Commissioning the south beam of Astra Gemini

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Figure 1. The Gemini laser area in September 2007.

Introduction

In last year's Annual Report[1] we described the installation of the services and major components of the Gemini laser system in the first-floor laser hall and the experimental area, the construction of the first amplifier and the commissioning of the pump lasers and beam transport optics. The past year has seen the completion and commissioning of the south amplifier, its compressor and diagnostic systems, the vacuum system for the compressors and interaction chamber and the laser control system. The first shot on target was fired on 29 September 2007, and the Gemini facility was inaugurated by the Hon. Ian Pearson MP, Minister of State for Science and Innovation, on 28 November 2007. The first experiment using the new facility began in January 2008. In this report we describe the commissioning process and present results of the performance studies carried out on the laser during the commissioning period. Figure 1 shows the appearance of the laser area in September 2007.

Completing the build of Gemini south beam

Several parts of the infrastructure required completion before the laser could become operational, including the vacuum system and its control software; the independent dry vacuum system for the spatial filters and beam expanders; the antennas and argon and oxgen gas pipes for the RF cleaning system; the beam tubes from the compressor chambers to the target area and their gate valves, which are fitted with sapphire windows to transmit low-power and CW beams for alignment. The rail system for the compressor chamber doors was installed: this allows the doors to slide parallel to the sides of the chamber to minimise obstruction of adjacent walkways. During this period the floor penetrations that are not currently in use were filled with removable concrete plugs to complete the radiation shielding.

Pump beam homogenisation

The intensity profiles of the green beams from the pump lasers were too non-uniform to be satisfactory for pumping the crystals. To meet the schedule for the project we were forced to develop our own solution for homogenising the beams, using diffractive phase plates. Figure 2 is a diagram of the scheme, which is compatible with the double-pass pumping technique[2] used for Astra Gemini; ref.[3] contains a detailed description of the arrangement. The original and homogenised beams are shown in figure 3.

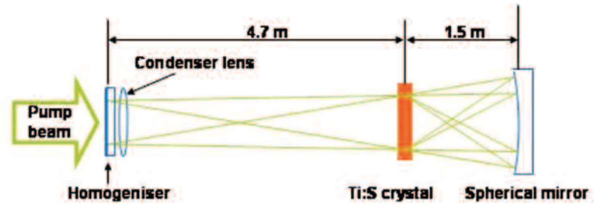

Figure 2. Setup for beam homogenisation in the Gemini amplifiers.

Amplifier setup and commissioning

An expanded 800 nm CW alignment beam can be injected into the path of the pulsed beam by a sliding mirror just before the 50/50 beamsplitter on the split & delay table. The collimation of this beam was set using a shear plate, and the wavefront measured with a Phasics SID4 wavefront sensor had a P-V error of 0.15 waves after the injection mirror. Wavefront measurements made elsewhere in the amplifier showed rather larger errors, which were traced to a few mirrors that had been clamped too tightly in their mounts, and to the achromatic lenses of the spatial filters not being accurately normalised. During this process we discovered that the input lens of the 3× beam expander was particularly sensitive to alignment with respect to the beam direction, so we installed a separate pair of kinematically-mounted crosswires to ensure the beam direction through the expander could be maintained correctly. Once the various distortions were corrected the amplifier was found to contribute a residual 0.4 waves of error, and the compressor 0.3 waves. This level of error was considered acceptable for commissioning purposes.

The triggers for the Quantel pump lasers are derived from the timing computer in Astra. Three triggers are used: one at 5 Hz to run the Quantel oscillator, plus a flashlamp trigger for the main amplifier chain and a Q-switch trigger, which arrive at the chosen firing rate of the laser (currently every 20 seconds). Each of these signals is initially used to trigger a Stanford delay box, then the signals for the two pump lasers are obtained from the outputs of the boxes. This allows the timings for the two lasers to be adjusted independently from within the Gemini laser area. The Q-switch timing was set first in synchronism with the arrival time of the 800 nm pulse, then the flashlamp trigger delay set to give maximum pump energy.

We characterised the amplifier in several stages, gradually increasing the pump energy in order to anneal the coatings on the homogeniser plates and the TiS crystals, and regularly checking for any signs of damage. In the first stage the small-signal gain was measured with a dry crystal, using an input from Astra of around 6 mJ with increasing pump energies. The fluorescence from the pumped region of the crystal was recorded with a CCD camera, and quite clearly shows the depletion due to transverse ASE once the pump energy exceeded 20 Joules. At this level of pumping the small-signal gain was also clamped at approximately 2.2 per pass. After the index-matching liquid was added to the cell around the crystal, the behaviour changed significantly, with the small-signal gain increasing to a maximum of 4.5 per pass, and only a slight hint of depletion in the fluorescence images at the highest pump energy. This performance followed the modelling that was done during the design stage, and demonstrated the success of the ASE suppression technique. Figure 4 shows the small-signal gains for the crystal with and without index-matching, and the fluorescence images recorded for the two cases.

