pulse front tilt is closely related with angular dispersion, i. e., with dependence of the wavefront orientation on the optical frequency. It is thus somewhat problematic to explain pulse front tilt as an angle between the pulse front and the wavefront, because the wave front orientation is frequency depended. Note the pulse front tilt can also result from simultaneous spatial and temporal chirp.

Pulse front tilt can appear in different situations. For example, there is a strong pulse front tilt when a laser beam with ultrashort pulses is spatially dispersed by a prism or a diffraction grating. Propagation of an angularly dispersed beam will induce spatial chirp. Another example, angular chirp is easily produced by slight misalignment of standard pulse stretcher and/or compressor setup. Angular chirp leads to titled pulse fronts in the near field and to strong reduction of intensity in the focus [2]. This effect is rather difficult to observe with standard diagnostic techniques.

Experimental task.

My supervisor has idea to check the beam quality at the output of the Hidra (laser amplifier for femtosecond pulses) pumping an OperA Solo (optical parametric generator and amplifier), in particular to measure a possible pulse front tilt. On the one hand such information is valuable for any experiment using the Hidra pulses and one the other hand a large pulse front tilt could be the reason for bad performance of the OperA Solo.

A task for me was to measure pulsfront tilts of laser beams and to build and to test the setup for such a measurement.

We concentrated on the problem of angular chirp induced by small misalignments in a typical stretcher-amplifier-compressor system. Ultashort lasers pulses could not be amplified directly without producing unwanted non liner effects. The onset of self-focusing of intense light pulses limits the amplification of ultrashort laser pulses. The same problem arises in radar because of the need for short, yet energetic pulses, without having circuits capable of handling the required peak powers. The solution for the radar transmission is to stretch the pulse by passing it through a positively dispersive delay line before amplifying and transmitting the pulse. The echo is compressed to its original pulse shape by a negatively dispersive delay line.[3]

In the first CPA (Chirped Pulse Amplification) embodiment the laser pulse was stretched in an optical fiber (positive group delay dispersion) and compressed by a pair of parallel gratings arranged to provide negative group delay dispersion. Although this first demonstration had led to a spectacular 100 times improvement in the peak power, it had the problem that the stretcher and compressor were not perfectly matched- i.e., the dispersion of the compressor (gratings), was not perfectly equal and opposite to the dispersion of the stretcher (a fiber). Unfortunately, after compression the pulse exhibited unacceptable pre-pulses and post-pulses. Therefore, following the first CPA demonstration started to looked ideal “matched stretcher-compressor system”.

The solution came about when, in 1987, Martinez proposed a grating compressor that could be arranged to provide positive group delay dispersion for communication applications. In optical communication application the wavelength of choice is 1.5 μm, a region where fiber exhibits a negative chirp. It is therefore necessary to use a dispersive delay line with positive group delay dispersion to recompress the pulse.

After examining this device, people came to the conclusion that the Martinez “compressor” was in fact the matched stretcher of the Treacy compression that they had been seeking.

The phase conjugation of the two systems demonstrated for the first time by Pessot et all who stretched an 80 fs pulse by factor of 1000 (to 80 ps) using

Martinez grating pair and compressed it to its original pulse duration (80 fs) using the Treacy compressor. This demonstration represented a major step in Chirped Pulse Amplification. The matched stretcher/compressor concept was incorporated for the first time into a CPA system that was used to produce a Terrawat pulse from a Table Top System. This first system used picoseconds pulses, but sub picoseconds pulses and femtoseconds pulse durations quickly followed. This arrangement has become the standard architecture used in almost all CPA system today. (See Figure 2) [4]

