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The Nexawatt: A Strategy for Exawatt Peak Power Lasers Based on NIF and NIF-like Beam Lines

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Abstract. An exawatt-scale, short-pulse amplification architecture based upon a novel pulse compressor arrangement and amplification of long-duration chirped beam pulses is described. This architecture is capable of extracting the full, stored energy of a NIF or NIF-like beam line and in doing so produce from one beam line a near-diffraction-limited, laser pulse whose peak power would exceed 0.2 EW. The architecture is well suited to either low- f -number focusing or to multi-beam, dipole focusing concepts that in principle enable focused intensities in the range of 10^{26} W/cm² or 5 orders of magnitude beyond that possible from present PW systems based on chirped pulse amplification.

1. Introduction

Modern, inertial confinement fusion lasers based on Nd:glass have amplification bandwidths that are capable of supporting sub-picosecond pulses. With the implementation of chirped pulse amplification (CPA), it is possible for beam lines at the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL), the Laser Mega-Joule (LMJ) facility in Bordeaux, France, the LFEX laser at the Institute for Laser Engineering in Osaka, Japan and the Omega EP facility at the Laboratory for Laser Energetics in Rochester, New York to create petawatt peak power laser pulses of nominally 1-kJ energy [1]. While these systems are at the forefront of present high-energy, high-peak power capabilities, they utilize only a small fraction (typically less than 10%) of the potential stored energy of the underlying Nd:glass laser amplification system. A single beam line at the NIF, for example, has a stored energy in excess of 25 kJ [2]. Scaling of existing PW systems to higher peak power and high energy per beam is limited by intensity dependent damage of final optics, lack of sufficient pre-amplifier bandwidth to support shorter duration pulses and insufficient stretched pulse durations required to avoid the onset of b-integral-dependent, non-linear damage of the main amplifiers and transport optics.

The NIF exawatt or “Nexawatt” concept circumvents traditional CPA limitations via a combination of chirped pulse and chirped beam [3] amplification, a novel pulse compressor arrangement capable of compressing 20-ns duration pulses and an increase in the final beam area via splitting beams before final compression. When combined with wide-bandwidth pre-amplifiers [4] these techniques can in principle produce near-diffraction limited pulses with peak powers in excess of 200 PW and pulse durations of order 100 fs from a single amplification beam line. It should be noted that amplification to the 25 kJ level of 100 fs pulse bandwidths is possible without having to change the main Nd:phosphate amplifier glass but does require significant modification of the pre-amplification stages



to include both optical parametric amplification and Nd:silicate amplifiers. These modifications enable the creation of joule-level, seed pulses whose spectrum is shifted and wider than the natural FWHM gain bandwidth of kJ-class Nd:phosphate amplifiers. Saturated amplification of such seed pulses to > 20 kJ output produces a net bandwidth capable of supporting sub-100-fs pulses. For the remainder of this manuscript we posit the existence of appropriate pre-amplification to enable 100 fs pulse production. [4]

The Nexawatt strategy also avoids final optic damage by increasing the beam area by splitting the amplified beam prior to the final compressor optics and then coherently recombining the beams prior to focusing. This approach is compatible with a variety of final focusing arrangements including low-f-number focusing and dipole focusing [5]. As such a Nexawatt beam line can potentially produce peak intensities in excess of 10^{26} W/cm² or more than 5 orders of magnitude beyond the existing state of the art for existing PW laser systems.