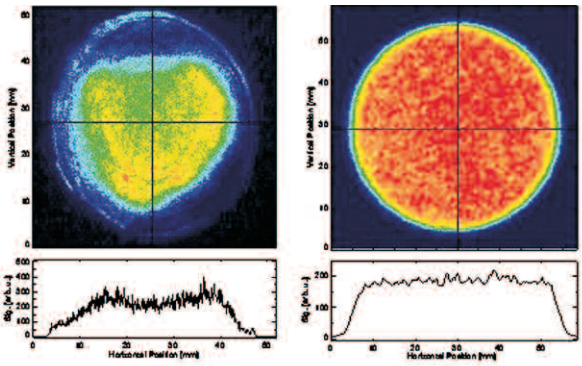

Figure 3. Raw 532 nm beam from pump laser (left) and after homogenisation (right).

With the small-signal performance of the amplifier established satisfactorily, the final stage was to increase the input and characterise the behaviour in the high-energy regime. A maximum output energy of 24 J from the amplifier was recorded. Full-aperture burn measurements were made at the input to the compressor to check the beam diameter and confirm the near-field had no severe hot-spots that might damage the gratings.

Compressor setup and optimisation

The mounts for the gratings and back mirror were assembled and tested offline, using the Zygo interferometer in the cleanroom to confirm the reproducibility of the positioning of each optic with respect to the encoder count. Once the chamber doors were installed, the optical mounts were lifted into the chamber and positioned, and the supports for the turning mirrors were installed. The drive motors for the mounts were tested and the encoder readouts calibrated, and a few minor mechanical problems corrected. The two gratings and the back mirror are each mounted in a cassette with bayonet fittings that engage positively with locating plates on the mounts. The optics are installed in the cassettes outside the chamber and can be relocated accurately if they have to be removed. Figures

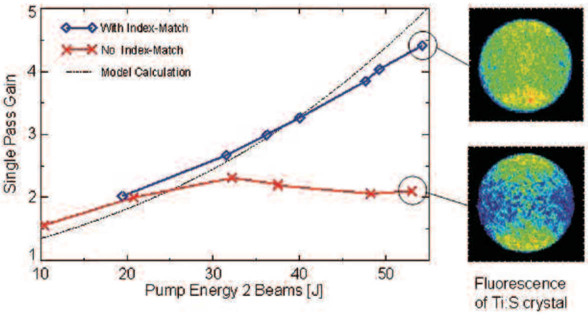

Figure 4. Small-signal gain measurements and TiS fluorescence images with and without index-matching liquid.

Figure 5. The first grating of the Gemini compressor mounted in the chamber, with the back mirror on the right.

Figure 6. The second grating and its mount inside the compressor chamber.

5 and 6 show the grating and back mirror mounts installed in the chamber, together with some of the turning mirrors.

The initial optical alignment of the compressor was performed with the 800 nm CW diode beam, and a small-aperture broadband diode beam was used to allow the groove orientations to be set parallel to a good approximation. The transmission of the compressor measured with this small-diameter beam was 74%, which is unexpectedly high and will mean that the maximum energy on the gratings can be kept lower, reducing the risk of damage. For normal short-pulse operation the first grating is fixed, and optimisation of the pulse length is done by moving the second grating. However, the first grating can be moved up to 300 mm towards the second to vary the duration of the compressed pulse if required. The compressor was adjusted using the 10 Hz beam from Astra, with the length of the compressed pulse being measured with a Grenouille in the small diagnostic beam that passes through a hole in the final turning mirror. A sliding mirror inside the chamber was used to set the grating planes parallel, and the far-field diagnostic was used to monitor the focal spot for the fine adjustments. After optimisation, the measured pulse duration was around 40 to 45 fs, not fully meeting the 30 fs specification, but considered close enough for the first experiment. The final component installed in the compressor chamber was the shutter between LA3 and TA3, which has an antireflection-coated disc of KG3 absorber glass mounted on it as a beam dump.

Diagnostic systems

Diagnostics in the amplifier include energy monitoring of the pump beams and amplified Ti:sapphire beam, near- and far-field images at the input and output of the amplifier and the pulse spectrum at input and output. These and other diagnostics are described in detail elsewhere in this report [4,5].

