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ABSTRACT

In this work we present a method used to study the spherical and chromatic aberrations contribution near the focal point of a refractive optical system. The actual focal position is measured by scanning a pinhole attached on the front of a power detector, which are scanned along the optical axis using a motorized stage with 1 µm resolution.

Spherical aberration contribution was analyzed by changing the pupil aperture, by modifying the size of the input iris diaphragm and for each case, measuring the actual laser power vs the detector position. Chromatic aberration was analyzed by performing the same procedure but in this case we used an ultra-broad-band femtosecond laser. The results between ML and CW operation were compare. Experimental results are presented.

Keywords: Femtosecond pulses, spherical and chromatic aberrations, group and phase focusing

1. INTRODUCTION

Temporal and spatial aberration compensation and compression of femtosecond pulses near the Diffraction Limit and Bandwidth Limited (BL) at the focal plane is fundamental for applications where maximum peak intensity or resolution is necessary. For instance in nonlinear fluorescence microscopy [1], nanophotonic applications [2-3], photolithography [4] and super- resolution imaging [5].

A fundamental part for usage of high intensity light is the focusing system. In general, main aberrations are mostly associate with spherical aberration, and chromatic effects such has the Group Velocity Dispersion (GVD), and Propagation Time Delay (PTD) [6] [7].

The state of the art on ultrashort laser pulses focusing demands a better understanding of phase and group focusing effects, considering the difference of the group refractive index instead of the phase refractive index and its effects on optical distortion of the pulse front and temporal aberrations [8-14].

In this work, we present experimental results of focusing broadband Mode-Locked (ML) femtosecond pulses and continuous wave (CW) using an achromatic doublet, typically used for femtosecond pulses focusing, to study the differences between the phase and group focusing. Experimental results of focusing performance has been achieved by applying a method based on a pinhole masked linear z-scan along the optical axis using a home-made Erbium Doped Fiber Laser (EDFL) @1550 nm.

2. EXPERIMENTAL SETUP

To measure the difference between phase and group focusing we have used a broadband femtosecond @ 1550 nm, delivered from an EDFL, operating during CW and ML operation regime. The transversal beam was expanded trough free spatial propagation of couple of meters. At the entrance of the experimental setup, just at the entrance of the optical focusing system, an iris aperture was located to control the input beam diameter. Iris aperture was adjusted from 0.53mm up to 7.67 mm to full fill completely all the focusing systems apertures. A 20µm pinhole was attached to a power meter (Coherent, LM-2IR sensor) and both together mounted in a motorized translation stage with 1µm resolution (Newport, M-UTM50CC1DD). The experiment was performed under different input beam diameters, CW and ML operation for the optical system under test. Experimental setup is demonstrated in figure 1.

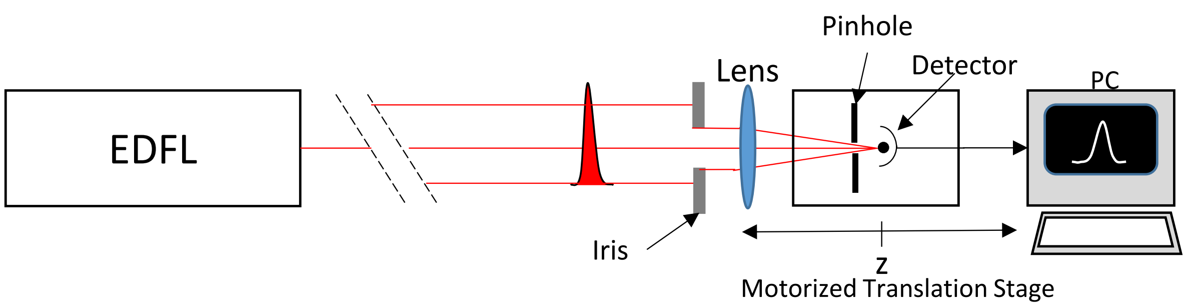

Figure 1. Experimental set-up of the pinhole masked linear z-scan method

A typical measurement of intensity vs. position, along the z axis is presented in figure 2.

Figure 2. Typical experimental measurement of z vs Intensity (left). Experimental unsymmetrical trace of z_r vs Intensity example due a misalignment condition (right).

A trace of z vs Intensity is obtained by varying the pinhole position (attached on the detector) with the translation stage and recording the power meter reading as a function of the z position. We have called this method as Pinhole Masked Linear z-scan (PML z-scan).