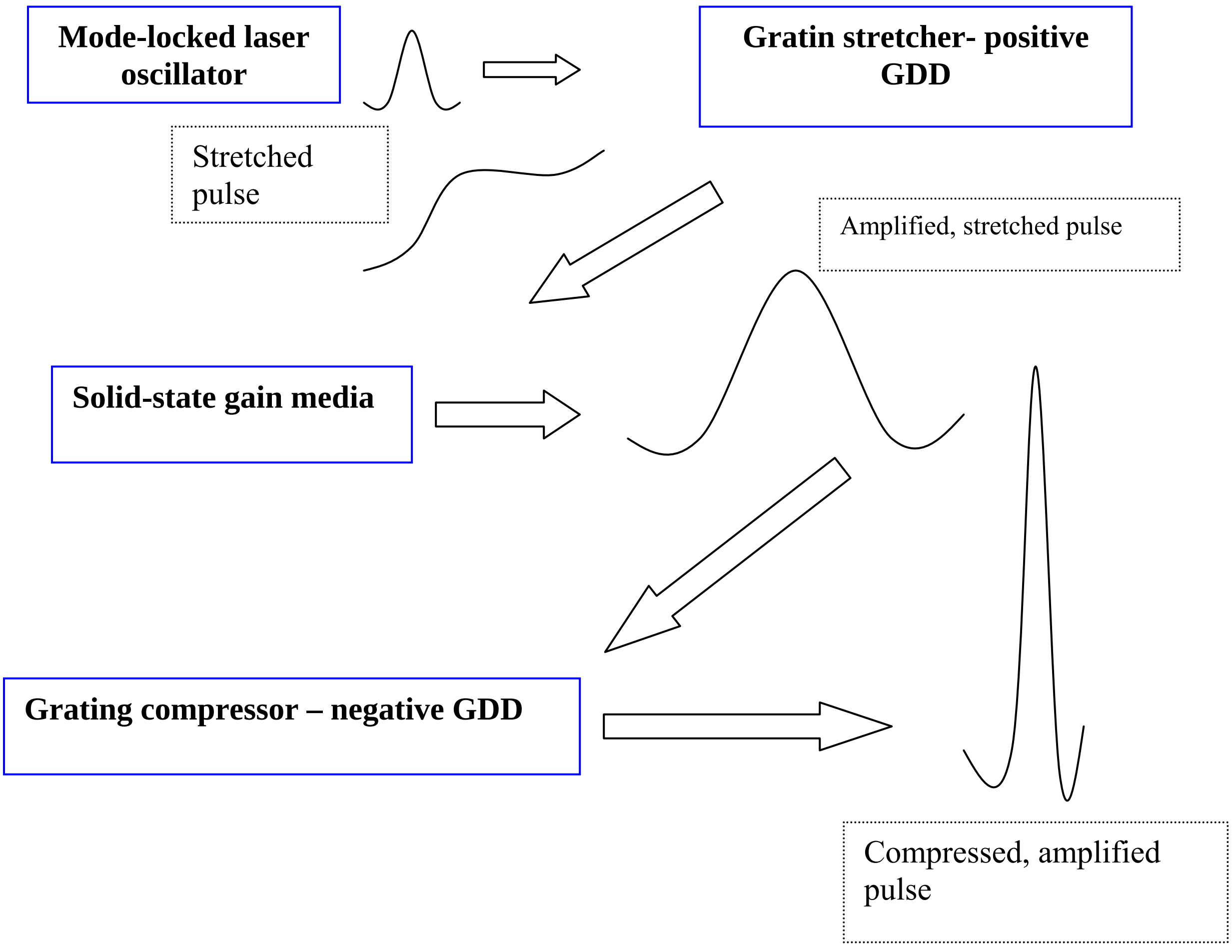
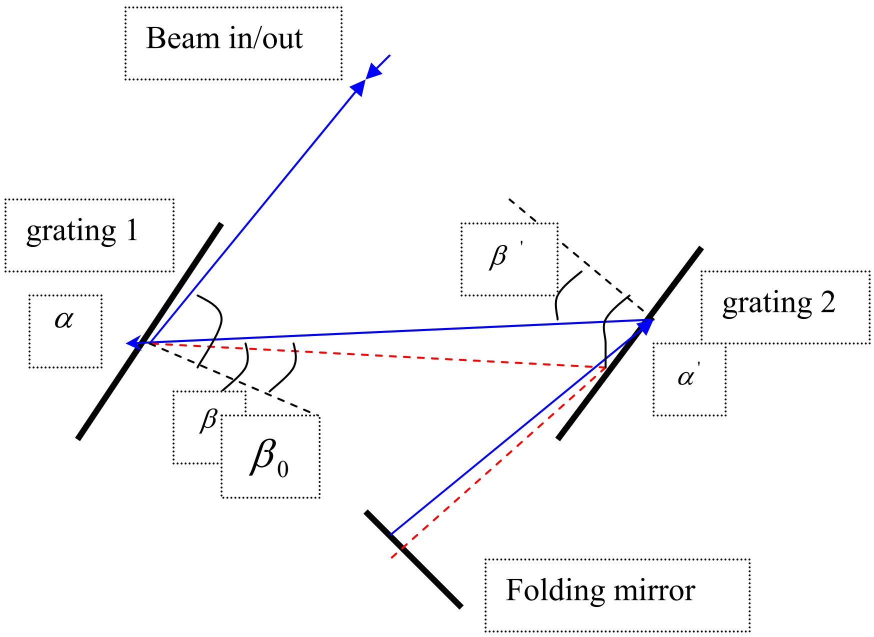


Figure 2. The chirped pulse amplification concept. To minimize the nonlinear effects the pulse is fist stretched several thousand times, lowering the intensity accordingly without changing the input fluence. The pulse is then amplified by a factor 10^6 to 10^7. The pulse is then compressed to its Fourier transform limit

Angular chirp from compressor and stretcher.

For angular chirp produced in CPA-laser pulse compressor we assume a standard double-grating/double-pass compressor (see Figure 3). If the two gratings are misaligned from exact parallelism, the angular dispersion produced by the first grating is not fully compensated by the second one and net angular chirp remains.



Figere 3. Double grating-double-pass pulse compressor as used in most CPA laser system. Incident and diffraction angles are indicated as well as gratin distance.

