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NOVETTE, A SHORT WAVELENGTH LASER-TARGET INTERACTION SYSTEM*

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The construction of Novette began in September of 1981 with the deactivation of the Argus laser. This winter, Novette's on-target laser energy at $0.53 \mu\text{m}$ will exceed 10 kJ in pulse lengths of 1.0 to 5.0 nsec.

Recent laser plasma interaction experiments at much lower energy confirmed more efficient coupling of laser energy to fusion targets at

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short wavelength.¹ At present, the desired performance characteristics of a multi-kilojoule short wavelength laser for fusion target irradiation can only be realized by frequency converting a Nd:glass laser system. Tight schedule constraints limited the Novette frequency conversion options to frequency doubling in monolithic arrays of potassium dihydrogen phosphate (KDP). The Novette laser contains two 120 m long Nd:phosphate glass amplifier chains, which are optically identical to the Nova system design, driven by a common master oscillator. These amplifier chains use Shiva components and borrowed large aperture Nova optics supported by special frames. After negotiating the three folds required to fit these chains into the space previously occupied by Argus, the emerging 74 cm diameter laser beams are frequency doubled to $0.53 \mu\text{m}$ and focused by f/4 doublet lenses into the refurbished Shiva target chamber.

Novette has been designed to deliver 18.0 kJ in 1 nsec and 28 kJ in 3 nsec as maximum damage limited drive to the frequency conversion arrays. We expect maximum frequency doubled on-target energies of 13 kJ in 1 nsec and 20 kJ in 3 nsec. Propagation studies performed as Novette has been activated will be reviewed and their bearing on the Nova laser design discussed. The characteristics of the incident laser radiation in the target chamber center will be described.

Introduction

Glass laser system construction at the Lawrence Livermore National Laboratory over the past decade has been an evolutionary process. The fundamental design, that of a master oscillator driving a single pass power amplifier, has been gradually improved by using successive generations of progressively more reliable, efficient, and cost effective components. Along the way, much has been learned about high power laser pulse propagation in dielectric media typically found in Nd:glass amplifier chains. This has led to the use of spatial filters in optically relayed designs to control local spatial intensity fluctuations in the laser beam. Maximizing the "fill factor", or efficiency with which each amplifier's aperture is used, while minimizing the ripple on the laser field, naturally minimizes the peak laser flux which each optic must tolerate to produce a given output power. Ultimately, it is always the damage threshold of the optical components which limits the single shot performance of such a laser. In addition, without careful attention to component maintainability and stability of alignment, laser systems with several hundred optics can not be successfully operated. Sealed modularized components have thus come into use through which the oscillator pulse is progressively amplified and beam expanded in order to stay below optical damage thresholds.

Nova is the current manifestation of this design philosophy and is scheduled to irradiate inertial confinement fusion targets in 1985.

1. C. Garban-LaVaune et al, Effect of Laser Wavelength and Pulse Duration on Laser-Light Absorption and Back Reflection, Phys. Rev. Lett. 48, 1018 (1982).

Nova's design draws upon experience gleaned from earlier LLNL lasers such as Shiva and its architecture has been dramatically affected by the advances made in understanding laser/plasma coupling over the past three years. For example, the Nova design now calls for harmonic conversion of the fundamental infrared (1.053 μm wavelength) laser pulse to green (0.526 μm wavelength) or to ultraviolet (0.351 μm wavelength) before the beam is focused on to the target. Experimental studies using short wavelength harmonic converted laser pulses to study laser/plasma target coupling have thus far been carried out with fairly modest laser energies. Consequently, many questions concerning scaling to ~ 100 kJ Nova energies need to be addressed. Problems with laser/target coupling, nonlinear pulse propagation, and operation of large aperture frequency converted laser systems can be addressed with a test bed laser. The Novette laser system emerges as a means to cope with many of these concerns and thus to assure the eventual success of Nova.

Laser Design

In designing the Nova system, the architecture which had proven effective in past systems was used. Repeatable high quality master oscillators typically have an output of approximately 10^{-4} J. Thus, obtaining 100 kJ output requires a gain of 10^4 between the oscillator and the target. The master oscillator pulse first passes through the preamplifier consisting of glass rod amplifiers and beam splitting elements to provide ten parallel beams of approximately 1 joule energy. The power amplifier which follows, consists of ten single pass, parallel chains of rod and disc amplifiers of increasing aperture with each stage output flux near the operating limit. Spatial filters capable of handling high power beams provide the beam expansion and propagation control between stages.

