New front-end for the Astra Gemini project

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Introduction

One of the aims of the Astra Gemini project is to increase the intensity of the existing Astra laser by three orders of magnitude from 10^{19} Wcm^{-2} in a single beam to 10^{22} Wcm^{-2} on target in each of two beams. This laser performance will require improvements to two important parameters: contrast ratio and B-integral. These parameters are to a large extent set by the design of the initial stages of an amplifier system and this report summarises proposed modifications to the front-end of Astra to enable the performance targets to be met.

The revised front–end of Astra is shown schematically in Figure 1 with new sections shaded blue. The main front-end modifications to be implemented are as follows:

1. The installation of a commercial high-contrast kHz pre-amplifier.
2. A single and double-pass stretcher configuration to reduce B-integral effects by providing longer pulses for chirped pulse amplification in Astra Gemini's proposed 4th amplifier.
3. A re-build of Astra's first TiS amplifier which currently amplifies stretched oscillator pulses from nJ to mJ energies in a 10-pass, confocal configuration. This will be replaced by a newly designed 3-pass amplifier, described in detail below, which will amplify the 0.2 mJ output pulses from the double-pass stretcher to the 5 mJ required input energy to the existing 2nd TiS amplifier.

Pulse contrast

At intensities of 10^{22} Wcm^{-2} on target a contrast level of ten orders of magnitude or better will be required to avoid the generation of plasma by pre-pulses. We have investigated a number of techniques for contrast enhancement including Kerr gating and saturable absorbers. These studies are reported elsewhere in this year's annual report. However, another beneficial approach is to use an oscillator and pre-amplifier with inherently good contrast. During this first development stage of the Astra Gemini project we shall install a commercial titanium-sapphire (TiS) oscillator and amplifier (Femtolasers Produktions GmbH, Compact-Pro). We have confirmed by measurement that this system will provide pulses for amplification with a contrast better than 5 x 10^{10}. Further contrast enhancing techniques will be added at a later stage of the development programme.

The kHz output train of the new pre-amplifier will be divided using a Pockels cell with 1 pulse in 100 being sent to the existing stretcher for further amplification in Astra. The remaining pulses will be sent to an experiment area for compression to 30 fs in a prism compressor. Further compression to 10 fs will be available using a recently acquired capillary compressor supplied by Imperial College. The provision of near kHz pulsed repetition rate will offer increased signal averaging to experimenters who use low-intensity pulses on Astra.

B-integral

The B-integral in Astra currently reaches around 1.3 after the final 3rd amplifier. In Astra Gemini the extension to a fourth amplification stage, with 40-50 cm of path in optical components at similar intensity, would increase the B-integral beyond the acceptable level. To overcome this we have to increase the pulse duration for Gemini. However, such a change would require us to rebuild the stretcher, and both existing pulse compressors, which would be prohibitively expensive. We have therefore developed a scheme for operating our existing stretcher in either single-pass or double-pass, and this is described below. Pulses intended for the existing target areas will be stretched to 530 ps, as at present, but pulses intended for shots in the new target area will be stretched twice, to 1060 ps. This scheme allows us to keep the B-integral at an acceptable level in the fourth amplifiers, without affecting the operation of Astra's existing target areas.