The compressed pulse diagnostics use three beams derived at the output of the compressor. The first is the 150 mm diameter beam transmitted through the 235 mm final turning mirror ((1) in Figure 7), which passes through the window (5) and is focused down by an F/8 achromatic doublet telescope lens (7). The main part of the beam is sent to the energy detector 14 (Gentec QE-12). An AR-coated optical wedge splits off a small fraction of the beam for monitoring the near-field profile and far-field/beam pointing on two CCD cameras (ref. [1]). The far field diagnostic includes a 10× microscope for imaging the diffraction limited spot size of ~6.6 μm. For pulse diagnostics a small part of the compressed pulse is transmitted through a 15 mm hole in the final mirror (1), to avoid stretching the pulse. An optical setup inside the vacuum chamber generates two beams of different intensity. The low-intensity beam is obtained via two front-surface reflections from uncoated wedges, and then leaves the compressor through a small aperture thin (t=2.5 mm) window (6). This beam is used for the measurements of pulse duration and spectrum. A second order autocorrelator (12) with spectral resolution, (a commercial

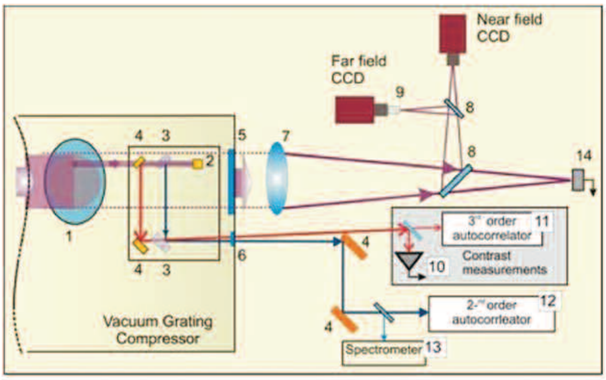

Figure 7. Schematic of the compressed pulse diagnostics: 1 - 235mm mirror with a 15 mm hole for the pulse probe; 2 - periscope for pulse probe diagnostics; 3 - uncoated glass wedges; 4 - mirrors; 5 - window; 6 - pulse probe window; 8 - glass flats; 9 - microscope objective for far field diagnostic; 10 - photodiode for contrast measurement; 11 - third order autocorrelator; 12 - second order autocorrelator; 13 - spectrometer; 14 - energy detector.

‘Grenouille’ 8-20 from Swamp Optics LLC) is used for the pulse-length measurements. The spectrum of the pulse is recorded by one of the channels of the Ocean optics spectrometer (13) in the Gemini diagnostics system (ref. EJD). The high-intensity beam is sent through the same thin window as the low-intensity beam, but at a slightly different angle to be spatially separated at the diagnostic table. This beam is used to measure the contrast with a third order autocorrelator (11) (Sequoia, from Fastlite), and pre-pulse with a fast photodiode (10). The optics for the higher intensity beam are designed to achieve a usable signal level at the Sequoia with pulses that have not been amplified in the Gemini amplifiers: these pulses arrive from Astra at 10 Hz repetition rate. The extra length of glass in the high-intensity beam is considered not to affect the contrast measurements, because the pulse will still be shorter than the time scale of the appearance of prepulses.

Laser performance

The output energy from the south amplifier has reached the 25 J design value of Gemini. The near-field profile of the beam is flat-topped with an acceptable level of modulation. The focal spot has been measured in the target area, and is around 1.5× diffraction limit on the majority of shots. The position of the focal spot is stable, remaining within a circle that is 0.35 of the diffraction-limited spot size. The contrast measured with a beam of relatively low energy was better than the instrument limit of 10^{-8} at 10 ps before the pulse; this measurement will be repeated with a higher-energy beam to improve the sensitivity. The pulse duration is typically between 50 and 70 femtoseconds at present, and this is the major limitation on the performance of Gemini. A campaign to bring the pulse duration down to the 30 fs specification will be conducted during the summer.

Summary

The south beam of Astra Gemini has been commissioned and used for two experiments in electron acceleration, which have both yielded significant new scientific results. The output energy has proved to be quite stable, and the beam quality and focal spot are generally good. There are some issues with long-term pointing stability, and the pulse length has yet to reach its specification; these matters will be addressed in the next few months. The operating philosophy of Astra has always been that the experimenters are given ‘shot on demand’ control over the laser, and this has been extended to Gemini: the laser fires at its repetition rate of three shots per minute, and the experimenters receive the next available shot. There are safeguards to shut the system down if a fault is detected, and to prevent shots being fired outside a pre-set range of parameters. This mode of operation is unique among high-power laser facilities, and the flexibility it offers has been greatly appreciated by the experimenters.

References

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