In such a system the principle design limitation on energy/aperture is laser damage to optical surfaces which depends upon the type of surface, the pulse duration, and the wavelength. Recently we have been able to replace low damage threshold thin film AR coatings by surfaces treated by the neutral solution leaching process which produces low reflectivity surfaces on borosilicate glasses with surface damage thresholds approaching that of the base polished glass, 12 to 16 J/cm² at 1 ns. This technology is being used on the large diameter spatial filter lenses, windows and target focusing lenses in Novette in preparation for Nova.

One of the main goals of laser design is to maximize the output energy without damaging the optical components in the chain. Ideally, one would propagate a square beam with output flux just below the damage limit. However, one cannot propagate such a beam for any useful distance because diffraction of the beam edges leads to constructive interference, regions of excessive optical flux and thus damage. To reduce diffraction, one rounds or "apodizes" the perimeter of the beam with the result that for a perfectly smooth beam one can extract only $\sim 75\%$ of the energy stored in the amplifier medium. In practice, a perfectly smooth beam cannot be realized and the actual average flux is further

reduced by beam spatial modulation arising from imperfections such as, accumulated damage, dirt on the optics, and upstream phase errors all of which are exacerbated by self-focusing instabilities. The most threatened components are generally the surfaces of the spatial filter input lenses. In the original Nova design we planned to leave these lenses uncoated to permit high fluxes at these locations. The substitution of lower loss neutral solution AR surfaces in Novette has allowed higher output energies and lowered the flux requirements early in the chains.

Novette is the first implementation of the Nova laser chains scheduled to start target experiments in late calendar year 1982. The Novette power amplifier largely consists of two borrowed Nova amplifier chains. The laser subsystems, including the master oscillators and preamplifiers, control, and laser diagnostics are all of the current Nova baseline design. Many parts through the 20.8 cm stage came from Shiva; the target chamber is the Shiva chamber modified to accept two large aperture horizontal beams. Initial target experiments will be conducted at the second harmonic wavelength of $0.53 \mu\text{m}$ generated in monolithic KDP arrays located between the final turning mirrors and the target chamber. The target diagnostics instruments include many from Shiva and Argus modified for Novette together with several entirely new systems.

Figure 1 is an optical schematic of a Novette laser amplifier chain showing the beam size and the relative location of the components. The beam begins at a 2.7 cm input aperture, passes first through a spatial filter where it is expanded to 3.75 cm and then amplified in a single 48 cm long glass rod amplifier. Following the rod amplifiers, the beam passes through a series of beam expanding and relaying spatial filters and glass disk amplifiers of increasing size. The first two series of amplifiers, with 9.4 cm and 14.5 cm clear apertures, are hardware removed from Shiva and refitted with phosphate glass disks. The 20.8 cm aperture amplifiers are of the more efficient box design. Through the first 20.8 cm amplifier each Novette arm is the equivalent of a Shiva arm. With the substitution of two Nova style 20.8 cm diameter amplifiers and with higher damage threshold coatings on the spatial filter optics, the energy capability at the 20.8 cm diameter is more than 3.5 times that of a Shiva beam. Following the 20.8 cm diameter stages, the beam is expanded to 31.5 cm, passes through the final Faraday rotator isolator in the chain, is turned by two mirrors to direct it down the final leg of the spaceframe where it is further amplified by four 31.5 cm aperture amplifiers and three 46 cm aperture output amplifiers. Each of these amplifiers contains two disks and there is provision to add one additional amplifier of each size to each chain if we can obtain output optics which are able to survive the additional flux. The output beam is now expanded to 74 cm to lower the flux on the turning mirrors and the frequency conversion and focusing optics. The frequency conversion array is located between the final turning mirror and the target focusing optics and is followed by a $1.05 \mu\text{m}$ absorber to remove the residual fundamental light. These chains differ from a Nova chain only in the addition of two folding mirrors at the 14.5 cm size, the locations of the 31.5 cm rotator and the final turning mirror arrangements. These changes

Figure 1. Optical Schematic of LLNL Mopa System Architectures

were necessary to fit the 120 m long laser and the target facility into the existing 70 m by 14 m building.

The "Malaprop" laser design code has been used to predict the ultimate performance of Novette. Figure 2 summarizes the calculated on target capabilities of a single Novette beam. The upper curve illustrates the maximum $1.05 \mu\text{m}$ on target energy projected by Malaprop while the lower band represents our best estimate of the $0.53 \mu\text{m}$ on target energy versus pulse duration.