The stretcher is the complementary element to the pulse compressor and may also produce angular chirp when misaligned. Figure 4 shows the widely user standard stretcher geometry consist of grating, imaging elements (achromatic lens, spherical or parabolic mirror; focal length f, at distant d from the grating), and two folding mirrors. Each beam leaving the first grating with an angle β is sent on the second grating with an incident angle $\beta' = -\beta$ by a 1:1 telescope. Therefore, all spectral components leave the second grating with the same angle α'. If the mirror M_1 is moved from the focal point of the imagining element by a distance ε, the incidence angle β changes.

Even very small misalignments may lead to considerable pulse front tilts. [2]

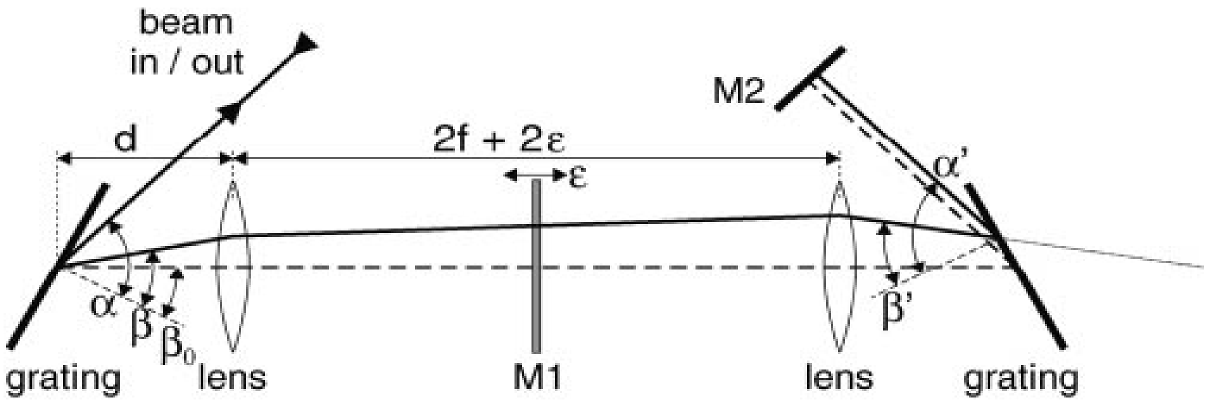


Figure 4.Standard CPA pulse stretcher consisting of one grating, one lens (or imaging mirror) and folding mirrors M_1 and M_2. Beams are reflected at the mirror M_1, and everything to the right of M_1 is virtual but shown for clarity. The incoming beam is spectrally decomposed at the grating and the components take different path through the arrangement.

Experiment.

We made our pulse front tilt visible with the help of a special interferometric field autocorrelator. In a standard autocorrelator, where the laser pulse is combined with its delayed but identical replica, a pulse front tilt remains undetected (see Figure 5.a) because the delay between the two pulses is the same at each position in the beam. The situation changes, however, if one of the two pulses is spatially inverted (see Figure 5.b): now the delay between the pulses depends on the position on the beam, if a tilted pulse is sent into the device.

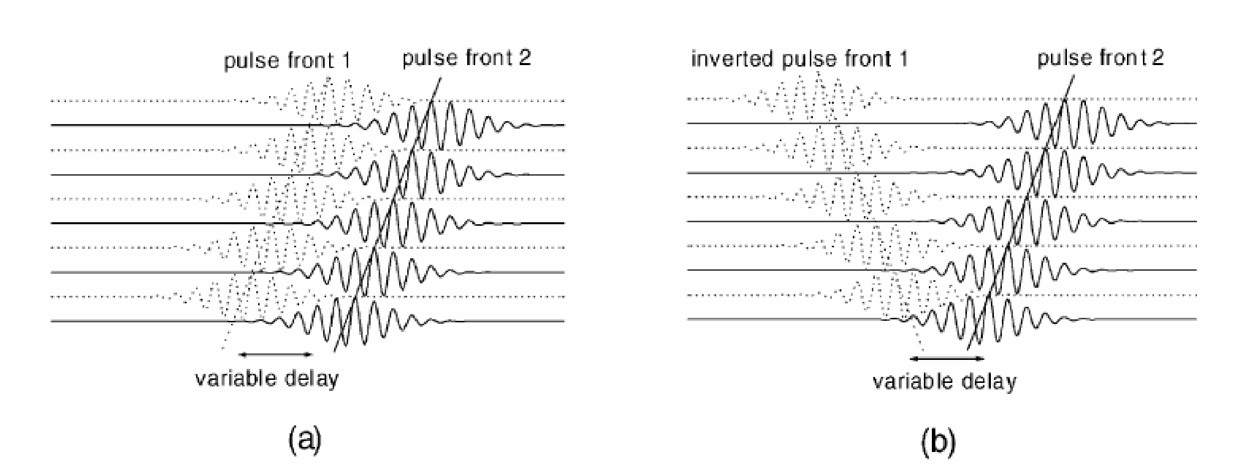


Figure5a,b. schematics of the pulse front overlap in a standard interferometric autocorrelator (a) and in interferometric autocorrelator with spatial inversion (b).