2. Nexawatt Architecture

Existing high-energy, petawatt lasers such as the ARC PW at LLNL [6] are based upon CPA in large-aperture, Nd:phosphate glass amplifiers and utilize meter-scale, high-damage-threshold, multilayer-dielectric gratings to compress the chirped pulses to their final, ps pulse duration. The exact size of the gratings in a typical four grating compressor such as that shown in Figure 1 is set by the combination of the projected area of the input beam on the grating at use angle and the duration of the chirped pulse that is to be compressed. For 1780 gr/mm gratings used in ARC, the highest efficiency and damage threshold is obtained at a use angle ~ 76.5 degrees. [6] As illustrated in Figure 1, at this use angle a chirped pulse with a duration of 3.34 ns and a full beam aperture of 37 cm x 37 cm would require a second (and third) grating of dimensions 37 cm x 200 cm. While the maximum aperture of the existing gratings used in the ARC system is currently 40 cm x 95 cm, the tools used to fabricate these gratings are in principle capable of producing a 200 cm wide optic via stitched lithographic exposure. For the remainder of this manuscript we will posit the existence of 200 cm wide gratings. In Figure 1, it is evident that the beam area in the dispersed dimension has been increased from 37 cm to 46 cm at the position between gratings 2 and 3. At this position one has a partially compressed pulse that has spectral content that is distributed both in time and in space. The center portion of the chirped-beam pulse has a pulse duration equal to half of the input pulse duration while the edges of the

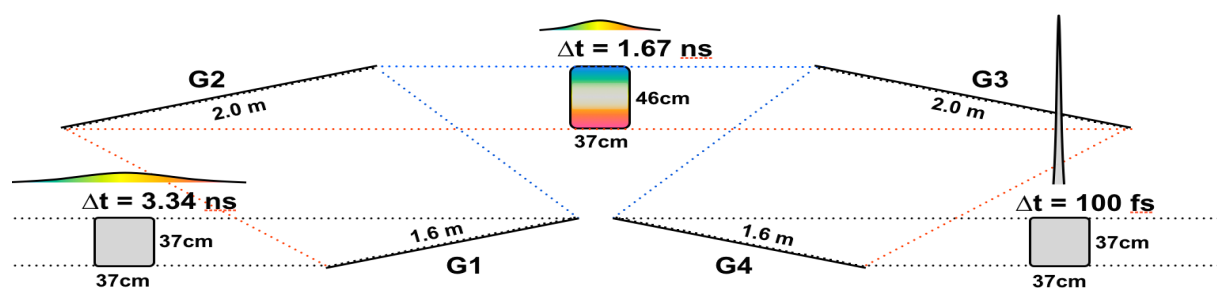


Figure 1. Standard parallel grating pulse compressor with 3.34 ns input chirped pulse duration and NIF beam dimensions

beam pulse do not contain the full spectral content of the input beam and are somewhat longer in duration. The second parallel grating pair (gratings G3 & G4) removes the spatial chirp from the beam and creates the remaining delay required to fully compress the pulse to its ultimate pulse duration of 100 fs. As is evident from examination of Figure 1, only 20% of the area of gratings G2 and G3 actually contributes to creating the delay required for pulse compression. The remaining 80% of the grating aperture is simply required because of the size of the input beam.

Because of b-integral limits [2], a 3.34 ns pulse can only be safely amplified in a NIF amplification chain to approximately 4.2 kJ prior to compression. To achieve higher energy, one must utilize a

longer duration chirped pulse. In principle it is possible to operate within the b-integral limits of NIF and produce a 25 kJ output pulse from a single beam line if the amplified pulse duration is 20 ns. It is certainly possible to create a chirped pulse of 20 ns duration but compression with a 4-grating compressor such as that in Figure 1 would require a grating aperture for gratings G2 and G3 of nearly 4.5 meters!

The Nexawatt amplification architecture and its six grating pulse compressor is illustrated in Figure 2. In this architecture the output from the pulse compressor is a beam with an area equal to half of the standard NIF beam, i.e. 18.5 cm x 37 cm while the input to the amplification chain is a chirped beam pulse with an area equal to the standard NIF beam, i.e. 37 cm x 37 cm. The duration of the chirped beam pulse is 20 ns and therefore can be amplified to ~ 25 kJ safely. In the compressor the first two gratings invert the spatial chirp and produce a delay such that the pulse after G2 is 11.7 ns. This 8.3 ns FWHM delay can be determined geometrically given the dispersion illustrated in Fig. 1 and the increased separation and beam area of gratings. The second two gratings further compress the pulse to 3.4 ns and create a chirped beam pulse with the same area as the input beam pulse but with the spatial chirp identical to the input beam-pulse. The final two gratings remove the beam chirp and provide the final 3.34 ns of delay required to produce an ~ 100 fs compressed pulse. It should be noted that this architecture only requires two 2-meter wide gratings yet is capable of compressing a 20 ns pulse.