Novette Construction

By late summer, 1981, wavelength scaling studies using the Argus laser in Building 381 were approaching completion. A survey of planar target plasma laser light absorption and subsequent x-ray emission had been carried out over a range of incident intensities and target materials. The plasma physics community generally agreed that over the range of laser intensities of interest to inertial confinement fusion research, $\sim 10^{13} \text{ W/cm}^2$ to $\sim 10^{16} \text{ W/cm}^2$, laser plasma coupling becomes progressively more dominated by the inverse bremsstrahlung absorption mechanism as the irradiating wavelength is reduced below $1 \mu\text{m}$. While there were certainly many interesting experiments which might have been performed with Argus, it's main work was done. Near midnight on August 31, 1981, Argus irradiated it's last target with a pulse of second harmonic (green) light. The next morning the Argus tear down began and what had been the world's two most powerful single arm

Figure 2. Novette Chain Performance, 1w (1.05 μm) and 2w (0.53 μm)

laser amplifiers became history. So fragile are these lasers that even though no components were damaged, before the morning was over it would have taken several months to reassemble and realign Argus. By the end of September, the bay was empty, stripped to the concrete. In the spring of 1982, the steel spaceframe was assembled where Argus had stood and Novette construction was well underway.

Even as Argus was being dismantled, plans were set in motion to decommission the Shiva laser system. Shiva, the world's most powerful glass laser system, had operated successfully since late 1977 irradiating a wide variety of targets. Shiva drove the targets that imploded to > 100 times liquid DT density in 1980 and it was with Shiva that much of the plasma physics of indirectly driven inertial confinement fusion was unraveled. Shiva's amplifiers, controls hardware and its capacitor bank were all required for Nova. Novette would require two sets of Shiva amplifier chain hardware by the spring of 1982. Shiva's oscillators would have to move even sooner and Shiva's target chamber was needed early in order to allow adequate machining time for adaptation to the much larger Novette lens positioners. Before the new year, Shiva had irradiated its last target. Gradually the components required for Novette were removed from Shiva and refurbished. The remaining components rest quietly in their cradles on the Shiva spaceframe until they are needed for Nova.

The laser pulse which will ultimately strike the target begins in Novette's master oscillator room. It emerges from an actively mode-locked Q-switched Nd:YLF oscillator as one of a train of about twenty pulses separated by 8 nanoseconds, the round trip time of the laser cavity. Each pulse in this burst exits the oscillator at a time known with subnanosecond accuracy relative to the Q-switch time due in large part to very precise oscillator flashlamp pulse shape control. Timed from the Q-switch trigger, the same pulse in the train is consistently selected by means of a Pockels cell gate. Oscillator/switch-out system has a shot to shot reproducibility of $\pm 2\%$ in energy and $\pm 1\%$ in pulse duration. The oscillator's plane output mirror is the plane optically imaged or relayed through the laser system and, as the oscillator is adjusted to lase only in its lowest order transverse mode, its output beam is spatially Gaussian with a 1.4 mm FW @ e^{-2} waist. Table 1 traces this temporally Gaussian pulse through the components located in the master oscillator room and then through the preamplifier stage in the laser bay. The configuration chosen for illustration in Table 1 is designed to deliver spatially uniform and temporally Gaussian ~ 10 mJ, 100 ps pulses to the inputs of Novette's two amplifier chains. Actually the master oscillator/preamplifier system must be a very versatile mechanism since it must provide outputs ranging from 20 ps duration 1 mJ pulses to 40 ns rectangular pulses carrying several joules. It accomplishes this by means of three synchronized oscillators and a regenerative amplifier. Once triggered by Novette's computer control system, the master oscillator system provides all of the subnanosecond timing and trigger pulses required by the laser and target systems. Add to this beam diagnosis, automatic alignment features and a pulse shaping capability and one can begin to appreciate how sophisticated a machine this master oscillator must be. Figure 3 shows a measured beam profile obtained at the output of the preamplifier. As indicated in Table 1, the beam is apertured once within the preamplifier (component number 34) and again at the inputs to the power amplification (component number 49) to remove all but the center of the beam. Spatial filtering also smooths the beam profile such that the beam presented to the two Novette power amplifier chains has less than a 10% intensity ripple in the form of a ring structure impressed upon it.