The most straightforward and intuitive way of detecting this position-dependend delay is analyzing the interference pattern created at the output of such an inverted autocorrelator (the two beams must be slightly tilted with respect to each other for producing interference fringes, but much less than the pulse front tilt to be measured, and normally this may be done in the plane perpendicular to the pulse tilt). Put simply, interference will only occur at such position on the beam where the two pulses overlap, and determining the spatial interference contrast function yields the pulse front tilt as shown below in detail. This detection principle is not sensitive to the actual pulse duration, but only to the coherence length. Thus, it dose not matter whether or not the pulse is chirped and it is possible to measure pulse front tilts of a few tens of femtoseconds over the cross section even in stretched pulses of a few hundreds of picoseconds duration.

To invert one beam of the autocorrelator with respect to each other we used a modify Mach-Zehnder-type interferometer. One arm is equipped with an additional folding mirror (see Figure 6).

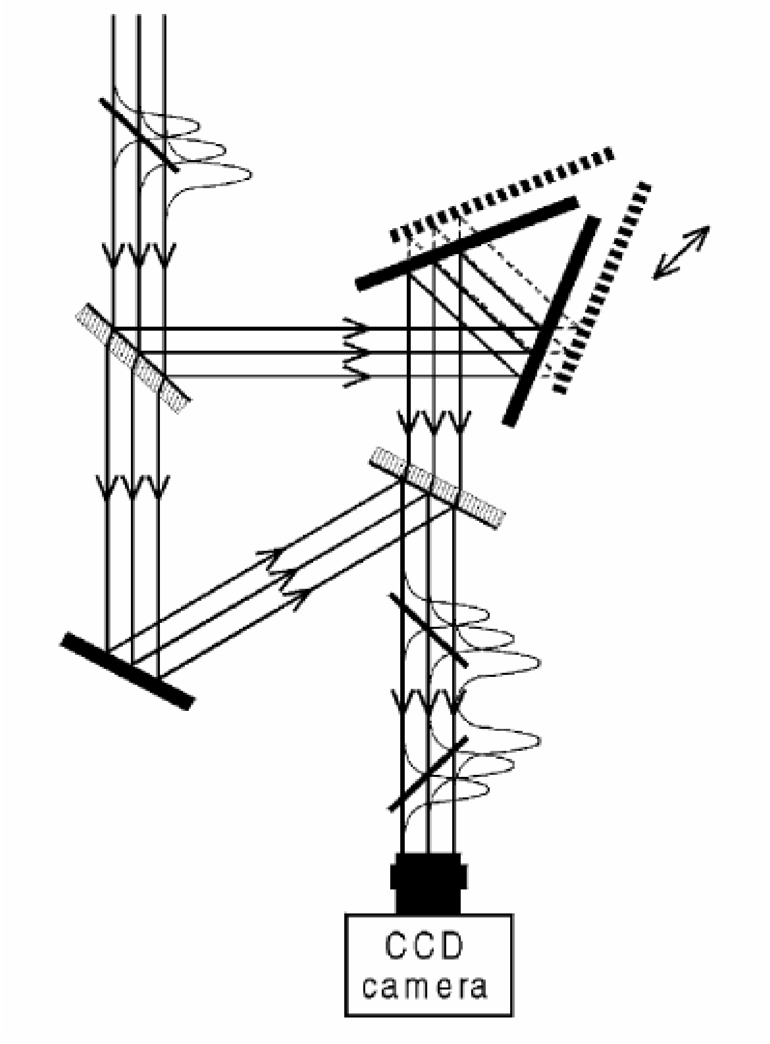


Figure6. a modified Mach-Zehndler-type interferometer, providing horizontal inversion of one pulse. This setup was used in this work.

Experimental device.

We calculated how the distance between moving mirrors are linked with the angle between them and the length of interferometer arms. We assume that our interferometer has an axis of symmetry. Further, making a simple geometrical transformation, we get the following relation:

$$\frac{l}{k}=\frac{(\cos\alpha+1)}{\cos\alpha(1-tg\alpha)}$$

l - length of interferometer arm,

k - distance between mirrors,

α - angle between mirrors.

This equation shows:

1. the angle between two mirrors must be less than 45^0 in the other case the setup dose not work;
2. for the right construction our interferometer angle between mirrors must be in the range of 30^0-42^0.

