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Ultraestable spatiotemporal characterization of optical vortices in the visible and near infrared

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Abstract. We show the versatility of the bulk lateral shearing interferometer characterizing complex spatiotemporal structures in different spectral ranges. Specifically, we have characterized constant and time-varying optical vortices in the visible and near infrared spectral ranges respectively. The high stability of the system combined with its spectral versatility will ease the spatiotemporal characterization of ultrafast phenomena.

1 Introduction

Recently the evolution of laser technology has enabled the possibility of obtaining complex ultrashort laser beams with multiple applications, for example [1,2]. As the beam complexity has increased, steadily new spatiotemporal characterization techniques have been proposed to analyse them [3]. However, these techniques usually involve complex systems with high dependency to external perturbations. In our recent work [4], we have implemented an in-line and ultraestable spatiotemporal characterization technique, which solves these issues. Furthermore, the technique has the additional advantage of being able to operate in different spectral ranges without modifications.

In this contribution, we present the application of the spatiotemporal technique to characterize a type of complex ultrashort laser beams called optical vortices in different spectral ranges. In particular, we characterize constant and time-varying vortices in the visible and near infrared spectral ranges, respectively.

2 Spatiotemporal technique

The spatiotemporal characterization technique [4] is based on the properties of uniaxial birefringent crystals to implement a bulk lateral shearing interferometer.

Essentially, the technique splits the scalar beam under test into two replicas and introduces a lateral displacement (i.e., walk-off) and a temporal delay between them. Thus, it combines the principles of spectral and lateral interferometry to measure the spatiospectral spatial phase gradient of the beam in the walk-off direction. Then, knowing the spectral phase at a reference point, which can be measured with a conventional temporal characterization technique, the gradient is integrated obtaining the complete spatiospectral or spatiotemporal phase profile. In our case we used an in-line and robust temporal characterization technique called amplitude swing [5] to obtain the reference phase, so the whole system is robust against external perturbation.

In order to perform 2D characterizations it is required to measure the spatiospectral gradient for two perpendicular directions of the walk-off and this is done by rotating the crystal that introduces the lateral displacement (birefringent crystal with the optical axis not contained in the crystal face, hereafter walk-off crystal). Furthermore, if the temporal delay introduced by the walk-off crystal is not suitable, it can be adapted using a retarder plate (birefringent crystal with the optical axis contained in the crystal face), which introduces a certain delay but not lateral displacement. In Fig. 1 it is shown the scheme of the spatiotemporal technique for the configuration with horizontal walk-off.

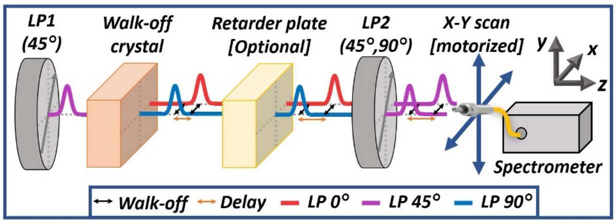

Fig. 1. Scheme of the spatiotemporal characterization technique introducing the walk-off in the horizontal direction.

3 Application to optical vortices

We used a Ti:Sapphire ultrashort laser (central wavelength around 800 nm) as light source and the optical vortices were generated using a nanostructured plate known as s-waveplate [4,6].