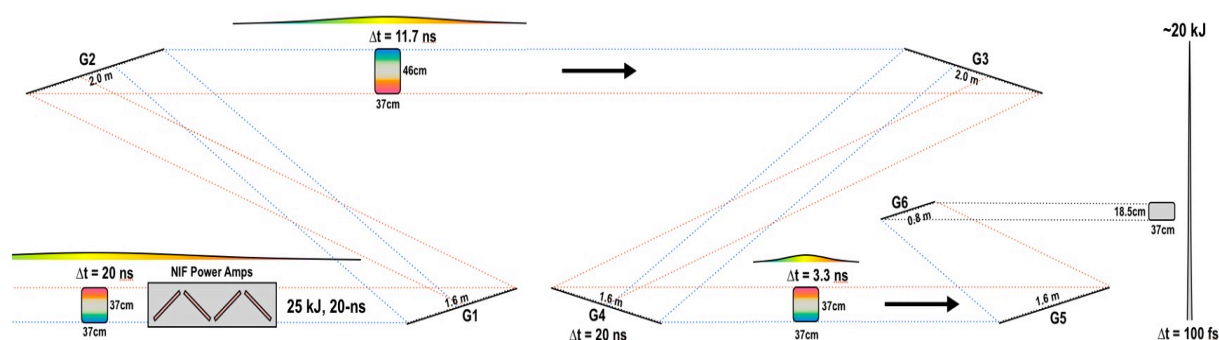


Figure 2. Nexawatt amplification and compression architecture for 0.2 EW pulse production

Gratings G1, G2, G3 and G4 operate within the long pulse damage limits of MLD gratings [6]. Of course the final grating (G6) illustrated in Figure 2 would be incapable of handling a 20-kJ, 100-fs pulse because of its limited 18.5 cm by 37 cm beam area. To alleviate this problem, the Nexawatt concept splits the beam after the fourth grating (G4) and before the fifth grating (G5) into N identical “beamlets”. As illustrated in Figure 3, it is possible to split the beam with an appropriate beam splitter arrangement so that each new beamlet is not only identical in energy but also in dispersion or chirp. The number of beamlets required for safe operation is determined by the damage threshold of the final grating and focusing optics.[6] Using the existing damage characteristics for ARC optics [6] and assuming a total combined output of 20-kJ in 100-fs, approximately 20 beamlets are required for safe operation. Combining the individually compressed pulses to form a coherent beam is possible with “cooperative-target”, beam-phasing architectures that have been previously investigated for beam phasing of ARC sub-apertures [7]. Such techniques can also be used to correct for beam spatial distortions and in principle to produce near-diffraction limited output. The multi-beamlet, final-focusing geometry of the Nexawatt concept is highly flexible and compatible with either low f-number focusing as illustrated in Figure 3 or with higher-intensity, dipole focusing concepts. [5] Dipole focusing could in principle produce intensities of greater than 10^{26} W/cm² from the 0.2 EW Nexawatt output of a single NIF beam line. It should be noted that only gratings G5 and G6 need be enclosed in a vacuum chamber as the pulse duration is long (3.4 ns) prior to grating G5.