At the output of the preamplifier, the beam is split into two beams whose relative timing is adjustable by means of variable path length sections and whose amplitudes are adjusted using waveplate/polarizer pairs. The wings of the beams have been truncated so that only the central 27 mm diameter portion of the beam is allowed to pass into the amplifier chain. Each beam now proceeds through the components listed in Table 2. The energies and fluences noted are appropriate for the propagation of 100 ps duration Gaussian pulses. Data is routinely taken at the several sensor packages and has occasionally been obtained at intermediate locations such as just before the 46 cm amplifiers. Three generic modular components make up each stage in the power amplifier chain: amplifiers, isolators and spatial filter beam expanders. Figures 4a) and b) indicate the locations of the spatial filters and Faraday rotator isolators in Novette. Figure 4c) shows a typical Shiva style cylindrical disk amplifier retrofitted with phosphate glass for

TABLE 1

Novette MOR/Preamp System

INPUT ENERGY(MILLIJOULE) = 0.10 ABSORPTION LOSS PER CM(%) = 0.15
PULSE DURATION (NS) = 0.10 SCATTER LOSS PER SURFACE (%) = 0.30

N	ID	L	BD	THIK	INDEX	RN2	BANK	GAIN	GAIN		B-TOT
			CM	CM		ESU	KV	NSSG	NET		
1	OSC	1	0.1	0.0	1.000	0.00	0.	1.00	1.00		0.00
2	MIR	2	0.1	0.0	1.507	1.24	0.	0.96	0.98		0.00
3	LNS	1	0.1	0.5	1.507	1.24	0.	0.99	0.99		0.00
4	POL	2	0.1	1.5	1.507	1.24	0.	0.98	0.98		0.01
5	POC	1	0.1	11.0	1.500	1.00	0.	0.92	0.92		0.03
6	POL	2	0.1	1.5	1.507	1.24	0.	0.98	0.98		0.03
7	POC	1	0.1	11.0	1.500	1.00	0.	0.92	0.92		0.05
8	POL	2	0.1	1.5	1.507	1.24	0.	0.98	0.98		0.06
9	MIR	2	0.1	0.0	1.507	1.24	0.	0.99	0.99		0.06
10	ROD	1	0.1	15.0	1.523	1.05	5.	0.92	0.92		0.08
11	MIR	2	0.1	0.0	1.507	1.24	0.	0.99	0.99		0.08
12	POL	2	0.5	1.5	1.507	1.24	5.	0.98	0.98		0.08
13	POC	1	0.5	11.0	1.500	1.00	5.	0.92	0.92		0.08
14	POL	2	0.5	1.5	1.507	1.24	5.	0.98	0.98		0.09
15	LNS	1	0.5	0.5	1.507	1.24	5.	0.99	0.99		0.08
16	ROD	1	0.5	15.0	1.523	1.05	5.	19.44	19.41		0.10
17	POL	2	0.5	1.5	1.500	1.00	0.	0.98	0.98		0.10
18	POC	1	0.5	11.0	1.500	1.00	0.	0.92	0.92		0.12
19	POL	2	0.5	1.5	1.507	1.24	0.	0.98	0.98		0.13
20	MIR	2	0.5	0.0	1.507	1.24	0.	0.98	0.98		0.13
21	SFL	1	0.5	0.5	1.507	1.24	0.	0.99	0.99		0.13
22	PIN		15.0	E-2		SPHI= 0.31		0.99			-0.13
23	SFL	1	2.2	1.0	1.507	1.24	0.	0.98	0.98		0.13
24	MIR	5	2.2	0.0	1.507	1.24	0.	0.98	0.98		0.13
25	ROD	1	2.2	48.0	1.523	1.05	20.	18.50	18.49		0.16
26	POL	2	2.2	0.3	1.507	1.24	0.	0.98	0.98		0.16
27	FR	1	2.2	1.5	1.670	2.10	0.	0.94	0.94		0.16
28	POL	2	2.2	0.3	1.507	1.24	0.	0.96	0.96		0.17
29	WP	1	2.2	1.0	1.500	1.00	0.	0.05	0.05		0.17
30	ROD	1	2.2	48.0	1.523	1.05	20.	18.50	18.48		0.19
31	SFL	1	2.2	1.0	1.507	1.24	0.	0.98	0.98		0.19
32	PIN		15.0	E-2		SPHI= 1.02		0.99			-0.06
33	SFL	1	2.2	0.5	1.507	1.24	0.	0.99	0.99		0.19
34	HA	1	0.6	0.0	1.000	0.00	0.	0.00	0.00		0.19
35	SFL	1	0.6	0.5	1.507	1.24	0.	0.98	0.98		0.19
36	PIN		15.0	E-2		SPHI= 9.21		0.99			0.00
37	SFL	1	3.4	1.0	1.507	1.24	0.	0.99	0.99		0.19
38	MIR	2	3.4	0.0	1.507	1.24	0.	0.98	0.98		0.19
39	ROD	1	3.4	48.0	1.523	1.05	20.	0.92	0.92		0.20
40	POL	2	3.4	1.5	1.507	1.24	0.	0.98	0.98		0.20
41	POC	1	3.4	11.0	1.500	1.00	0.	0.87	0.87		0.20
42	POL	2	3.4	1.5	1.507	1.24	0.	0.98	0.98		0.20
43	ROD	1	3.4	48.0	1.423	1.05	20.	18.50	18.49		0.21
44	POL	2	3.4	1.5	1.507	1.24	0.	0.98	0.98		0.21
45	FR	1	3.4	1.0	1.670	2.10	0.	0.94	0.94		0.21
46	POL	2	3.4	1.5	1.507	1.24	0.	0.98	0.98		0.21
47	POC	1	3.4	11.0	1.500	1.00	0.	0.87	0.87		0.22
48	MIR	4	3.4	0.0	1.000	0.00	0.	0.99	0.99		0.22
49	HA	1	2.6	0.0	1.000	0.00	0.	0.50	0.50		0.22

