Operation of the Astra TA2 hollow fibre pulse compressor with increased pump energy

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Introduction

In order to probe the hot plasmas generated using intense laser irradiation, we have installed a hollow fibre pulse compressor in Astra Target Area 2 [1-3]. Such systems are capable of providing multi-millijoule output energies [4] but until now we have not operated a hollow fibre with an input energy exceeding 1mJ in the CLF. To do so we have implemented auto-alignment [5] to maintain the pointing of the pump laser beam thus avoiding damage to the fibre entrance.

Hollow fibre arrangement

The hollow fibre is operated at 10 Hz using a pick off from the main Astra system after the second amplifier. The pump pulse energy can be controlled by computer using a combination of a half-waveplate and cube polariser and is compressed in air using a separate compressor to the main TA2 drive pulse. The pump is brought to a high quality focus with 130 µm diameter using a focal length of 1 m (Figure 1a). This is slightly smaller than the ideal focal spot of 160 µm for coupling into the fibre and a longer focal length lens has been purchased for future integration. The final turning mirror into the fibre has a reflectance of 99.5% and the leakage is directed onto a far-field monitor which images an equivalent plane to the fibre entrance. The position of the focal image is used as feedback to pico-motors steering the penultimate mirror in order to maintain the position of the focus [5]. The coupling of the beam into the fibre is optimised with very low pump energy by observing a high magnification camera directed at the fibre entrance and a beam-profiler monitoring the transmitted beam. Poor coupling is noticeable through a change in the output beam profile and bright flashes of white light when the fibre is operated at higher energy.

High energy hollow fibre performance

We have investigated the transmission properties of the fibre with a pump energy of up to 6 mJ. Figure 2 shows the pump beam energy (blue) and the energy transmitted in vacuum through the fibre (red) and the as the energy-control waveplate is scanned. The transmission of the fibre of ~40% enables fibre operation with 2 mJ output energy for 5.5 mJ input energy. The transmission of the fibre is not expected to decrease at higher gas pressures [3]. During this test, the near field beam profile of the fibre was slightly elliptical (ε~0.8) but does not change for the higher input energies. The beam profile shown in Fig. 1b is the near field after the fibre pumped with 5.5 mJ.

The corresponding pulse spectra at the exit of the fibre are shown in Fig. 3 for increasing input energy. Spectral structure can be seen for the higher energies even without a gas fill. This could be the onset of self-phase modulation in the residual neon gas inside the fibre

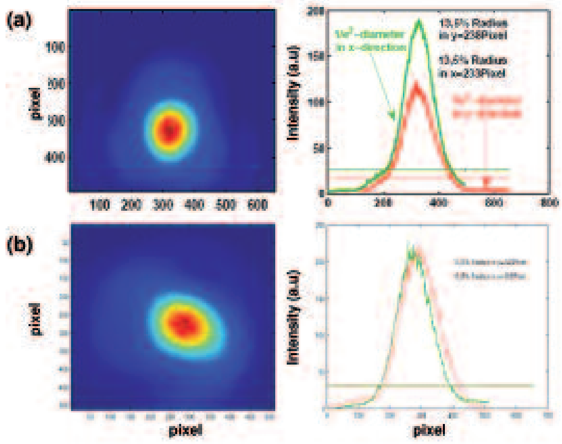

Figure 1. (a) Pump beam far field profile at fibre entrance with 1/e diameter ~130 µm. (b) Near field exit profile after collimation with 1/e diameter ~7 mm.

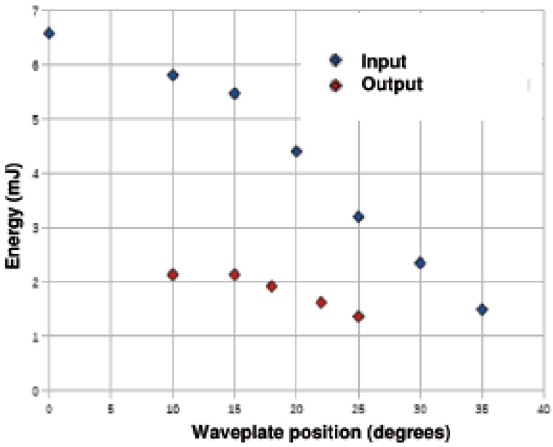

Figure 2. Energy of input (blue) and output (red) pulse from the fibre as the energy control waveplate is scanned.