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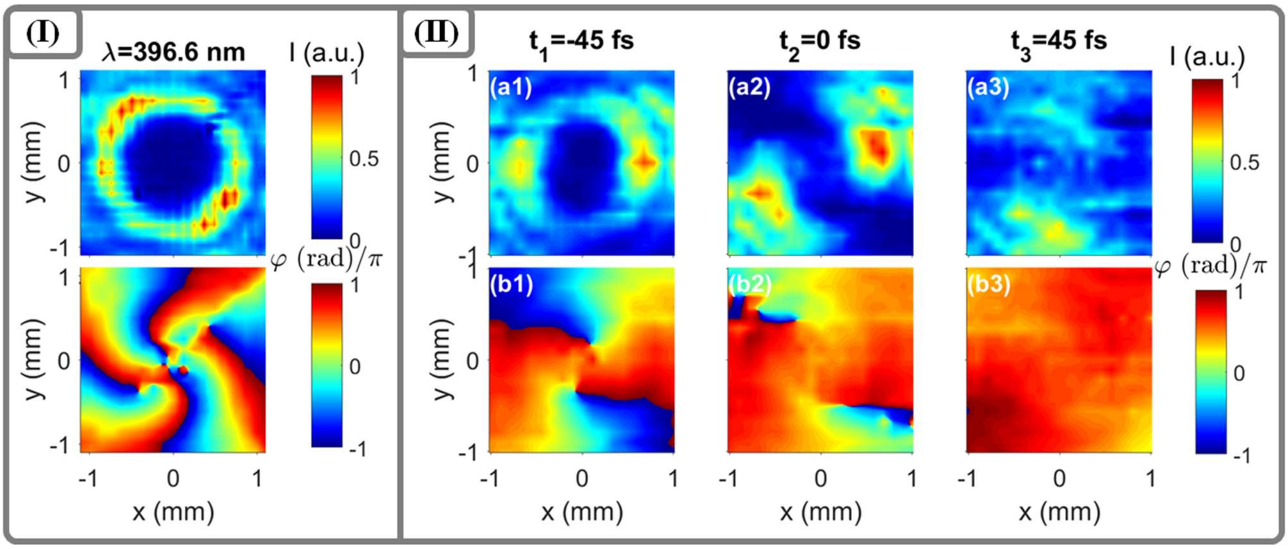

Fig. 2. Intensity (first row) and phase (second row) profiles for: (I) Frame for the central wavelength (396.6 nm) of the complete spatiospectral characterization of an ℓ=+4 optical vortex in the visible range. (II) Three temporal frames of the complete spatiotemporal characterization of the combination of ℓ=+2 and ℓ=0 optical vortices with a 65-fs delay between them.

As explained in [6], depending on the incident beam properties, the s-waveplates can generate two circularly polarized optical vortices of different orbital angular momentum (OAM or ℓ). Then, using linear polarizers and zero order waveplates we can manipulate them and select only one of the vortices or a combination of both [4].

3.1. Constant optical vortices in visible range

Although our s-waveplates are designed to generate optical vortices in the Ti:Sapphire spectral range (around 800 nm), we can generate vortices in the visible range by doubling the frequency using a second harmonic crystal.

Following this idea, we transformed a constant ℓ=+2 optical vortex in the near infrared into an ℓ=+4 optical vortex in the visible. In Fig. 2(I) it is shown the frame corresponding to the central wavelength (396.6 nm) of the complete spatiospectral characterization obtained for the ℓ=+4 optical vortex.

3.2. Time-varying optical vortex in near infrared

Another possibility as explained in [4] is to introduce a delay of the order of the FWHM of the initial beam to obtain two delayed optical vortices. The average spatiotemporal phase profile of that combination corresponds to a time-varying OAM.

Fig. 2(II) shows three frames of the complete spatiotemporal characterization of the combination of ℓ=+2 and ℓ=0 optical vortices with a delay of 65 fs between them. On the one hand, t_1 and t_3 corresponds to the tails of the average pulse in which we only have one optical vortex of ℓ=+2 and ℓ=0, respectively. On the other hand, t_2 shows the combination of both for the central time of the average pulse. This evolution agrees with the theoretical simulations as shown in [4].

4 Conclusions

In conclusion, the robust and ultraestable spatiotemporal characterization technique can ease the characterization of complex spatiotemporal structures in different spectral ranges without modifications. Due to its versatility and robustness, we believe the system can become a keystone in the characterization of ultrafast phenomena in different applications.

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