CHAIN SUMMARY (N8NOPTIMIZED)

70.65

Output energy

7.07 millijoules

0.22

Figure 3. Beam Profile at Chain Input Sensor

Novette. Large aperture, high power beams require efficient large aperture amplifiers. The large Nova box amplifiers store approximately 2% of the electrical energy in the capacitor bank as inversion in the disks at pulse propagation time. The beam single pass extracts up to approximately 40% of this energy from the phosphate glass disks as light energy. Average output fluence during high energy operation is typically 3 - 3.5 times the saturation fluence of 4.3 J/cm². Figure 5 has photos of the three sizes of box amplifiers used in Novette; 20.8 cm, 31.5 cm and 46.0 cm apertures. Depumping from amplified spontaneous emission within the disk imposes a size limitation on glass disks. With well index matched absorbing cladding on the disk edges, ASE depumping limits the gain length product αD along the largest axis of the disk to between 3.0 and 4.0. To preserve high stored energy and efficiency, the disks in the largest Nova amplifiers (46 cm clear aperture) are split along their minor axis. At maximum gain these disks operate with $\alpha D = 3.2$. The Nova 46 cm output amplifiers are of the box design with flashlamps only on the sides facing the disks. Each amplifier is pumped with nominal stored energy of 500 kJ in the capacitor bank at 20 kV. The nominal stored inversion energy is 8.2 kJ and the small signal gain 1.7.

TABLE 2

Novette South Laser Chain

INPUT ENERGY (MILLIJOULE) = 20.00 ABSORPTION LOSS PER CM(%) = 0.15
PULSE DURATION (NS) = 0.03 SCATTER LOSS PER SURFACE (%) = 0.30

