A method to measure the wavefront of short pulsed lasers through second-harmonic generation

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Purpose

Nowadays, ultraintense femtosecond lasers are widely used in high-field physics experiments, biomedicine and material processing among others. However, one of the main problems of these systems is that the wavefront is usually highly aberrated [1] and it is detrimental to obtain the highest peak intensity [2] after focusing.

Here we report a novel technique to characterize the phase of this kind of systems: the wavefront dependence of nonlinear processes [3] is used to build a sensor based on second-harmonic generation (SHG).

Methods

The experimental setup developed for the purpose of this work is shown in Fig. 1. The high-power broadband femtosecond input laser beam is divided into two replicas. The first one is directed towards a multiwave shearing interferometer (SID4-HR, Phasics) for wavefront measurement and serves as a reference for later comparisons. The second one is frequency doubled (SHG) in a nonlinear crystal and imaged into a motorized spectrometer.

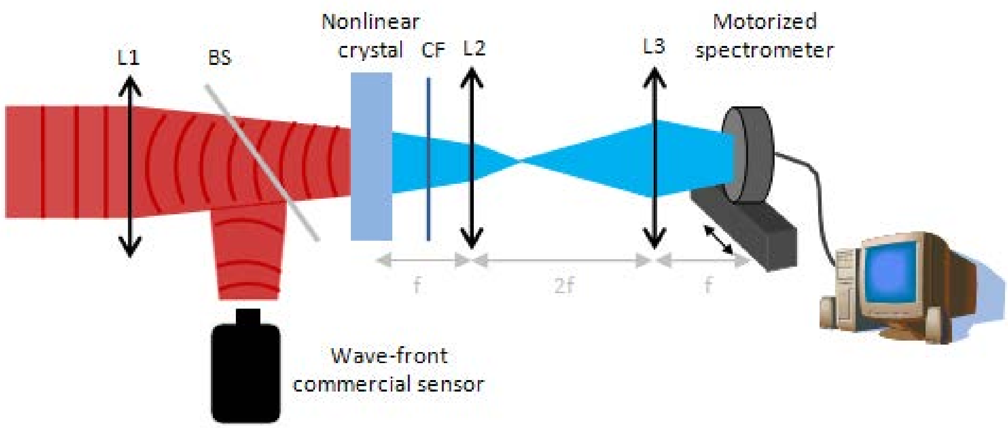

Fig. 1. Experimental setup of the wavefront sensor. L1, trial lens; BS, beam-splitter; CF, band-pass filter; L2 and L3, 4f imaging system.

The SHG maximum efficiency is achieved at a particular wavelength. This wavelength strongly depends on the angle between the wave vectors (perpendicular to the wavefront surface of the propagating beam) and the optical axis of the nonlinear crystal. Then, it is possible to retrieve the wavefront values across (for instance) the X (horizontal) direction by recording the spectrum at different points along that axis.

The method has been applied for wavefront sensing of a 0.5TW, 120fs Ti:Sapphire laser at the University of Salamanca in close collaboration with the Centro de Láseres Pulsados (CLPU).

The theoretical basis of wavefront sensing using this technique was also developed. The outcomes of these numerical simulations were compared with experimental results obtained when measuring the wavefront of the beam provided by different lenses (both convergent and divergent) placed in front of the nonlinear crystal. The dependence with crystal thickness and beam spatial profile was also explored.

Results

An example of the results is shown in Fig. 2. For this particular case, a 500-µm thick BBO crystal was used for SHG. The incoming beam was focused by means of a 400-mm focal length lens placed 354 mm in front of the BBO crystal.

In Fig. 2 (left) the spectrum of the SHG beam across the X direction is presented. For the central SHG wavelength Fig. 2 (right) compares the wavefront aberration (along same horizontal axis) computed with the method here reported and that measured with a commercial wavefront sensor.

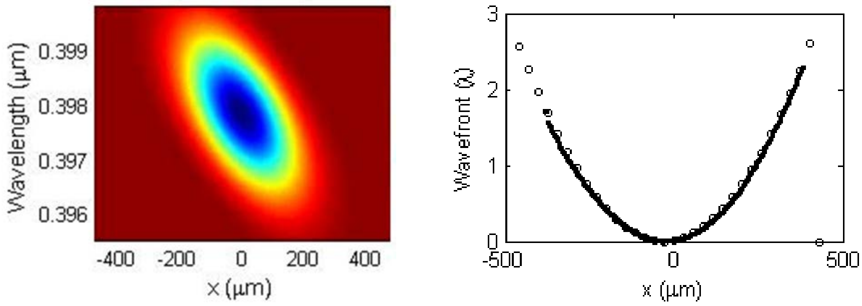

Fig. 2. Experimental results for a beam focused on the BBO crystal. Spectral trace of the SHG beam across the X direction (left); comparison between the wavefront values experimentally retrieved (black symbols) and measured with a commercial sensor (white symbols).

Conclusions

A new method to reconstruct the wavefront aberration from a femtosecond laser beam has been reported. This is based on spectral measurements at different locations across the beam. It could be useful to explore the dependence with the wavelengths and to sharp intensity patterns. This retrieval method has also been proved to be robust when areas with discontinuities are involved. Moreover, since the sensor is a fiber-based model, it is possible to achieve high spatial resolution, suitable for small beam diameters.

The main drawback is related to the choice of the crystal thickness. Thicker crystals impose a limit to the range of aberrations to be measured. On the opposite, thinner crystals are shown to induce a higher error in the phase retrieval due to noise in the spectral trace.

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References

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