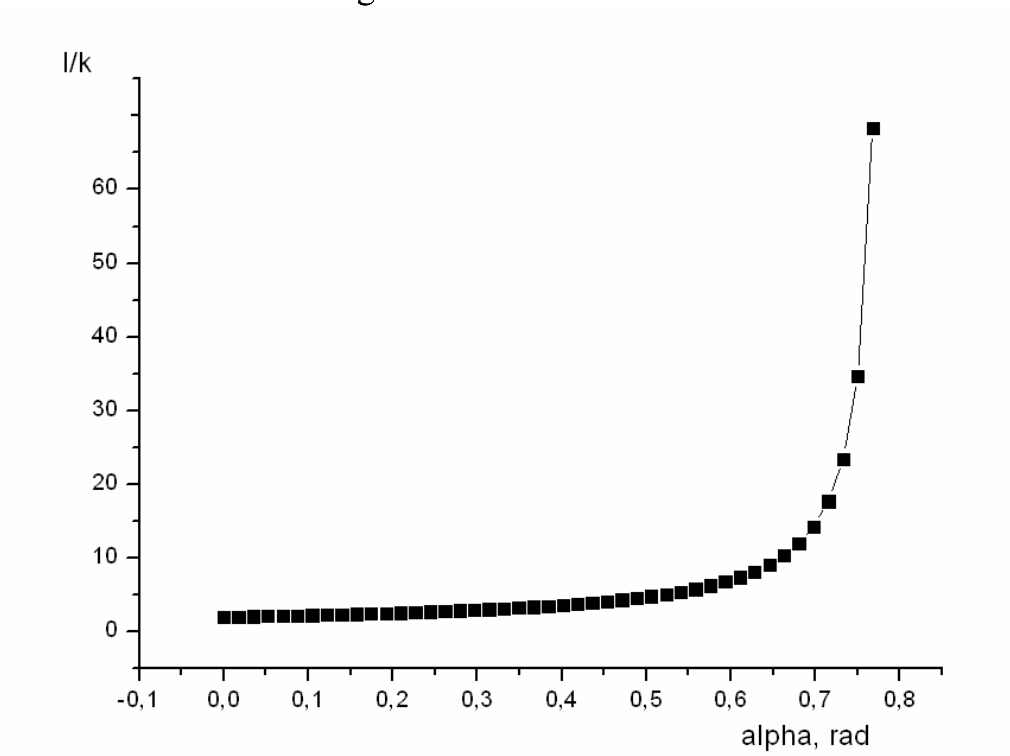


Figure7. Graphical relationship between length of interferometer arm, distance between mirrors and angle between them.

In the next step, for different angle between mirrors we calculated how the shift mirrors influenced the length of the interferometer arms.

$$\frac{l}{\delta}=\frac{1+\cos\alpha}{\sin\alpha}$$

δ - Shift of translation stage.

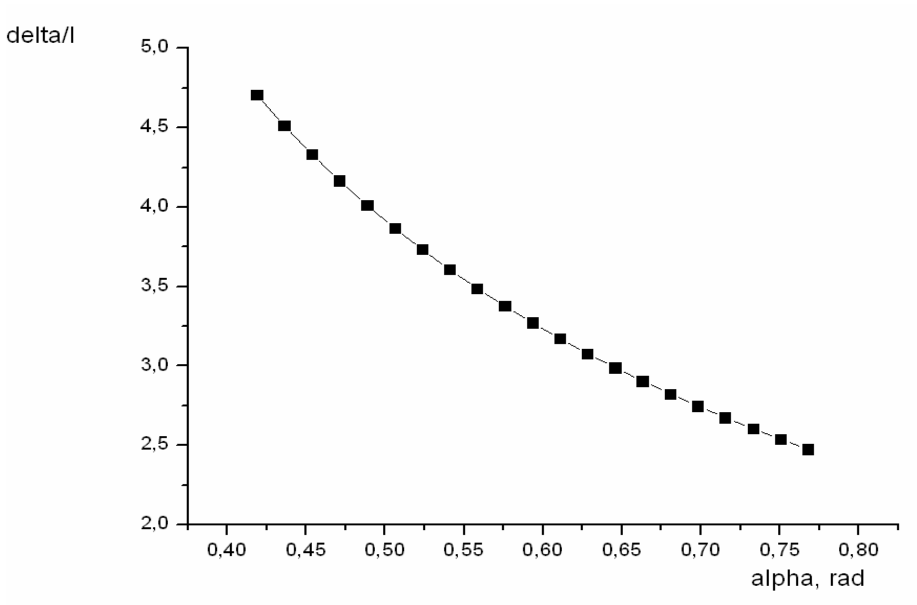


Figure 8. Dependence between $\frac{l}{\delta}$ and angle between mirrors.

This dependence shows, that we need to use as large an angle as is possible. Only in this case our device has the least sensitive to the movement of the delay stage.

Combining both these dependencies, we make the following conclusion for the design of our device:

1. The angle between two mirrors must be as large as possible, but it must be less than 45^0.
2. Distance between mirrors must be not too large to build a compact construction of our interferometer, but not too small to avoid beam clipping.

For out setup we choose a value of 40 degrees for the angle between mirrors. It is very convenient angle for our device. $\frac{l}{k} \approx 14$, $\frac{l}{\delta} \approx 2{,}75$. They are quite good correlation for our setup.

Experimental part.