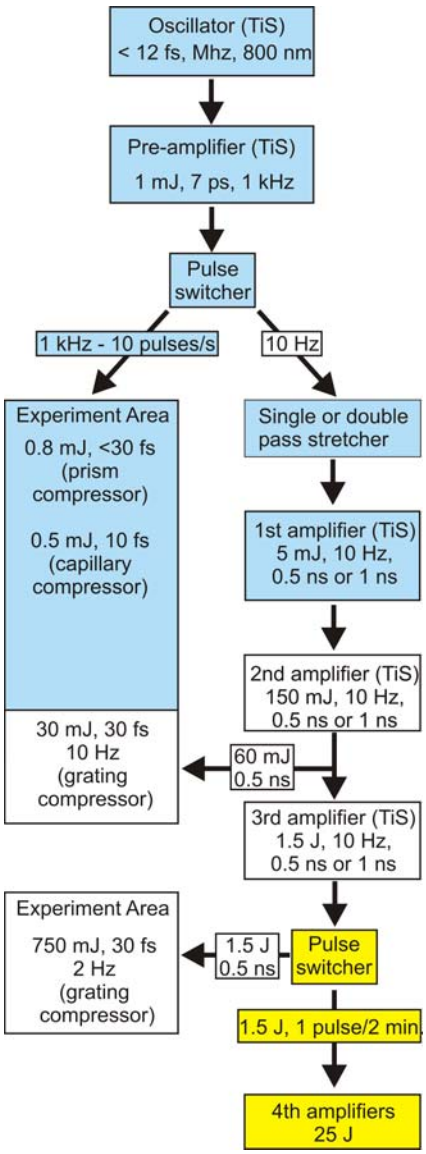

Figure 1. Schematic layout of the proposed Astra front-end changes. New front-end sections are shaded blue. Other Astra Gemini sections under development are shaded yellow.

Single and double-pass stretcher scheme

A schematic diagram of the novel stretcher configuration is shown in Figure 2. The stretcher is described in detail elsewhere[1)] but consists briefly of an input grating (1480 lines/mm) placed at the centre of curvature of a large spherical mirror. The spherical mirror directs the dispersed beam down out of the dispersion plane by a few mm onto a second grating and thence onto a rear mirror for retro-reflection back through the stretcher. The essential feature here is that the input and output beams are collinear and counter propagating. This makes it possible for the stretcher to form part of a cavity into which a pulse can be injected for multiple passes and, in our stretcher, be stretched by 530 ps on each pass. After the desired number of passes have been obtained the pulse can be switched out of the stretcher and directed towards later stages of amplification.

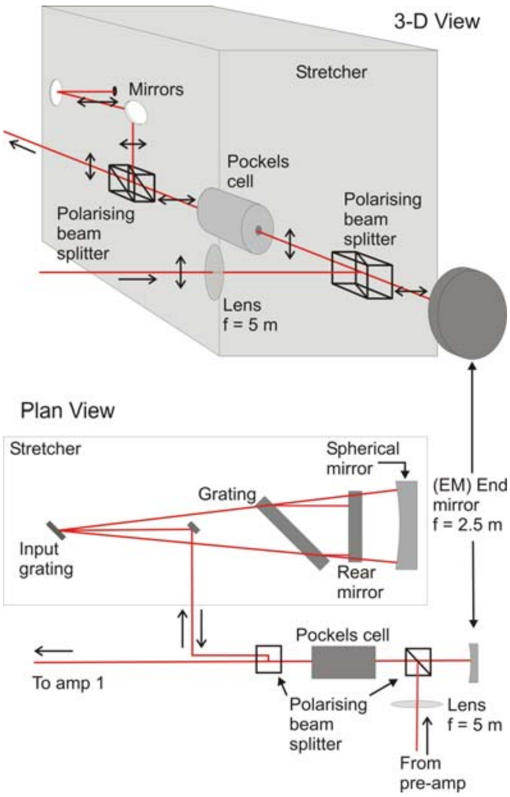

Figure 2. Single and double-pass stretcher scheme.

Referring again to Figure 2, the vertically polarised output of the pre-amplifier will be introduced to the stretcher via a polarising beam splitter. A Pockels cell will rotate the polarisation to horizontal and the beam directed upward into the stretcher via a second polarising beam splitter and a series of mirrors. The horizontally polarised beam returning from the stretcher, and back through the de-energised Pockels cell, will be redirected back into the stretcher via a curved end mirror (EM). The pulse will be retained within the stretcher for the required number of passes until the Pockels cell is used again to switch the beam polarisation back to vertical. The beam will then pass out through the 2nd polarizing beam splitter and on to the first amplifier.

Clearly this arrangement requires non-standard operation of a high voltage driver which must cause the Pockels cell to open and close twice in rapid succession. The timing is set by the total cavity length (6 m) and the distance between the Pockels cell and the mirror EM (1.5 m). Thus the laser pulse transit time between the Pockels cell, stretcher and back is 30 ns, and between the Pockels cell and focusing mirror is 10 ns. The time between a pulse being switched in and out of the cavity is 40 ns for single-pass and 80 ns for double-pass. This arrangement will be achieved using a specially commissioned, independently triggered two-channel FET pulse generator from Kentech Instruments Ltd. and an 8 mm aperture, double crystal, fluid filled Pockels cell (EM508/2) from Leysop Ltd. Both 2.8 kV outputs of the pulse generator have a 4 ns rise-time, a 5 ns on-time and a 21 ns fall-time to 0 volts.