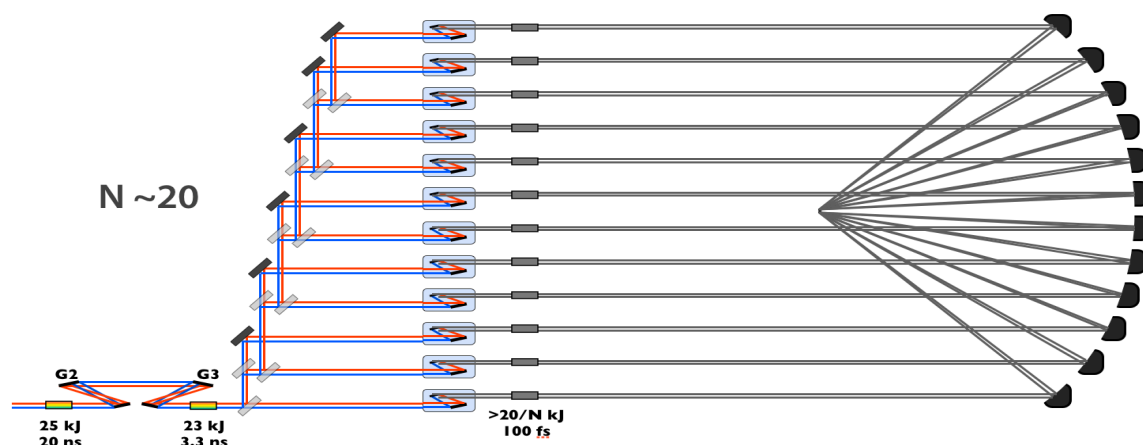


Figure 3. Nexawatt beam splitting and final focusing concept

3. Conclusions

The Nexawatt concept enables full extraction of the stored energy from large-scale, Nd:glass laser amplifiers and the generation of exawatt-scale, 100-ps pulses. It increases short pulse amplification efficiency from <10% to nearly 100%. The concept is based on demonstrated designs and damage thresholds for final optics, is compatible with existing tools for fabrication of compressor gratings and requires only two, 2-meter compressor gratings. The concept operates within the established pulse-width dependent amplification capabilities of NIF and NIF-like amplifiers and unlike other exawatt concepts that aim to combine individually amplified beams, the Nexawatt concept phases “identical” beams after amplification and is compatible with existing beam phasing technologies. The multi-beamlet final output of the Nexawatt is compatible with dipole focusing and theoretically could enable extension of ultrahigh intensity laser science by > 5 orders of magnitude.

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References

- [1] Zuegel J D, Borneis S, Barty C P J, Legarrec B, Danson C, Miyanaga N, Rambo P K, Le Blanc C, Kessler T J, Schmid A W, Waxer L J, Kelly J H, Kruschwitz B, Jungquist R, Moses E, Britten J, Jovanovic I, Dawson J and Blancot N 2006, *Fusion Science & Tech* **49**, 453-482
- [2] Haynam C A, Wegner P J, et al. 2007, *Applied Optics* **46**, 16, 3276-3303
- [3] Barty C P J 2004 Optical Chirped Beam Amplification & Propagation, *US Patent #6,804,045*
- [4] Gaul E, Martinez M, Blakeney J, Jochmann A, Ringuette M, Hammond D, Borger T, Escamilla R, Douglas S, Henderson W, Dyer G, Erlandson A, Cross R, Caird J, Ebberts C, and Ditmire T 2010, *Applied Optics*, **49**, 9, 1676-1681
- [5] Gonoskov A, Bashinov A, Gonoskov I, Harvey C, Ilderton A, Kim A, Markland M, Mourou G and Sergeev A 2014, *Physical Review Letters*, **113**, 014801
- [6] Barty C P J, Key M, Britten J, Beach R, Beer G, Brown C, Bryan S, Caird J, Carlson T, Crane J, Dawson, J, Erlandson A, Fittinghoff D, Hermann M, Hoaglan C, Iyer A, Jones L, Jovanovic I, Komashko A, Landen O, Liao Z, Molander W, Mitchell S, Moses E, Nielsen N, Nguyen H, Nissen J, Payne S, Pennington D, Risinger L, Rushford M, Skulina K, Spaeth M, Stuart B, Tietbohl G and Wattelier B 2004 *Nuclear Fusion* **44**, 266-275
- [7] Baker K L, Homoelle D, Utterback E, Stappaerts E, Siders C W and Barty C P J 2009, *Optics Express* **17**, 19 16696