N	ID	L	BD	THIK	INDEX	RN2	BANK	GAIN	GAIN	ENERGY	B-INC	B-TOT	FLUX	Exp
			CM	CM		ESU	KV	NSSG	NET	JOULE			J/CM2	J
1	MIR	2	3.4	0.0	1.000	0.00	0.	0.98	0.98	0.02	0.00	0.00	0.00	
2	POL	1	3.4	0.0	1.000	0.00	0.	0.49	0.49	0.01	0.00	0.00	0.00	
3	MIR	1	3.4	0.0	1.000	0.00	0.	0.99	0.99	0.01	0.00	0.00	0.00	
4	WP	1	3.4	1.0	1.450	1.00	0.	0.99	0.99	0.01	0.00	0.00	0.00	
5	MIR	2	3.4	0.0	1.000	0.00	0.	0.98	0.98	0.01	0.00	0.00	0.00	
6	POL	1	2.6	0.3	1.507	1.24	0.	0.98	0.98	0.01	0.00	0.00	0.00	0.0083
7	HA	1	2.6	0.0	1.000	0.00	0.	0.58	0.58	0.01	0.00	0.00	0.00	
8	SFL	1	2.6	0.5	1.507	1.24	0.	0.92	0.92	0.00	0.00	0.00	0.00	
9	PIN		15.0	E-2				0.99		0.00			0.00	
10	SFL	1	3.6	0.5	1.507	1.24	0.	0.99	0.99	0.00	0.00	0.00	0.00	
11	POL	2	3.6	0.3	1.507	1.24	20.	0.96	0.96	0.00	0.00	0.00	0.00	
12	ROD	1	3.6	40.0	1.523	1.05	20.	19.21	19.18	0.09	0.04	0.04	0.01	
13	POC	1	3.6	11.0	1.500	1.00	0.	0.87	0.87	0.08	0.02	0.06	0.01	
14	BS	2	3.6	0.5	1.507	1.24	0.	0.37	0.97	0.07	0.00	0.06	0.01	0.0715
15	SFL	1	3.6	0.5	1.507	1.24	0.	0.92	0.92	0.07	0.00	0.06	0.01	
16	PIN		15.0	E-2				0.99		0.07			-0.06	
17	SFL	1	0.8	1.0	1.507	1.24	0.	0.99	0.99	0.07	0.00	0.06	0.01	
18	DSK	6	0.8	2.4	1.523	1.05	20.	6.24	6.24	0.42	0.01	0.07	0.01	
19	POL	2	0.8	1.0	1.507	1.24	0.	0.96	0.96	0.40	0.00	0.00	0.01	
20	FR	1	0.8	1.5	1.670	2.10	0.	0.94	0.94	0.36	0.00	0.00	0.01	
21	POL	2	0.8	1.0	1.507	1.24	20.	0.96	0.96	0.36	0.00	0.00	0.01	
22	DSK	6	0.8	2.4	1.523	1.05	20.	6.34	6.32	2.20	0.06	0.14	0.04	
23	SFL	1	0.8	1.2	1.507	1.24	0.	0.92	0.92	2.10	0.01	0.16	0.05	
24	PIN		5.0	E-2				0.99		2.00			-0.10	
25	SFL	1	14.4	1.2	1.507	1.24	0.	0.99	0.99	2.06	0.00	0.16	0.02	
26	MIR	2	14.4	0.0	1.000	0.00	0.	0.98	0.98	2.02	0.00	0.16	0.02	
27	FR	1	14.4	1.0	1.670	2.10	0.	0.94	0.94	1.89	0.01	0.17	0.02	
28	POL	2	14.4	1.0	1.507	1.24	20.	0.96	0.96	1.82	0.01	0.17	0.01	
29	DSK	4	14.4	3.0	1.523	1.05	20.	4.21	4.19	7.63	0.07	0.25	0.04	
30	SFL	1	14.4	1.4	1.507	1.24	0.	0.92	0.92	7.02	0.02	0.27	0.06	
31	PIN		7.5	E-2				0.99		6.95			-0.11	
32	SFL	1	20.0	1.9	1.507	1.24	0.	0.99	0.99	6.88	0.01	0.28	0.05	
33	BS	1	20.0	2.0	1.507	1.24	0.	0.97	0.97	6.67	0.01	0.29	0.02	6.61
34	POL	1	20.0	1.0	1.507	1.24	0.	0.98	0.98	6.54	0.01	0.30	0.02	
35	FR	1	20.0	1.0	1.670	2.10	0.	0.94	0.94	6.15	0.01	0.31	0.05	
36	POL	1	20.0	1.0	1.507	1.24	20.	0.98	0.98	6.02	0.00	0.31	0.02	
37	DSK	3	20.0	2.5	1.523	1.05	20.	2.05	2.05	12.34	0.05	0.36	0.14	
38	DSK	3	20.0	2.5	1.523	1.05	20.	2.05	2.04	25.23	0.11	0.47	0.06	
39	DSK	3	20.0	2.5	1.523	1.05	20.	2.05	2.03	51.20	0.21	0.68	0.15	
40	SFL	1	20.0	1.8	1.507	1.24	0.	0.92	0.92	47.17	0.09	0.77	0.21	
41	PIN		10.0	E-2				0.99		46.70			-0.50	
42	SFL	1	30.3	2.0	1.507	1.24	0.	0.99	0.99	46.23	0.06	0.82	0.09	
43	POL	1	30.3	2.0	1.507	1.24	0.	0.98	0.98	45.31	0.03	0.86	0.06	
44	FR	1	30.3	2.0	1.670	2.10	0.	0.94	0.94	42.59	0.06	0.91	0.08	
45	POL	1	30.3	2.0	1.507	1.24	0.	0.98	0.98	41.74	0.03	0.94	0.05	
46	MIR	2	30.3	1.0	1.000	0.00	0.	0.97	0.97	40.49	0.00	0.94	0.08	
47	DSK	2	30.3	4.3	1.523	1.05	20.	1.85	1.84	74.39	0.16	1.10	0.10	
48	DSK	2	30.3	4.3	1.523	1.05	20.	1.85	1.83	136.02	0.30	1.40	0.18	
49	DSK	2	30.3	4.3	1.523	1.05	20.	1.85	1.81	246.54	0.54	1.95	0.32	
50	DSK	2	30.3	4.3	1.523	1.05	20.	1.85	1.79	440.29	0.97	2.91	0.57	
51	SFL	1	30.3	2.6	1.507	1.24	0.	0.92	0.92	405.06	0.47	3.38	0.80	
52	PIN		15.0	E-2				0.99		401.31			-2.61	
53	SFL	1	44.2	3.7	1.507	1.24	0.	0.99	0.99	397.00	0.30	3.60	0.37	406.
54	DSK	2	44.2	4.3	1.523	1.05	20.	1.65	1.62	643.12	0.69	4.37	0.39	
55	DSK	2	44.2	4.3	1.523	1.05	20.	1.65	1.60	1029.50	1.11	5.48	0.63	
56	SFL	1	44.2	3.7	1.507	1.24	0.	0.92	0.92	947.14	0.74	6.22	0.88	
57	PIN		25.0	E-2				0.99		937.66			-2.83	
58	SFL	1	71.2	5.7	1.507	1.24	0.	0.99	0.99	928.29	0.41	6.63	0.33	
59	MIR	3	71.2	0.0	1.000	0.00	0.	0.96	0.96	891.16	0.00	6.63	0.32	
60	WIN	1	71.2	4.0	1.507	1.24	1.	0.92	0.92	819.86	0.27	6.90	0.29	
61	SHC	1	71.2	1.8	1.500	1.00	1.	0.91	0.88	724.70	0.09	6.98	0.26	
62	WIN	1	71.2	4.0	1.507	1.24	0.	0.98	0.98	710.21	0.22	7.21	0.25	
63	FO	1	71.2	12.7	1.550	2.48	0.	0.91	0.91	646.29	1.30	8.51	0.23	

