Novel Design of Ultrashort Pulse Excimer Laser Amplifier System II

(Temporal Gain Control and Phase Distortion/ASE Characteristics)

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Abstract—The previous design work for very large final amplifier pumped by electron beam module was described from the point of view of energy characteristics. In this work, the design problems for phase front distortion, ASE, and gain control in large aperture amplifier are presented in detail.

Index Terms—low pressure wide-aperture amplifier, ultrahigh power KrF laser, ultrashort high intensity laser.

I. INTRODUCTION

Recently, the national agencies for scientific research in European countries have decided to investigate the case for a European facility for basic and applied research using pulsed power lasers. The facility that has already been identified would provide short-wavelength pulses of up to 100kJ in the nanosecond regime and up 10^{15}(petawatt) in the subpicosecond regimes. Because of the large cross-sections of the two main amplifiers, we proposed the low pressure operation regime in previous paper[1]. With very low pressure operational mode, which can use a thin and large aperture window in order to reduce nonlinear effects such as self-phase modulation and multiphoton absorption at high intensities.

A numerical study was performed for a very low pressure below 200 Torr buffer-free KrF laser amplifier medium pumped by a short pulse (10 ns FWHM) electron beam with an excitation rate of 200 kW/cm^3 because of the large cross-sections of the two main amplifiers. These amplifiers can only be electron-beam pumped in large KrF system[2]. Since only one double-pass of the pulse through the amplifiers is planned, a short e-beam pulse (~10ns) is sufficient and leads to a relatively small energy that must be applied by a marx generator. The total energy deposition as a function of distance is shown in Figure 1. The results shows the sufficient energy deposition in the low pressure operation regime. For high efficiency the pumping should occur in the form of traveling-wave pumping. This could be done by proper delays between the manifolds of diodes.

This paper deals with the critical issues of a large aperture KrF laser system like as phase-front distortion, Amplified Spontaneous Emission(ASE) effect, focusability, and the temporal control of gain in the amplifiers.

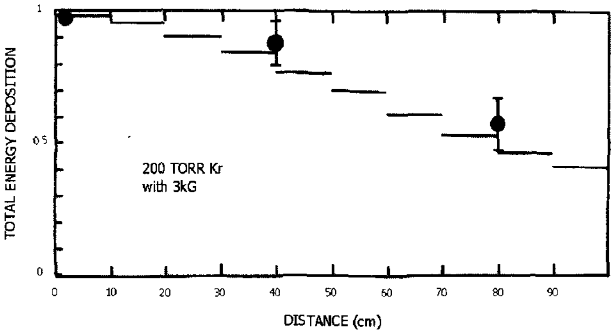

Fig.1 Total energy deposition as a function of distance

II. PHASE FRONT DISTORTION

The other important requirement for the power amplifier is to achieve minimum phasefront distortion during amplification. The resulting phase shifts from amplifiers distort the coherent phasefront and limit the far field beam quality. The effect of phase shifts on far field beam quality follows from the normalized Strehl intensity[3]. The important requirement for the power amplifier is to achieve minimum phase front distortion during amplification.

The mechanism of transient refractive index change has been studied in the case of XeF gas mixture[4]. Changes in the refractive index are due to several processes, each of which has its own characteristic time scale. The development of density fluctuations due to heat energy from the e-beam is limited by the speed of sound, so that these effects are negligible during a relativistic e-beam pulse. The main effect is due to plasma dispersion, fuel burn-up and anomalous dispersion. The dominant change is due to the halogen burn-up effect because of the relatively large difference in the refractive index of F2 and F. The changes are more significant at shorter wavelengths and higher energy deposition. When we limit our pumping time at a power of 200 kW/cm^3 to 10 ns, the energy deposition is only 2 J/l. With this relatively small energy deposition, it is possible to assume that $dn = 10^{-9}$ as the refractive index change between the pumped and un-pumped regions. With an active length of L=3m (double pass), the wave front change of dnL is only wavelength of 1/80. It is also pointed out that richer halogen mixtures show smaller levels of transient refractive index changes than normal

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lean mixtures, though this may result in less efficient amplification due to increased absorption. In a low pressure operation mode, the F2 burn-up may come earlier than in the normal pressure mode because of reduced total F2 abundance.

A report from the university of Illinois group describes this issue in their discharge pumped amplifier[5]. The contribution to nonlinear distortion from the amplifier medium, consisting of a 1.6 atm He-buffered gas mixture of 5 m length, is negligible. A measurement of the beam distortion of the gas flow system demonstrated a rms distortion of the first small-aperture discharge amplifier in the front-end stage, After the first pinhole this is treated as the background of the seed fs-pulse which has a lower energy but the same beam divergence as the seed pulse. The other is from the amplifier itself that is isotropically generated with higher energy. In order to minimize the amplifier-originated ASE and thus reduce the energy loss through ASE and keep the high contrast ratio, the requirements are as follows sign to beam distortion seems much less than that of the output window.

