Upgrade to the Astra amplifier 3 optical pumping scheme

Contact *tiago.pinto@stfc.ac.uk*

T. de Faria Pinto, O. Chekhlov, Y. Tang, S. Hawkes

Central Laser Facility, STFC
Rutherford Appleton Laboratory,
Didcot, OX11 0QX, UK

Introduction

While next generation high repetition rate petawatt laser facilities such as the Extreme Photonics Application Centre (EPAC) will enable user groups to collect data at an unprecedented rate, productive operation of a high repetition rate facility requires extensive testing and development of laser and secondary source techniques as well as auxiliary features such as diagnostics and data management.

Gemini Target Area 2 (TA2), with its 10 Hz joule-level capabilities, is a prime location for this development work [1,2]. As such, it was closed to open applications in 2022 and is now dedicated to internal experiments and technology development for EPAC, with planned upgrades to increase the available laser energy from 1 J to 2 J before pulse compression.

This report details an upgrade to the Astra amplifier 3 optical pumping scheme, which resulted in a doubling of the available pump energy from 3.5 J to 7 J and a smoother pump beam profile. This will be followed in the future by the installation of a larger-aperture Ti:Sa crystal which will allow Astra amplifier 3 to double its output from 1 J to 2 J at 10 Hz.

Pump lasers

Astra amplifier 3 was previously optically pumped by 4 frequency-doubled Spectra-Physics Quanta-Ray, each producing up to 1 J of 532 nm at 10 Hz. In addition to the limited energy, the output beam profiles from these lasers were not smooth, showing high spatial frequency structures. These features were imprinted on the seed beam, leading to optical damage issues in subsequent amplification stages.

The new Q-smart HE 1500 deliver the same 1 J of 532 nm at 10 Hz as the Quanta-Rays, but their smaller size allows for 8 systems to be installed in a stacked configuration in the space previously occupied by the 4 Quanta-Rays, as shown in Figure 1, doubling the available pump energy while keeping the same table footprint.

Figure 1: Pump system stacked mounting configuration

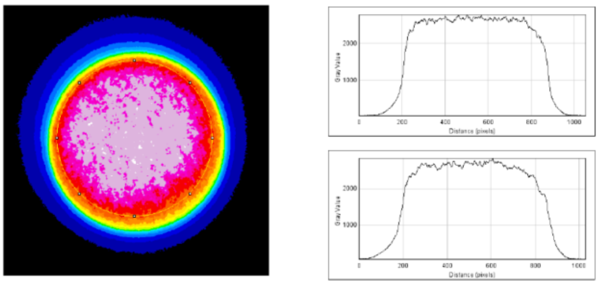

Figure 2: Typical Q-smart HE 1500 output beam profile.

Additionally, the Q-smarts output a near flat-top supergaussian beam shown in Figure 2, a great improvement over the spatial profiles of the Quanta-Rays. The spatial profile of the latter contain high spatial frequency features that are imprinted on the seed beam during amplification, leading to hotspots that result in optical damage to components further in the amplification chain (Figure 4, left).

Figure 3 shows a layout of the pump beams of Astra amplifier 3. The 8 beams are split into 2 sets of 4 beams, routed to opposite faces of the gain crystal, for even pumping. On either side, each set of beams is arranged in a tight 2 x 2 grid, with each beam occupying a separate quadrant of a diffractive homogeniser. Each homogeniser is preceded by a 2000 mm focal length plano-concave field lens, resulting in 4 overlapping 18 mm diameter flat-top beams on each side of the Ti:Sa crystal. Lastly, curved spherical mirrors on each side of the crystal reimage the unabsorbed energy back onto the crystal surface to make maximum use of the available energy.

Using a diffraction-based homogeniser creates a high quality flat-top pump beam at the crystal position without the need for lens-based imaging, greatly improving the near-field profile of the seed beam, as shown in Figure 4 (right). This configuration also results in a more compact layout, with improved stability and reliability by reducing the number of optics in the beam path.

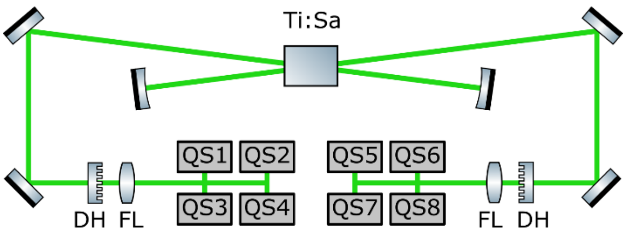

Figure 3: Astra amplifier 3 optical pumping layout. DH: diffractive homogeniser; FL: field lens

System performance

Immediately following installation, the lasers suffered from frequent damage to internal optics, significantly reducing the maximum safe output energy or leaving the systems inoperable until repaired. This had a significant negative impact on the operational schedule of the Gemini facility over the course of many months. A thorough investigation carried out by the manufacturer in collaboration with Gemini staff identified issues with the laser design, which were addressed with an upgrade package fitted to all the systems. After this upgrade, all 8 lasers operated reliably at their design specification.

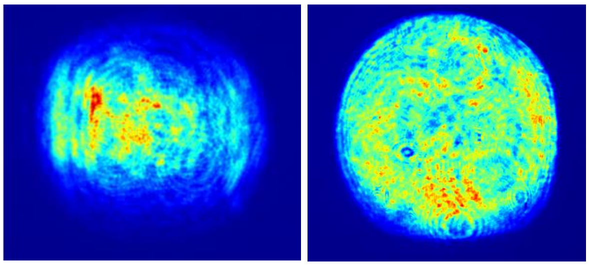

Figure 4: Left: Typical TA2 input near-field when pumped with Spectra Physics Quanta-Ray lasers. Right: Typical TA2 near-field when pumped with Lumibird Q-Smart HE 1500 lasers. Pulse energy of 1 J in both cases.

Conclusions and outlook

Despite some initial reliability issues, which were solved with effort from Gemini staff and the manufacturer, all 8 Q-Smart lasers are now operating at their specification. This first upgrade stage resulted in a significantly improved beam profile and more reliable achievement of the nominal 1 J output energy due to the extra redundancy.

While at the moment only 4 J of pump energy can be used without the risk of optical damage to the Ti:Sapphire crystal, the next step will be to install a larger crystal to allow for larger pump and seed beams, such that the full 7 J of pump can be used to deliver up to 2 J to Target Area 2 and the Gemini Laser Area 3. This will double the energy available in Target Area 2, making the area more attractive for electron acceleration via LWFA. The additional seed energy into the Gemini amplifier will allow the system to more easily deliver its nominal 15 J twin beams at a lower pumping energy, lessening the strain on the pump lasers and improving facility reliability.

References

[1] S. J. D. Dann *et al.* Laser wakefield acceleration with active feedback at 5 Hz. **Phys. Rev. Accel. Beams 22**, 041303

[2] Shalloo, R.J., Dann, S.J.D., Gruse, JN. *et al.* Automation and control of laser wakefield accelerators using Bayesian optimization. **Nat Commun 11**, 6355 (2020)