CHAIN SUMMARY (N0OPTIMIZED)
GAINS FROM INPUT

32314.38

646.29

0.51

Figure 4a. Novette Spatial Filters

Figure 4b. Novette Faraday Rotator Isolators

Propagation Studies

Figure 6 illustrates the beam profile, as measured and calculated at the 20.8 cm stage. Passive phase errors, not included in the beam profile calculation, begin to wash out much of the diffractive structure leaving only the prominent outer ring by the time this beam exits the power amplifier. In practice, minute thermal changes in components,

Figure 4c. Novette Cylindrical Disk Amplifiers,
92 mm and 150 mm

Figure 5a. Novette 208 mm Amplifiers

small misalignments and minor density fluctuations in the nitrogen gas filling the beam line all modify this fine structure. Viewed thus as a statistical entity, the rms intensity fluctuation imposed upon the beam becomes a natural quantity to measure. Risk of optical damage locally to the laser optics is presumed to depend only on the local fields experienced. Comparison of measured beams with simulations which use "realistic" component imperfections is meaningful only in an average

Figure. 5b. Novette 315 mm Amplifiers

Figure 5c. Novette 460 mm Amplifiers

Figure 6. 20 cm Beam Profiles

sense. Figure 7 plots calculated fluences (circles) along with those measured (squares). While the simulations may fail to mimic measurements exactly, they are adequate predictors which apparently allow safe system design and operation. It remains to be seen whether or not gain saturation, spatial filter pinhole closure and other laser system engineering issues are correctly modeled. The Novette test bed will be used in the coming months to study these questions. Table 3 lists the most significant Novette shots performed to date. Damage free operation has already been achieved at a routine or normal operational flux at ~ 0.1 ns and at half this level at ~ 0.8 ns.

Novette Final Optical Train

Beyond the output sensor packages, the two beams are reflected up to the target chamber level. Approaching the target chamber from the east and west, the first optics these pulses encounter are apodizers as shown in Figure 8. Bead blasted bands softly shadow the interstices between crystals in the second harmonic generation arrays. Not only are these low damage threshold regions of the array assembly protected from the incident laser flux, but by preventing diffraction from uncontrolled phase discontinuities between crystals, the focusing lenses are shielded from potentially damaging intensity ripples.