Mode matching

The multi-pass stretcher configuration can be regarded as a stable cavity formed between the flat retro mirror inside the actual stretcher and the curved end mirror ME. The overall length of this cavity is dictated by mechanical constraints and by the switching time of the Pockels cell which gives the minimum round trip length between the cell and ME. Taking everything into account, and as described in the last section, an overall length of 6 m was chosen. The fundamental eigenmode of this cavity, i.e. the beam diameter as a function of distance, was calculated for several different radii of curvature of EM using the Gaussian matrix formalism. The radius which gives the smallest possible spot size (and hence the lowest wave front aberration[1)]) on both the input grating and the spherical mirror inside the stretcher was found to be 5 m. This mode shows a beam waist about half way between the first grating and the spherical mirror and the diameter of this waist is 0.91 mm. The beam diameter on EM is 5.4 mm.

The parameters of the stretcher input beam, i.e. location and diameter of the beam waist must be matched to the fundamental eigenmode of the stretcher cavity. Knowing the beam parameters of the Compact Pro output, the following solution was chosen: the rather divergent output beam will be re-collimated using an f = 1.5 m lens, giving a beam diameter of approx. 5 mm, and then the beam will be focused into the stretcher with an f = 5 m lens. The mode matching is fine-tuned by varying the positions of the two lenses.

Figure 3 shows the evolution of the beam diameter for two passes through the stretcher. It can be seen that mode matching is achieved: the mode is the same for both passes through the stretcher and also on the way into and on the way out of the stretcher. After being coupled out from stretcher cavity, the beam still has same mode and hence comes to a beam waist about 5 m away from EM. At this point a pinhole for spatial filtering will be inserted.

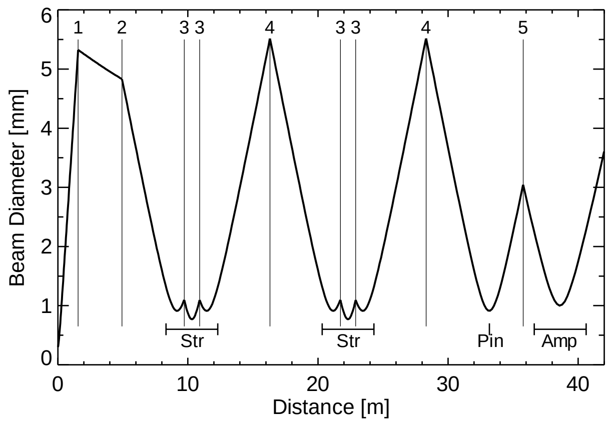

Figure 3. Evolution of beam diameter between Compact Pro and first amplifier. Vertical lines denote focusing elements, **1**: lens f = 1.5 m, **2**: lens f = 5 m, **3**: spherical mirror in stretcher, **4**: spherical end mirror (EM) of stretcher cavity, **5**: lens f = 1.5 m. Horizontal bars denote optical sub-systems: **Str**: stretcher, **Pin**: pinhole, **Amp**: three-pass amplifier.

Inside the three-pass amplifier which follows next and which will be described in the next section, a beam diameter of 1 mm is required. Hence another lens is used to refocus the beam such that it comes to a 1 mm-waist on its second pass through the amplifier crystal.