In the trace, we can associate three parameters: distribution width @ FWHM (w_R), maximum intensity value (I_{max}) and focal position shift (z_r), relative to the paraxial focal position (z_r=0). The location of the paraxial focal point was measured by locating z_r with the iris aperture open at 2 mm (at CW operation), below this aperture diameter the diffraction effect produced a shift of the focal position further away. The selection of the pinhole diameter is important in order to keep a compromise between a good signal contrast and good resolution for the peak position location (z_r). If the pinhole diameter is to large, w_R becomes too wide and z_r difficult to locate, and the opposite, if the pinhole diameter is too small, z_r is easy to locate and w_R too narrow to be measured. Additionally with a pinhole diameter too small the system becomes more difficult to align and diffraction effects comes into a play. Also, in this case, the active area of the power sensor must be very close to the pinhole in order to colect all the energy emerging from the pinhole. A good guidance, during alignment procedure, consist on checking a symmetric trace retrieval. This will guaranty that the z-scan has been performed along the optical axis with the pinhole centered, all the way long, respect the center of the transverse beam. In figure 2 also is presented an example of a case of unsymmetrical trace of z_r vs Intensity due a misalignment condition.

The motion of the translation stage and the acquisition of the signal was automatized, synchronized and registered with a computer trough LabView program.

With this method is possible to measure relative focal position shifts, respect the paraxial focal position, the $w_{R,}$ which is can be related with the Rayleigh range and peak intensity I_{max}. With these parameters we have compared the phase and group focusing process in a refractive optical system.

The EDFL can be easily controlled to operate in CW or ML regime. The experiment was performed by keeping some laser parameters constant as average power and spectral intensity.

The laser parameters are: CW and ML, P_{avg} =100 mW (average power), λ_{CW}=1530 nm (CW central wavelength) λ_{ML}=1584 nm (ML center of mass of the spectral intensity), $\Delta\lambda$=100 nm (spectral bandwidth) .

The CW and ML spectral intensity characterization is presented in figure 3.

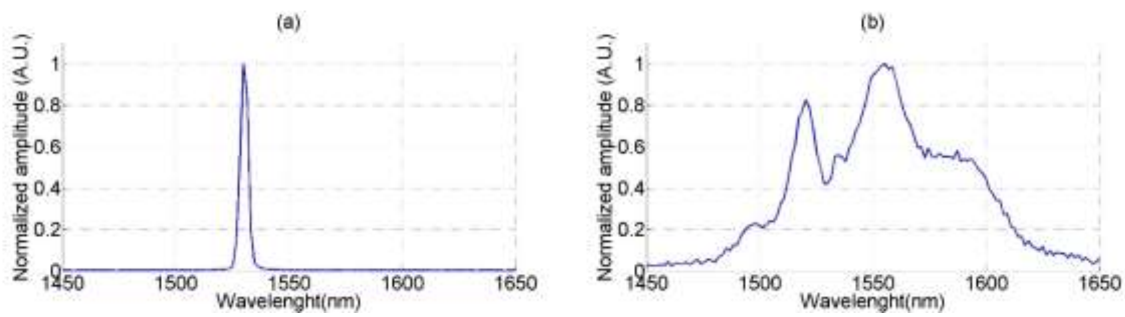

Figure 3. (a) CW Spectral Intensity and (b) ML Spectral intensity of the EDFL

The optical system under study was an Achromatic Doublet (Edmund, 12mm diameter x 30mm focal length, N-LAK22/N-SF6) designed for the NIR.

3. RESULTS

In figure 4, the rows (a), (b) and (c) correspond to Iris aperture vs z_r, Iris aperture vs I_{max} and Iris aperture vs w_R. Inset figures represents the results with Iris apertures from 0.53mm to 2 mm, considered the region where diffraction comes into play. The red solid lines are for ML operation regime and blue dashed for CW.

