100-J Level Green Laser Beam Homogenization to a Pump Petawatt Class Ti:sapphire Chirped-Pulse Amplification Laser System

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The capability of diffractive optical elements (DOE) for beam homogenization of 100-J level high-energy Nd:glass green laser has been experimentally demonstrated. With the large-aperture homogenization optics, we have successfully generated near-perfect top-hat-like green beam intensity distributions at the target plane. The output of the system is readily suited for pumping a large-aperture Ti:sapphire crystal, making it possible to develop high beam quality, chirped-pulse amplification (CPA) systems at the petawatt (PW) power level.

Key Words: Diffractive optical element (DOE), Nd:glass laser, Ti:sapphire laser, Chirped-pulse amplification (CPA)

The advantages of chirped-pulse amplification (CPA) together with the unique properties of titanium doped sapphire (Ti:sapphire) media has made it possible to realize performance at the 100 TW or even petawatt (PW) power level, opening many new research frontiers in high-field laser-matter interactions. The frequency-doubled large-aperture high-energy Nd:glass green lasers are widely used as the pump lasers for such PW power level laser systems. The green pump beam for large-aperture Ti:sapphire amplifiers have to be as close as possible to a smooth, flat-top intensity distribution to generate a uniform population inversion in the pumped area. This enhances the amplified beam spatial quality, minimizing damage on large Ti:sapphire crystal and large gratings which are very expensive optics in the system. This also improves the amplification efficiency. However, the direct output beam of a high-energy, large-aperture Nd:glass laser system typically exhibits poor spatial profile quality which can lead to local hot spots that are responsible for strong intensity modulations and enhance parasitic transverse lasing. In order to reach the PW power level, it is essential to carefully control the green pump beam spatial intensity distribution where a top-hat-like intensity distribution is mandatory. For high-energy Nd:glass green lasers to pump high peak power Ti:sapphire CPA lasers, Aoyama et al. and Liang et al. use the image relaying technique, Eterl et al. employ diffractive optical elements, and Ple et al. use microlens arrays. However, to date, there have been only a limited number of reports on beam homogenization of high-energy lasers.

Here, we demonstrate the shaping of 100 J class high-energy green pump beams with a homogenizing system based on diffractive optical elements (DOE). We have successfully obtained 51 mm diameter near-perfect flat-top green pump beam intensity distributions for pumping both sides of a large-aperture Ti:sapphire crystal. Maximum green output pulse energies of 64 J have been achieved with the diffraction efficiencies of 82 %.

Figure 1 illustrates the experimental arrangement for the beam homogenization using a frequency doubled high-energy flash-lamp pumped Nd:silicate glass laser system. This laser has a single-pass master oscillator power amplifier (MOPA) architecture. In the system, a long-cavity 1,064 nm Nd:YAG master oscillator generates 200 mJ pulses with about 28 ns (FWHM) duration, which are then shaped by a soft aperture to a near-flat-top intensity distribution. The pulses are then amplified to 1 J by a 9-mm diameter Nd:YAG rod preamplifier. The energies are further increased in a chain of 16, 25, 45, and 64 mm diameter Nd:silicate glass rod amplifiers to approximately 180 J. Spatial filters and optical isolators (a pair of Faraday isolators) are used to prevent pulses from propagating back up the laser chain at appropriate locations.

The 1,064 nm output pulses are down-collimated to 40 mm diameter and then are frequency doubled to 532 nm with two 60 mm × 60 mm Type I KD2PO4 (DKDP) crystals (Cleveland Crystals, Inc). DKDP crystals are chosen because of the easy availability in large sizes. The input and output faces of the crystals are SolGel AR coated for both 532 and 1,064 nm laser
radiation. A two-stage DKDP crystal architecture is used in order to achieve high conversion efficiency and to minimize back-conversion. A maximum green pulse energy of 95.5 J is generated with an incident fundamental energy of 177.4 J at 504 MW/cm², corresponding to an energy conversion efficiency of 54 %. The dichroic mirrors separate the green and unconverted fundamental frequencies. With a half-wave plate and a thin-film polarizer, we have split the green pulses from the DKDP crystals and balanced the pulse energies to provide similar energies for pumping both sides of the Ti:sapphire crystal. The two pulses are delivered to Ti:sapphire crystal using reflective optics, image relaying optics, a half-wave plate and DOEs. The polarization plane for one side is suitably oriented with respect to the Ti:sapphire crystal using a half-wave plate. Some techniques of beam homogenization have been investigated such as the micro lens array and DOE. We have selected DOEs (SILIOS Technologies) for beam homogenization because they could produce a circular top-hat profile with sharp edges and they were readily available in the required size. The clear aperture of our antireflection-coated DOEs are 80-mm. Each DOE is divided into about 200 sub-cells which are all expanded onto the same area at the target plane which lies in the Ti:sapphire crystal. The eight level striped pattern corresponding to the engravings in the sub-cells in 1-mm thick fused silica material are specially calculated for our requested shape. The diffraction efficiency of DOE is measured to be 82 %. The non diffracted and focused on the axis beams are dumped. The measured transmittance efficiency from second DKDP to Ti:sapphire crystal including the DOE efficiency is 67 %.

Figure 2 shows the near-field spatial intensity distributions of the green beams from each DKDP crystal and the intensity distributions along the vertical and horizontal cross-sections of these beams are also shown. The near-field spatial intensity distributions are imaged by CCD camera through a set of image-relay optics with ~100-J high-energy green beams. As seen, the beams exhibit poor spatial qualities which are not suitable for directly pumping the Ti:sapphire amplifier. Most of the energy is concentrated in outer edge area and therefore optical damage or parasitic oscillation could occur. Figure 3 shows the homogenized intensity distributions that are generated in the plane of the Ti:sapphire crystal for both pumping sides (as seen in Fig. 1) after passing through the DOEs. A maximum homogenized total green energy of 64 J is obtained at the plane of the Ti:sapphire crystal. From these figures, it is seen that near-perfect top-hat-like intensity distributions are successfully generated. The DOE capability for beam homogenization is clearly demonstrated. Because the use of beam homogenizers can prevent crystal damage or parasitic oscillation due to the spatial irregularities of pump beams, this should allow greater amplification by pumping the crystal with a higher fluence.

In conclusion, we have demonstrated experimentally the capability of DOEs for beam homogenization of a 100-J level high-energy Nd:glass green laser system. We have obtained near-perfect top-hat intensity distributions with a total homog-
enized green pulse energy of 64 J. This DOE approach can be easily scaled up in energy by simply increasing the DOE size to accommodate input green laser beams with larger cross-section. By virtue of the large size availability DOEs are very useful for the homogenization of high-energy Nd:glass laser system emission. This scheme is currently being applied for pumping an 80-mm diameter Ti:sapphire amplifier aimed at producing PW class performance.

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