Progress on delivery of a cross-polarised wave generation temporal filter for the Gemini laser

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Introduction

One of the key parameters for high power laser systems based on chirped pulse amplification (CPA) [1] is temporal contrast of the compressed pulse. The temporal contrast could be adversely affected by a number of processes: amplified spontaneous emission (ASE), conversion of post pulse replicas from transmissive optics into pre-pulse due to accumulated nonlinear optical phase in the CPA chain [2], the quality of optical elements in the grating stretcher/compressor combination [3]. Various of techniques have been implemented to enhance temporal contrast in CPA systems [4-7]. Cross-polarised wave (XPW) generation [5,6,10-14] has become a powerful tool for contrast enhancement.

XPW [9] is a degenerate third-order nonlinear process involving the generation of a new wave with a polarisation direction orthogonal to the direction of the linearly polarised incident wave at phase matched conditions. The main attraction of XPW applications is the ability to enhance the temporal contrast of ultra-short pulses [5, 6, 10-14] due to the cubic intensity-dependence of the third order nonlinear process. In addition, generation of the XPW is accompanied by a shortening of the pulse and hence a broadening of the spectrum [10-14]. The XPW has been intensively investigated [6,10-14] and devices based on the XPW technique have become commercially available [15].

Gemini, which is a CPA laser system [8], provides near-infrared laser pulses at intensities up to 10^{21} Wcm^{-2}. Within Gemini a number of methods are used to improve the temporal contrast [3,4]. Recently a commercial temporal filter based on XPW has been purchased from "SourceLAB Laser Plasma Technologies" [15]. We report here on work to incorporate the XPW temporal filter into the Gemini laser system.

The XPW stage forms the main part of a temporal cleaning unit designed to be inserted in the amplification chain between the 1 kHz stretched pulse front end amplifier (Femtolasers Compact Pro) and the multi-pass main grating stretcher. The temporal filter unit includes a pulse compressor, XPW stage and dispersion control (Fastlite Dazzler). The temporal stretch and energy level of the pulse out of this arrangement will be matched to the normal operating level with a short pulse material stretcher and a booster amplifier before the main stretcher.

The performance of the XPW and the spectral broadening of the output pulse are dependent on spatio-temporal parameters of the input pulse. The characterisation of the input pulse and the XPW process includes a spectral dispersion-scan study for optimising the initial parameters of the input pulse, along with an investigation of the generated spectra for assessing the performance of the XPW stage. In addition, spatial characterisation has been performed for the generated XPW beam.

The experimental setup

The pulse to be filtered temporally is a sub mJ near infrared pulse having a bandwidth of ~38 nm generated by the 1 kHz "Compact Pro" laser at the front end of the Gemini laser. Pulses with a spectrum centred around 797 nm and energy up to ~700 μJ were available for the pulse compression.

The 4 mm (2*w* @e^{-2}) beam output of the laser is first directed to a compressor consisting of two transmission gratings each with a line density of 1480 line/ mm. The separation between the two gratings is in the range of ***d***=12.5 mm corresponding to the temporal stretch (FWHM) of the input pulse ~10 ps (FWHM). Optimal compression with diffraction gratings separated by ***d*** requires additional compensation of the third order dispersion (TOD) of the spectral phase of ~2.8e5 fs^3. The transmission-grating compressor is used with a subsequent chirped mirror compressor that gives an additional (-)1000fs^2 of group delay dispersion (GDD). This combination is used to minimise accumulation of nonlinear phase by having under compressed pulse in the substrate of the diffraction grating. The compressor is arranged in a double-pass Littrow configuration. Although the vertical size of the diffraction gratings is only ~12 mm, the input and output beams to the compressor were separated in the vertical direction, perpendicular to the dispersion plane of the compressor, with a tilt of the back mirror of the compressor of about 0.18 degree. The effect of the non-normal incidence on the gratings on the spatial profile of the beam was minimised by having symmetrical input and output angles of incidence in the vertical direction. A scheme for the experimental setup of the compressor and the XPW stage is shown in figure 1. The dashed outline indicates "SL-XPW-1000" XPW stage from "SourceLAB Laser Plasma Technologies"[15].

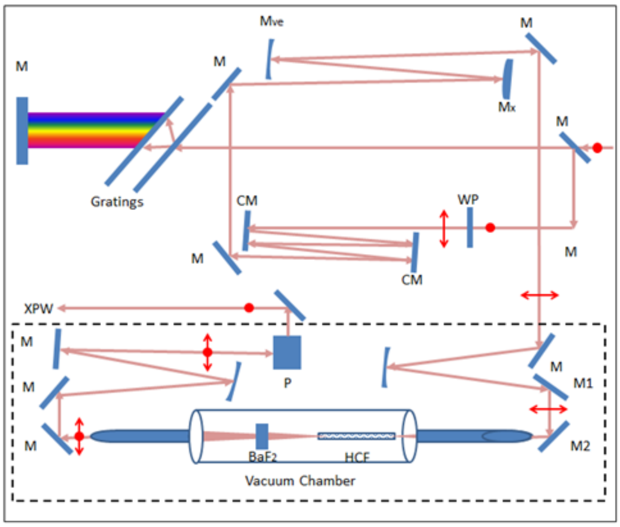

Figure 1: Schematic of the experimental setup of the XPW generation stage including the "SL-XPW-1000""; Mx- convex mirror; Mve- concave mirror; CM- chirped mirror; WP- wave plate; HCF- hollow core fibre; P- polariser. M1 and M2 have motorised mounts to actively maintain the pointing of the focus onto the fibre entrance.