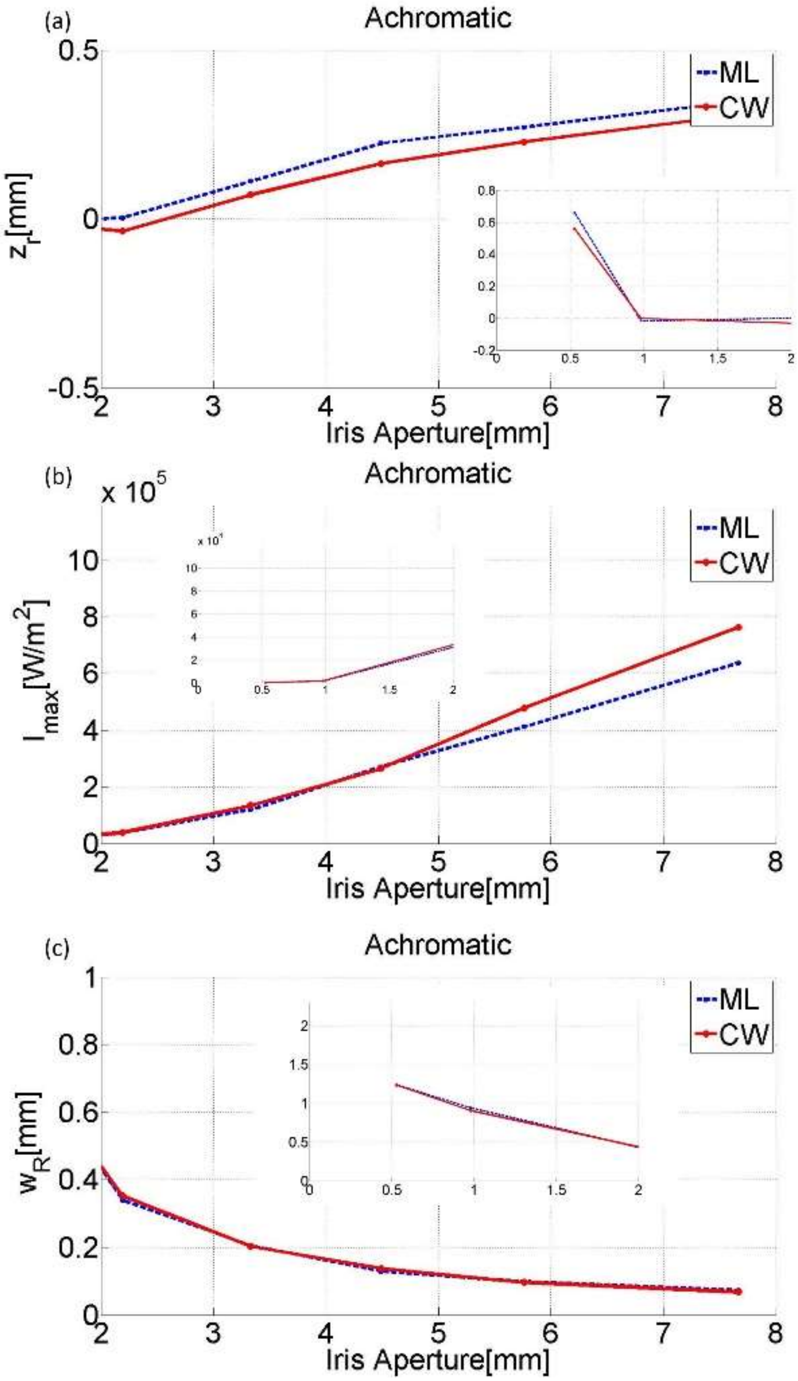

Figure 4. Achromatic doublet results (a) Iris aperture vs z_r (b) I_{max} vs z_r and (c) w_R vs z_r .The red solid lines are for ML operation regime and blue dashed for CW.

From the results presented in figure 4 (a), it can be seen that z_r shifts, respect the paraxial focus estimated at 1 mm, up to 1.3%, away from the lens. CW and ML focusing remains parallel for each aperture with a constant offset of about 0.05mm of z_r, which represents a 0.1% difference respect paraxial focal length. Also a maximum intensity value (I_{max}) is achieved for CW in compare with ML operation. The I_{max} is measured with the ratio of the actual power over the pinhole area. The last results, w_R (distribution width), provide information related with the Rayligh range which is reduced as aperture is opened.

4. CONCLUSIONS

In this work, we present experimental results of focusing continuous wave (CW) and broadband Mode-Locked (ML) femtosecond pulses, delivered from a home-made Erbium Doped Fiber Laser (EDFL) @1550 nm. For the experiment, we have analyzed spatial effects of an achromatic lens designed for the NIR. For the system evaluation, we have applied a method that we have called as Pinhole Masked Linear z-scan (PML z-scan). With the PML z-scan is possible to measure accurately the relative focal shift, relative intensity variation along the optical axis and the variation of Rayleigh range. With these parameters, we have evaluated the optical systems and found differences between phase and group focusing based on spherical and chromatic aberration behavior. We can also conclude that with the PML z-scan method is possible to evaluate, depending the application, if a given optical system will be useful or not and if it can replace a complex system, for instance an Apochromatic microscope objective, to focus broadband femtosecond pulses.

5. ACKNOWLEDGEMENTS

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