Construction of our interferometer is presented on the photo. It contains

1. two beam splitters 50/50 1,2 they are fixed on a base plate,
2. metallic mirror 3 is fixed on the base plate,
3. two metallic mirrors 4,5 are fixed on the translation stage 6 they can change their position relative to mirror 3 with by means of a translation stage,
4. CCD camera 7 to record interference pattern.

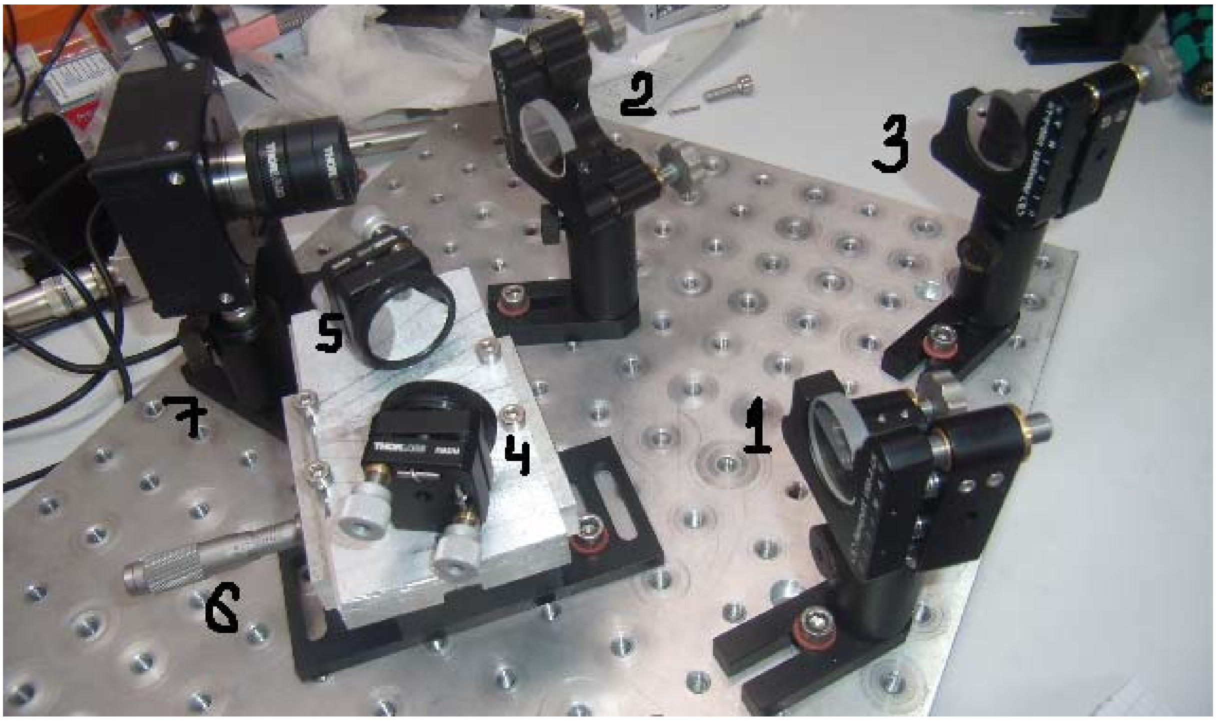


Figure 9. Experimental setup. Modified Mach-Zehndler type interferometer

For the further work both arms of interferometer must be equal, and we need to align our setup as precisely as we can. For the first step we used a diode laser as light source. This type of laser has a large coherence length, and it is very convenient to use this laser to see interference picture first time. We saw this picture by eyes. CCD camera imagine is presented at fig. 10.

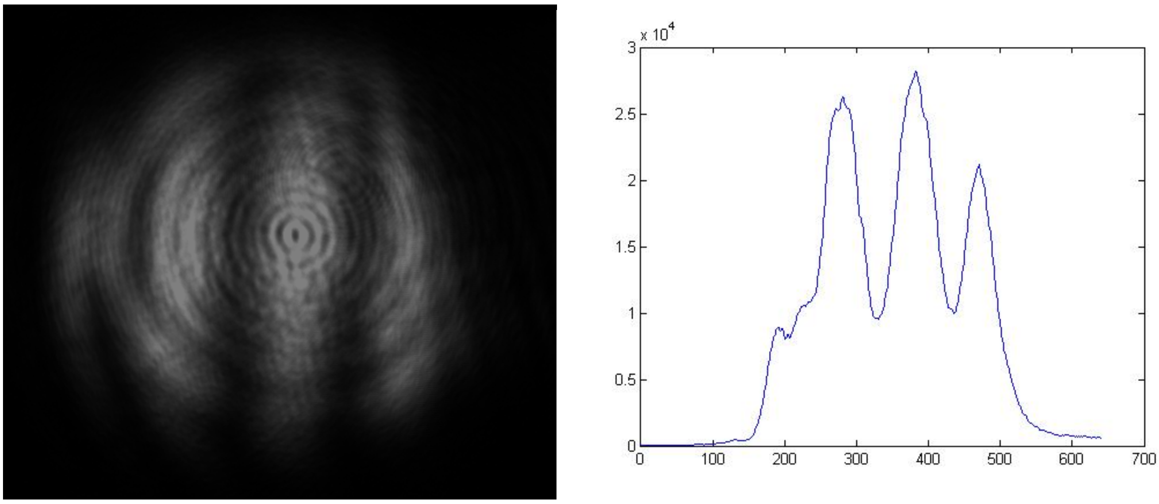


Figure 10. Interference picture of diode laser. CCD camera imagine (left picture) and intensity modulation (right picture)

In a second step we used fiber laser. Its coherence length is about 0.20 mm. It means that we can deviate from the right position no more than 0.08 mm in each direction in our condition. It is more difficult to find interference picture in this case, but it gives more precisely results. A CCD camera imagine is presented in fig. 11.