The conversion of laser light to its harmonics in nonlinear birefringent media is a well known process which was first demonstrated more than twenty years ago. Because shorter wavelengths were shown to couple more effectively to fusion targets, considerable interest arose in using this upconversion process to generate short wavelength beams to

Novette South Laser Chain

Figure 7. Laser Flux Down Chain

irradiate fusion targets. Within the last three years, efficient conversion of 1.0 μm light to its 2nd, 3rd, and 4th harmonics in KDP for beams of up to 100 mm diameter has been accomplished in several laboratories. Currently, material and optical coating limitations restrict the harmonic fluxes tolerable in large, high power, fusion systems. The handling and focusing of the second harmonic, 0.53 μm light, is possible with the same materials and coating technologies used for 1.0 μm light, and is therefore relatively straight-forward. At the third harmonic, 0.35 μm , scalarization of most optical glasses, low damage thresholds, and high nonlinear index of refraction are of concern. While solutions to these problems may be realizable, we could not apply them rapidly enough to build Novette and meet an early experimental schedule.

Upconversion of Novette's output beams requires doubler optics of greater than 74 cm diameter. We have done this by constructing frequency conversion arrays of smaller crystals. The second harmonic generation array architectures for the initial activation of Novette were dictated by the availability of KDP. One 5 element by 5 element array of 15 cm by 15 cm crystals and one 3 element by 3 element array of 27 cm by 27 cm crystals has been built. In the array assembly, the crystal and "egg crate" support structure are sandwiched between BK-7 windows with neutral solution anti-reflection processed outer surfaces. The windows constrain the KDP to insure that all array elements are oriented the same within ± 30 $\mu\text{radians}$. Losses at the KDP/window interface are reduced by an index matching fluid. The faces of KDP plates for each array have been precisely oriented with the phase matching angle and finish diamond

TABLE 3

NOVETTE PERFORMANCE AT INPUT TO 46 cm STAGE

<u>PULSE WIDTH</u> <u>ps</u>	<u>INPUT</u> <u>mJ</u>	<u>CHAIN</u>	<u>ENERGY</u> <u>J</u>	<u>POWER</u> <u>TW</u>
94.7	6.8	NORTH	381.	4.02
93.5	8.3	SOUTH	406.	4.34
780.0	66.8	NORTH	1760.	2.26
803.0	66.5	SOUTH	2070.	2.58

NOVETTE PERFORMANCE AT TARGET CHAMBER

<u>PULSE WIDTH</u> <u>ps</u>	<u>INPUT</u> <u>mJ</u>	<u>CHAIN</u>	<u>ENERGY</u> <u>J</u>	<u>POWER</u> <u>TW</u>
102.0	3.7	NORTH	612.	6.00
99.0	17.2	SOUTH	1097.	11.10

machined. Future arrays may use larger KDP crystals and/or do away with the "egg crate" support structure which occults 4% of the beam. Calculations anticipated up to 80% conversion efficiencies of the fundamental infrared radiation to the green second harmonic in the 1.8 cm thick type II KDP crystals. Presently, the first testing will be underway on the eastern 5x5 array of 15 cm square crystals. Figure 9 is a photograph of a 5x5 crystal array during assembly.

Frequency converted light now proceeds to the f/4 doublet focusing lens and is concentrated on the target. Presently measurements to survey the focal region will be carried out; in anticipation of these data, however, we have used our simulation code, "Malaprop", to calculate instantaneous beam profiles near the target chamber center. Taken together, the phase errors, active and passive, accumulated in the system and the crystal array are expected to give rise to the highly structured beam profiles indicated in Figure 10.

Figure 8. Novette Final Optical Train and Target Chamber

The gradual, evolutionary process of laser system design which was mentioned at the start has led to the construction of Novette. Now, quite suddenly, we have a relatively compact laser, each of whose arms exceeds the output of all twenty of Shiva's. Beyond this, Novette has gone together in well under a third the time required to build Shiva and will require less than half the manpower to operate. As sometimes happens in evolutionary progressions, this step has been so large as to seem a difference in kind.

The Novette Laser Fusion system provides a high power target experimental capability at the second harmonic of Nd:glass. Novette will provide more than 10 TW to fusion targets at $0.53 \mu\text{m}$ before the end of calendar year 1982. The system will test the Nova laser performance and operability and will provide the first test of harmonic generation in large aperture multi-element arrays of KDP. In the future Novette will provide a facility to allow early tests of Nova target physics, third harmonic generation and focusing systems.

Figure 9. Assembly of a 5x5 Crystal Array

Figure 10. Novette Focal Region

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