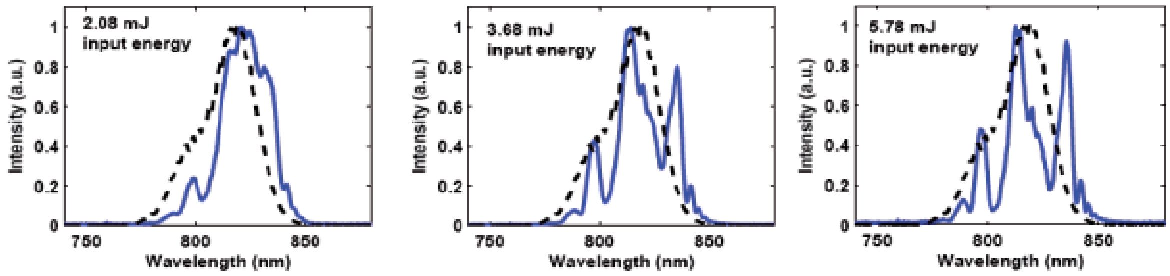

Figure 3. Output spectra with no gas fill (3 mbar) and input pulse energy of (a) 2.1 mJ, (b) 3.7 mJ and (c) 5.8 mJ

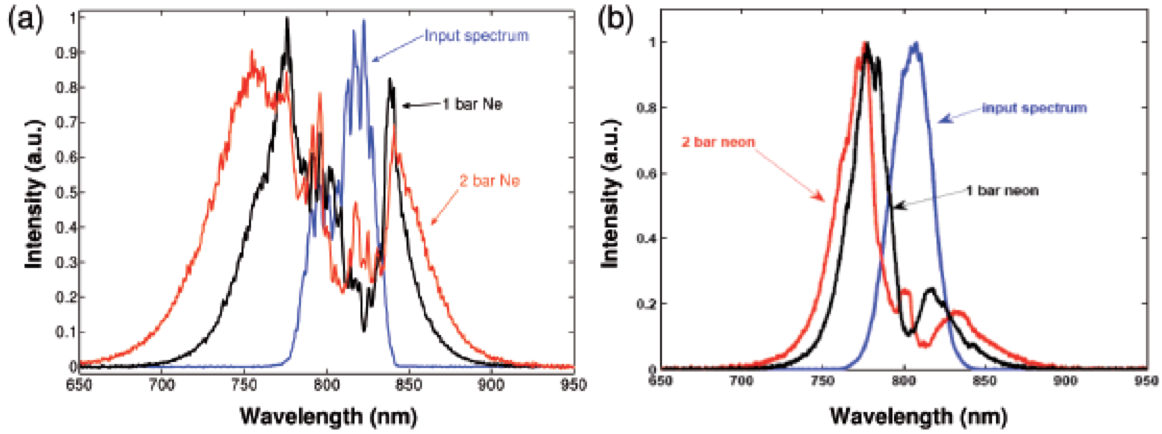

Figure 4. Output spectra with a neon gas fill to 1 bar (black) and 2 bar (red) with the input spectra in blue. In (b) the blueshift effect of ionisation at the fibre entrance is visible.

which is still at a pressure of ~3 mbar. This is distinguishable from ionisation of the gas at the entrance of the fibre which introduces a characteristic blue shift, as shown in Fig 4(b) for neon pressures of 1 bar and 2 bar at the exit of the fibre. This ionisation occurs despite the system being differentially pumped to maintain a low pressure at the entrance of the fibre[3]. Currently, the entrance pressure rises to 17.4 mbar at the entrance for a pressure of 1 bar at the exit. However, this problem is straightforward to solve by increasing the vacuum pumping capability and the fibre has previously been demonstrated to provide sufficient spectral broadening at lower pump energies (Fig. 4a).