Three-pass amplifier

After passing the stretcher, the energy of the pulses needs to be boosted to about 5 mJ to provide sufficient input for the following amplifier stage, hence an additional amplifier will be needed. This amplifier will be constructed by using the Ti:sapphire crystal and the pump laser from the first multipass amplifier of the old Astra system[2)]. The crystal is 6 mm thick and the absorption coefficient is 4.5 cm^{-1}, hence the pump light absorption is 93 %. If the crystal is pumped from both ends at a fluence level of 1.5 J/cm^2, the resulting single pass gain is about 5. In a two-pass configuration, the unsaturated gain would be around 25, so an input of 0.2 mJ would be needed to reach the required 5 mJ output. As the pulse energy is likely to be below 0.2 mJ after a double pass through the stretcher, it was decided to set up the new amplifier in a three-pass configuration. In order not to degrade the pulse intensity contrast, one has to stay below the gain saturation fluence of 1 J/cm^2, therefore a diameter of 1 mm was chosen for the signal beam. To allow for the divergence of the signal beam and the angular walk-off between pump and signal beams, a slightly bigger pump beam diameter of 1.2 mm was chosen. This implies that a total pump energy of 34 mJ is required to reach the fluence of 1.5 J/cm^2 on both faces of the crystal. The results of a more detailed calculation of the expected output energy for the stated crystal and beam size parameters are given in Figure 4. This calculation was carried out using the Frantz-Nodvik formalism and assumes flat intensity distributions for both signal and pump beams.

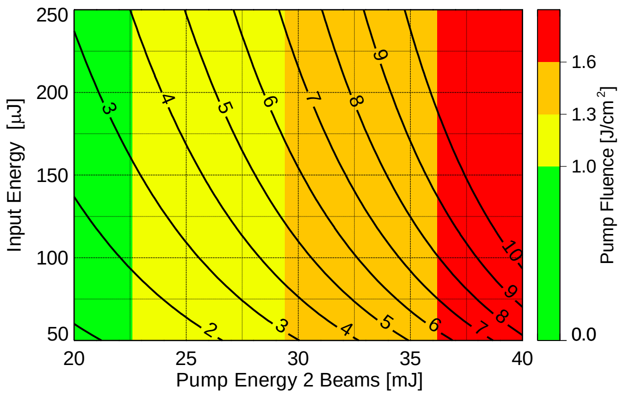

Figure 4. Output energy of the three-pass amplifier as a function of input and pump energy. Contour lines indicate the output energy in mJ, the colourmap indicates the pump fluence. Crystal and beam parameters are stated in the text.

Figure 5 shows the planned layout of the three-pass amplifier. Each arm of the pump beam is image-relayed onto the crystal and de-magnified from its original diameter of 6 mm using f = 75cm lenses positioned 90 cm in front of the crystal. The signal beam passes the crystal at an angle of 2° for the 1^{st} and 3^{rd} pass and under an angle of 6° for the 2^{nd} pass. The layout is chosen such that specular reflections from the crystal faces do not go into later passes in order to avoid the formation of pre-pulses.

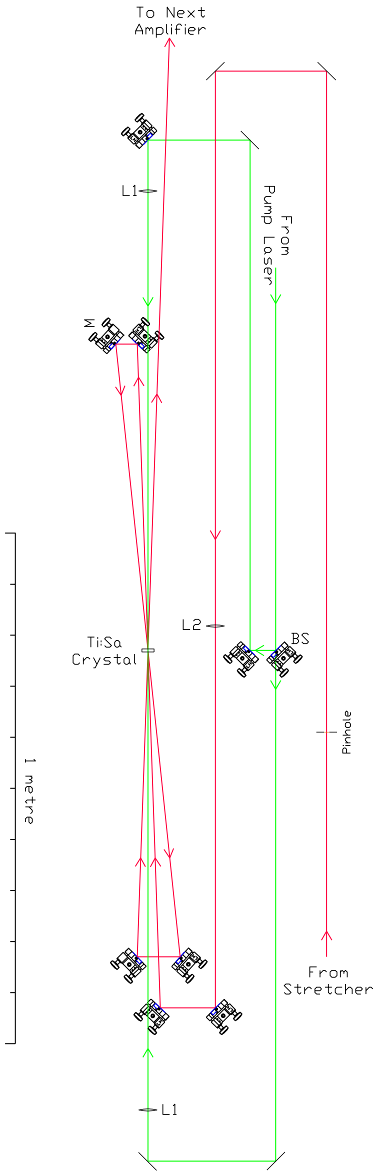

Figure 5. Layout of the three pass amplifier, BS: beam splitter, L1: lens f = 75 cm, L2: lens f = 1.5 m.

Acknowledgements

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