III. AMPLIFIER ORIGINATED ASE

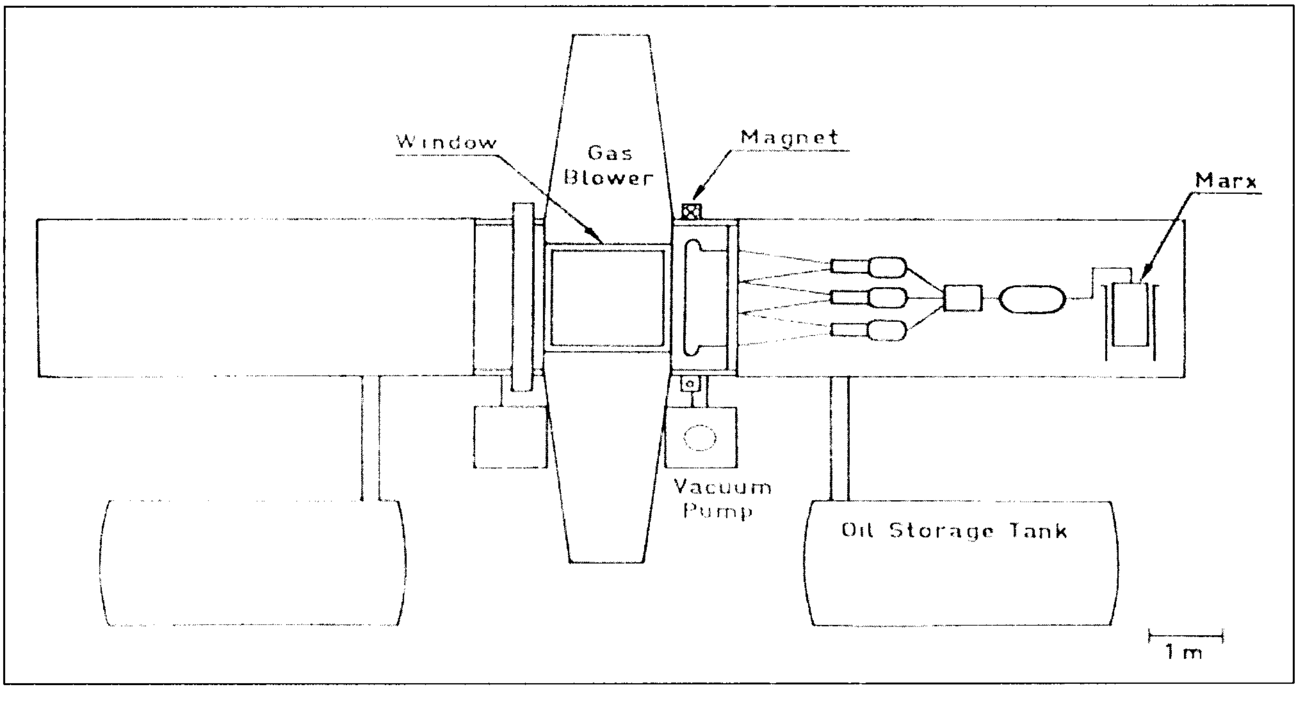
Short pulse amplification experiments that have been carried out have all shown rather high levels of ASE background in KrF fs-pulses. Recent experiments in Max-Planck-Institute have shown an ASE energy content of 10^{-7}on the target due to the optimization of the amplifier chain. This ASE effect is divided into two categories. One is originating from the first small-aperture discharge amplifier in the front-end stage, After the first pinhole this is treated as the background of the seed fs-pulse which has a lower energy but the same beam divergence as the seed pulse. The other is from the amplifier itself that is isotropically generated with higher energy. In order to minimize the amplifier-originated ASE and thus reduce the energy loss through ASE and keep the high contrast ratio, the requirements are as follows :

(1) maintain low wall reflectivity,
(2) minimize unextracted volume,
(3) keep small signal-gain at low level,
(4) control the temporal behavior of gain.

Reducing the gain window to a minimum is effective in reducing the ASE feedback(this was implied by a LANL experiment) and the total ASE energy and it increases the extraction efficiency. The gain it increases the extraction efficiency. The gain duration time T is the important parameter determined by the amplifier optical double-transit time, KrF kinetics, the e-beam propagation time across the aperture, and the rise time of the e-beam current.