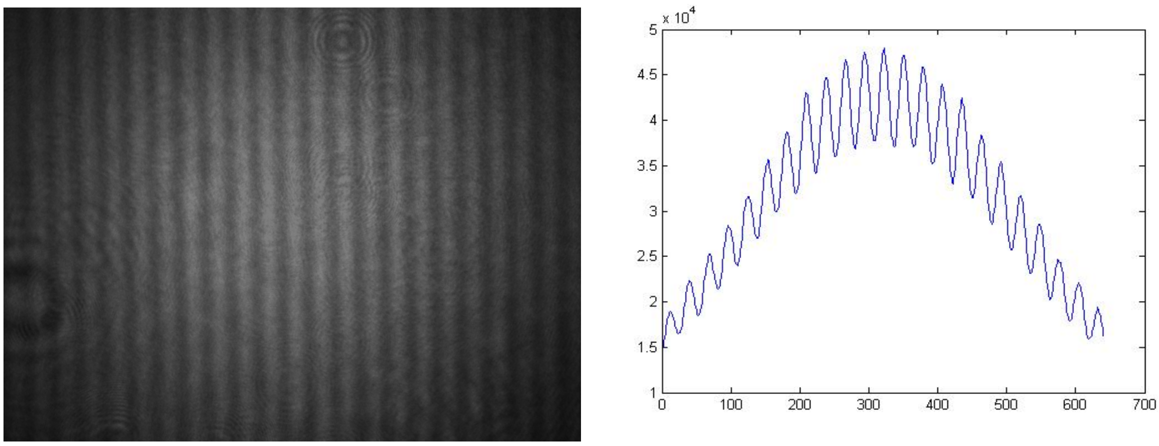


Figure 11. Interference picture of fiber laser. CCd camera imagine (left picture) and intensity modulation (right picture)

In a next step we decided to use the beam from the Ti:sapphire oscillator that seeds the Hidra amplifier. This light source gives short pulses. The duration of these pulses is 50 fs. It means that coherence length of the oscillator is very small. We calculated a range of various position of the delay stage in which we can see interference pattern. A deviation of the correct position is 0.02 mm in each direction. In additional this beam has slight pulse front tilt. The pulse front tilt is created by a prism that is located on the laser beam way. We know the relation between the angular dispersion and the pulse front tilt.

$$\tan\gamma = \bar{\lambda}\frac{d\varepsilon}{d\lambda},$$

where γ is the angle between the tilted pulse front and the wave front, that is the pulse front tilt, $\bar{\lambda}$ is the main wavelength and $\frac{d\varepsilon}{d\lambda}$ is the angular dispersion.

Material of the prism is fused silica. We calculated the expected pulse front tilt for both case. It is about and 0,04 degrees. It is very small and its influence on the interference picture is not much. In this case we should be able to see an interference pattern. But we did not have success. We suggested that the diameter of the beam was very small (1mm) to see anything and constructed a Kepler telescopic system to increase diameter of our beam three times. But it did not give any result.

We decided to measure the pulse front tilt using the fiber laser. We put a silica prism in the path of the laser beam. Its apex angle is $68^0 48'$. The expected pulse front tilt is $\gamma \approx 2^0$ in this case. In theory if we get pulse front tilt we observe next picture (see figure 12). Moving of the translation stage will influence our picture if we have a pulse front tilt. If we find a correct position of the delay stage the interference picture will be in the center of overlapping beams. If we change the delay stage the interference pattern shifts to the right or to the left part