To provide a focused beam within the specified 150 um diameter (2w @e^{-2}) required to couple into the hollow-core fibre, a 3x mirror telescope was set up before the XPW stage. This consisted of concave and convex mirrors with focal lengths of -250 mm and 750 mm respectively.

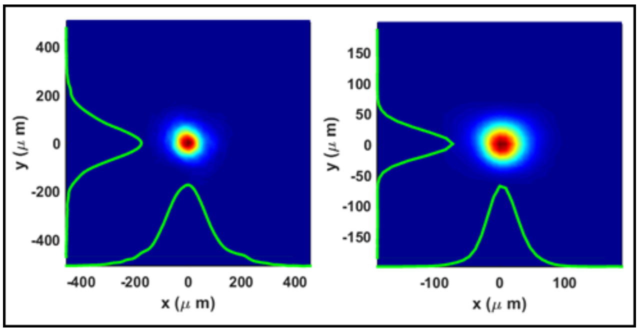

Figure 2 a): The focal spot of the laser output after the compression and expansion stages. The focusing element is a 1.5 m focal length concave mirror. (b) The focal spot of an XPW beam generated in a 2.5 mm BaF_2 crystal without a wave-guide. The focusing element is a 300 mm focal length plano-convex lens. x and y represent the horizontal and the vertical directions respectively

The key elements of the XPW system [12,14] are the hollow-core fibre – which acts as a filter– and the BaF_2 crystal. The beam is focused by a 1.5 m focal length mirror onto the entrance of hollow-core fibre having a 250 μm inner diameter. The beam pointing is actively stabilised by two motorised mirrors which are driven by a computer controlled loop. The beam monitoring and auto stabilisation system with a designated software ("XPW BeamStab") were supplied together with the XPW system [15], see Fig.3. A BaF_2 crystal of a holographic-cut is positioned at optimum distance from the exit of the fibre. The fibre provides a divergent beam having a perfectly smooth spatial profile with transmission efficiency of ~ 82%. The intensity of the beam incident on the crystal is optimised by changing the distance between the fibre exit and the crystal using a translation stage. The fibre and the crystal are enclosed in a vacuum chamber with two Brewster windows. The output of the crystal is re-collimated using a concave mirror and the two polarisations are separated using a polariser.

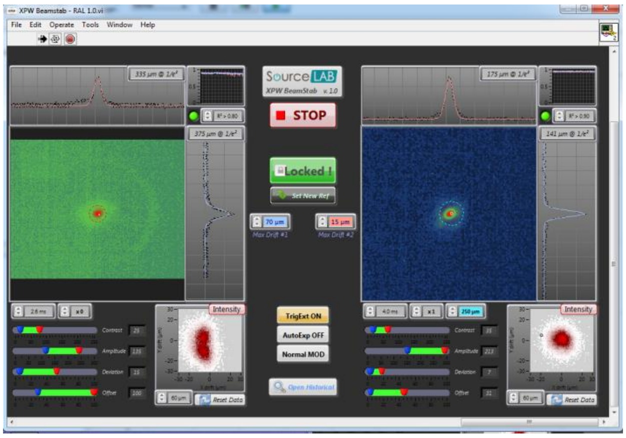

Figure 3: Example of a screen with automatic beam pointing stabilisation software "XPW BeamStab" running at 10Hz.

Results and discussion

Spatial and temporal parameters of the focussed pump beam were thoroughly tested before the beam was available for the XPW system. The focal spot of the beam after the whole compression and expansion stages is shown in Fig. 2 (a). Measurements of the temporal compression of the non-focused pump beam were first achieved by using "Grenouille" and "LX-Spider". To test the compressed pulse at focus another optimisation routine was performed. The routine is based on scanning parameters of the spectral phase dispersion with simultaneous collection of the spectra of light generated by the pulse at the focus in a non-linear process. Two non-linear processes were independently used in this test: second harmonic generation (SHG) and XPW.

For the spectral phase scanning routine with XPW process a setup identical to that shown in Fig.1 was used but without a waveguide and a vacuum chamber. The fundamental beam was focused onto a 2 mm long BaF_2 crystal by a 3 m focal length concave mirror. The XPW signal was separated using a polariser. After that, the XPW beam was either reimaged using a 300 mm focal length lens for spatial measurements or sent into a spectrometer. The far-field spatial profile of the XPW beam (Fig 2 b) shows that during the XPW process the small pedestal around the spot of the input beam is suppressed by the non-linear generation process.