IV. GAIN CONTROL IN LARGE KRF SYSTEM

The important issue in the prototype design is the assembly of modules with emphasis on the temporal control of the gain and easy maintenance accessibility. Figure 2 is the front view of the assembled amplifier design as shown the top view in Fig. 2 in Ref. [1]. For each side, six modules are stacked. A module has its own power-deliverly section(intermediate capacitor, main gap, 3 PFLs, 3 peaking gaps, and 3 transmission lines), diode section, and vacuum section(vacuum chamber and



pump). Two Marx generators and one pair of guiding magnets are the common equipments. Each Marx generator has 2MW output voltage and 24 kJ energy storage capability. Many supporting facilities such as oil tanks, oil pumps, vacuum pumps, guide magnet power supply, Marx bank charging power supply, and diagnostic shield cabin should be positioned on the lower level of the main facility for easy access. A gas flow guide vane is attached to the laser chamber on the top and the bottom. The gas blower is installed just behind the total reflection mirror.

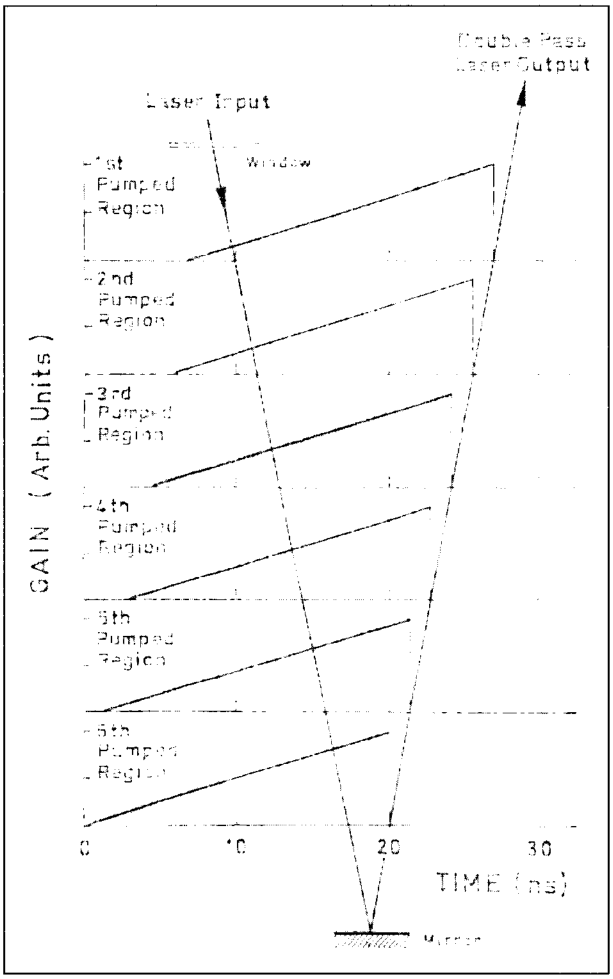


Fig. 3 A quasi-travelling excitation scheme of the 100 J amplifier. The gain is completely depumped by the saturating pulse.

The back mirror should be installed to be perfectly free from mechanical vibrations of many pulse power /vacuum components. The temporal behavior of each gain module and the amplified pulse are shown in Figure 3. The initiation of each e-beam is adjusted for the amplified pulse to deplete the gain in the second path completely. A quasi-traveling excitation scheme as shown may be achieved by sub-nano second precise triggering of the 2MV main gap switch. The Hermes III accelerator of Sandia National Laboratory is the most developed power modulation system up to now based on a similar modular concept[6]. A one-sigma jitter for a single switch of <2ns was obtained with 15 mJ, 20 ns KrF light. It is pointed out that the jitter is possibly reduced to the sub-nano –second region with faster rise time of the trigger laser pulse. The other effort is now under way in RAL(Rutherford Appleton Laboratory) for the Super Sprite PFL[7]. The main features are four channel laser trigger switching to support 2.4 MV, 200 kA, 250 ns pulsed power. The expected technology development in the amplifier construction coincides with pulsed power efforts in other places. A sub-ns jitter, fast current rise(< 10 ns), broad area e-beam (25 cm x 25 cm) module development is the key factor.

CONCLUSION

This conceptual design work including previous paper is an optimization of the e-beam pumping technology for a short-pulse amplifier with very low pressure operational mode. Several estimations were made to determine the specifications as follows.

Relation between acceleration voltage, current density, guiding magnet strength, Kr/F_2 gas pressure, chamber structure for 200 kW/cm^3 pumping power and 1-2 % cm^{-1} small-signal gain coefficient by a 10ns e-beam pulse.

To confirm the temporal simultaneity of e-beam deposition over the aperture in the chamber. (Drift velocity of electrons in ~ 200 Torr Kr)

Transient reflective-index changes in the KrF low-Pressure gas mixture and its influence for optical quality. To confirm the single pass small signal gain in the actual situation at the low pressure regime and ASE gain depletion effect.

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