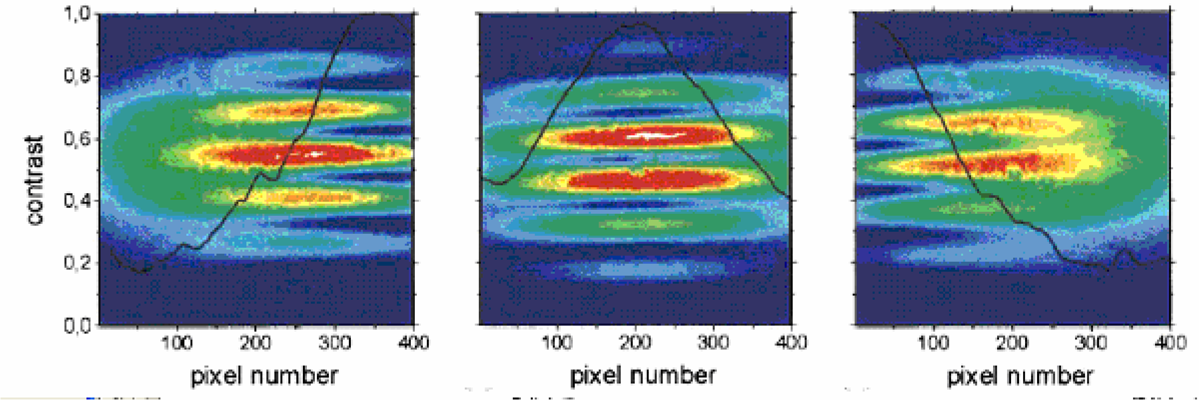


Figure 12 Interference picture with pulse front tilt. We expected to observe a picture like that. Translation stage have a right position on the middle picture.

It is a big problem to see any shift in our case. We calculated the area where interference pattern can appear. The diameter of this area is 5,7 mm. the diameter of our laser beam is 5.4 mm. It means that it is impossible to see any shift. But we get interference picture in this case is presented on the picture 13.

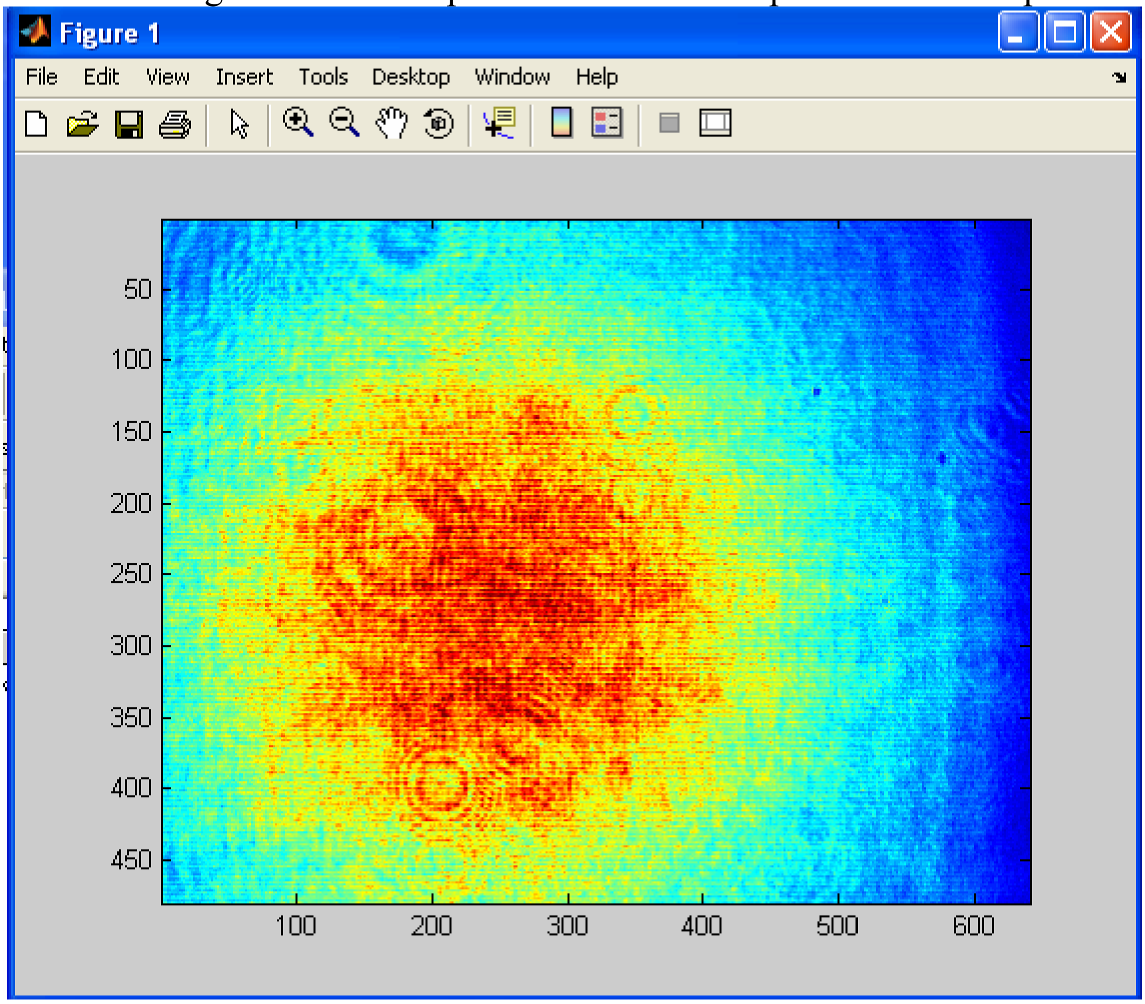


Figure 13. Interference picture with pulse front tilt.

Acknowledgments

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References and links.

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