We also see an increasing amount of white light generated in the walls of the fibre as the energy rises. This was viewed (Fig 5) with a camera located vertically above the fibre entrance behind a short pass filter (<750 nm). This comes from the wings of the laser focus but does not induce any lasting damage ascertained by viewing with the entrance observation camera.

After the initial fibre installation we could operate for about 20 minutes until a change in output beam profile indicated a drift in the pump beam direction. This would lead to regular damage to the fibre entrance when using high pulse energies. This issue has been resolved by introducing the auto-alignment system mentioned previously[5]. We investigated the effectiveness of this method by measuring the ellipticity of the beam using the beam-profiler for 600 seconds. A beam drift causing poor coupling of the pump pulse into the fibre is noticeable by deterioration of the beam profile (and so ellipticity) coming out of the fibre. The beam ellipticity is shown in Fig 6 for three increasing pulse energies. Apart from a few shots, the ellipticity remains at ~0.8 throughout this period demonstrating that the autoalignment corrects for these beam drifts.

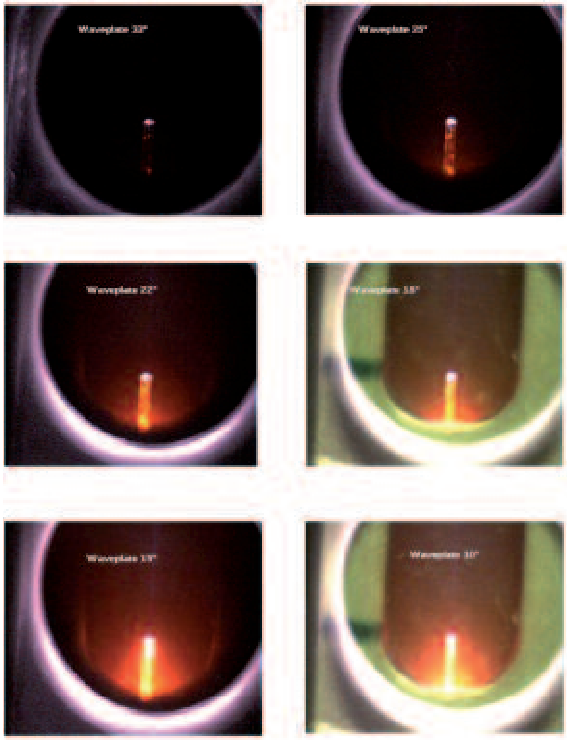

Figure 5. Images taken with an observation camera placed above the fibre entrance behind a short pass filter (<750 nm) for increasing input energy.

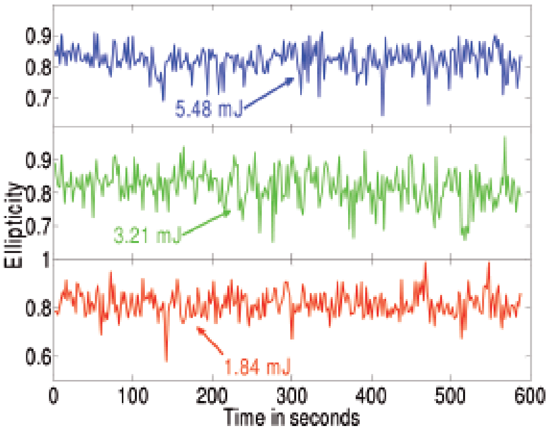

Figure 6. Ellipticity of the fibre output near field over a period of 600 seconds for increasing input energy.

Summary

The hollow fibre can be operated with high energy pump pulses up to 6 mJ with no significant degradation in beam transmission or output profile. At lower energies, sufficient bandwidth is generated for sub-10 fs compressed pulses. The shortest pulse we have measured was ~12 fs but in this case the fibre spectral broadening was not optimised. The onset of an ionisation blueshift and spectral modulation with no gas fill indicates that the system requires an improved vacuum pumping capability to operate at full specification.

References

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