One of the attractive features of the dispersion scan routine is the ability to build a parameter map and find a global minimum position for the pulse duration. The spectral dispersion-scan study of the XPW showed that a change of GDD within ±500 fs^2 can significantly affect the spectral broadening and efficiency of the system. The XPW spectrum scan presented in fig.4 b shows distinctive dynamics of the spectra in dependence on the change of GDD. Several dependencies can be retrieved from the scan: the XPW output (fig.4 b), central wavelength position (fig.4 d) and width of the spectrum (fig.4 a). For instance, the scan shows that the maximum of XPW output (fig.4 c) was observed at a lower value of GDD than that required for the maximum width of the spectrum (fig.4a). The dynamics of the central wavelength position show a rapid blue shift occurs at the point of maximum broadening due to XPW. However, for the current system ~75 fs^2 GDD results in the generation of a pulse having optimum efficiency and bandwidth. TOD in the range of ±15k fs^3 can significantly reduce the bandwidth of the generated pulse and decrease the efficiency to about 50%. On the other hand, only high values of forth order dispersion (FOD) can result in noticeable effects in the spectral properties and the efficiency of the pulse. For the pulse of interest, ±100k fs^4 FOD results in small changes in the characteristics of the pulse and the effects can be partially compensated by some GDD of an opposite sign.

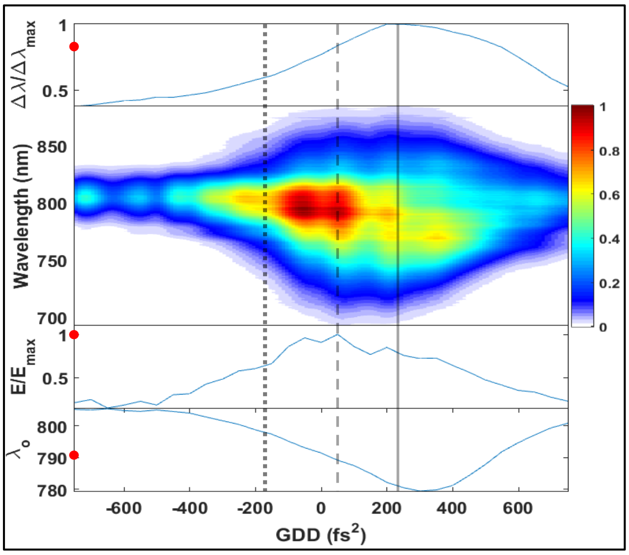

Figure 4: The characteristics of the generated XPW pulse as a function of GDD of the input pulse. $\Delta\lambda_{max}$ is the maximum achievable bandwidth, E_{max} is the maximum achievable energy which corresponds to about 18% conversion efficiency. The solid black line corresponds to the maximum bandwidth, the dashed lines corresponds to the maximum energy, the dotted line is the region where the central wavelength of the input and the XPW pulses are matched and the red dots on the axes indicate the working values of the corresponding property.

The installed XPW system, with optimised pump beam parameters routinely shows a global efficiency of > 15%, and

> 18% as energy conversion efficiency of the XPW process alone. The XPW signal is in the region of ~70 µJ.
The generated pulse shows about 30% bandwidth broadening relative to the input pulse. The spectrum of the generated XPW pulse indicates that a transform limited pulse with a minimum duration of <15 fs can be obtained. With optimised compression, the XPW pulse would be 40% shorter than the input pulse, and 35% shorter as an average value integrated over the whole beam. Implying that, in addition to the spectral broadening, a spectral smoothing and chirp linearization are achieved as results of the total dispersion and the XPW process. This indicates a negligible effect from the nonlinear phase shifts in the XPW and the optics in the system on the quality of the generated pulse. The bandwidth enhancement achieved from the XPW process can at least partially compensate the spectral narrowing into the following amplifiers.
The stability of the XPW system is comparable to that of the laser system as it was reported [14]. This implies that XPW was at a semi-saturation point when cubic intensity dependence of the XPW does not bring additional seed-instability.

Conclusions

We report on progress towards incorporation of a temporal contrast filtering unit into the Gemini laser system. The unit is based on the cross-polarised wave generation (XPW) process. The main parts of the temporal filter are a specially designed double-stage pulse compression stage, an XPW system (a commercial spatio-temporal filter "SL-XPW-1000" from "SourceLAB Laser Plasma Technologies"[15]) and a booster amplification stage with dispersion control. The pulse compression stage was characterised and optimised with help of a dispersion scanning routine. The newly installed XPW system routinely obtains an overall energy conversion efficiency exceeding 15% in a pulse having a smooth spectrum with ~30% bandwidth enhancement. The achieved spectral broadening, along with the simulated phase, indicates a 35% temporal shortening in the resulting pulse (from ~ 24.5 fs to ~ 16 fs).The output of the XPW system will be injected into the main Gemini stretcher after passing a pre-stretching and dispersion control unit and a booster amplifier.

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