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THE OPTICAL SYSTEM FOR ARGUS 355-nm 90-mm APERTURE
TARGET-ILLUMINATION EXPERIMENTS

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THE OPTICAL SYSTEM FOR ARGUS 355-nm 90-mm APERTURE
TARGET-ILLUMINATION EXPERIMENTS*

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The requirements of laser alignment, crystal tuning, target alignment, and laser beam diagnosis are provided by this optical system. Initial setup and preshot alignment techniques are discussed. Layout and operation are contrasted with the 532 nm target experiments.

INTRODUCTION

For the past two years, the LLNL Argus laser has been utilized to answer questions associated with frequency conversion of the laser light and with target performance at short wavelengths. Our primary goal has been to assess the practicability and desirability of equipping Nova with a short wavelength option. After completing the baseline series of target interaction experiments at the laser frequency second harmonic, 532 nm, we began a complementary series of target shots at 355 nm, the third harmonic, which we completed in January, 1981. In both of these experiments we used single-sided illumination, employing only the south arm of the laser.

Argus was the 1064 nm driver for 9 cm clear aperture KDP crystals which convert the laser energy from its fundamental frequency to the second harmonic with an external (including Fresnel losses from the crystal faces) efficiency of 60%, or to the third harmonic with an external efficiency of 55%. In the 355 nm experiments, the doubler and mixer crystals were mounted between the last turning mirror and the target chamber, avoiding the high-power short-wavelength dielectric-coated turning mirrors used in the 532 nm experiments. Anti-reflective coatings were used on the target chamber window, f/2.2 target illumination lens, and debris shield as well as on the second surface of a beam dump which removed residual 1064 nm and 532 nm energy from the laser beam by reflection. The beam dump dielectric coatings have proven to be the weakest of the optical components. Trichroic coatings for 355 nm experiments have damaged at fluences between 0.8 and 1.3 J/cm², 700 ps. Dichroic beam dumps used for 532 nm experiments have damaged at 1.0 to 2.5 J/cm², 700 ps.

An uncoated, wedged splitter following the beam dump sampled both the incident beam and the beam reflected from the target. A diagnostic package for each beam contained a multiple image camera and a 2x reducing telescope used to image the target equivalent plane on a crosswire. Additional diagnostics monitored reflected and incident 355 nm energies

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and temporal profiles.

A similar diagnostic package viewed the target plane through the north f/2.2 target lens. The TV camera in this transmitted beam diagnostic (TBD) package was the alignment sensor for the target chamber. A streak camera was used for energy transport measurements.

Three different alignment beams for 355 nm experiments were obtained from an active mode-locked, Q-switched (AMQ) YAG oscillator. The small, diverging 1064 nm oscillator beam was inserted at the output of the Argus south arm and bore-sighted with the Argus master oscillator. It generated enough 355 nm light in the 9 cm diameter crystals to enable an angle-tuning adjustment to be made before each target shot. This was an improvement over the 532 nm experiment procedure which required several preamplifier shots. The 355 nm light from this beam was also monitored on the TBD TV and used to correct the target illumination lens position. The oscillator beam could also be converted efficiently to 355 nm by a small KDP crystal pair. This converted beam could be transmitted without collimation to the TBD table, where it was directed backward through the target chamber to backlight the target, or collimated at 4 cm-diameter and inserted into the main beam line just before the mixer crystal. The backlighted target image was used to focus the reflected beam diagnostic (RBD) telescope for the appropriate equivalent plane. The focal spot provided by the collimated beam at the target plane was viewed by the TBD TV and used to set the spot size and location and also to backlight the target.

Beginning with the first target shot on 26 September, we performed 151 target shots at 355 nm, of which about 70% have been nominally 30 J, 700 ps shots. Target requirements have ranged from a few joules to 45 J. In addition to the full system target shots, we fired the preamplifier 1322 times for alignment and 286 times for general laser testing and troubleshooting.

The target experiments show a significant increase in laser energy absorption and a significant reduction of superthermal high energy x-rays with increased laser output frequency.

OPTICAL LAYOUT

We modified the optical layout considerably from the comparable 532 nm beam path because of the more stringent alignment requirements for the tripling configuration and a healthy respect for the fragility of presently available 355 nm coatings. The primary modifications were the elimination of all coated reflectors after the KDP crystals and the addition of the AMQ oscillator for crystal and target alignment purposes.

Main Beam.

The 28 cm diameter output beam from the final Argus spatial filter was followed by a 3X beam reducing telescope (Fig. 1). At this point, the recollimated laser beam was 8 cm in diameter. Its alignment, and therefore the alignment of the Argus south arm, was determined by the 1064 nm IBD, located behind the first of three Target Bay turning mirrors. The three mirrors directed the laser beam into the target chamber, turning the beam through 270° and changing the beam height by 30 cm. The resulting odd angles between the laser plane of polarization and the planes of incidence at the mirrors also rotated the plane of

polarization of the laser beam. In order to obtain the desired final polarization, a quartz halfwave plate was mounted between the second and third turning mirrors.

Following the third (final) turning mirror were the doubler and mixer crystals. Both crystals were KDP, cut in a Type II orientation: the doubler crystal, 11.9 mm thick and the mixer, 9.9 mm thick. Between the two crystals was a 4% beamsplitter which sampled the combined 1064 nm and 532 nm beams between the crystals. Initial color separation was accomplished by a dichroic beam dump which transmitted 532 nm and reflected 1064 nm. The energy at each wavelength was then determined with filtered calorimeters (filters: BG-18 for 532 nm and RG-1000 for 1064 nm transmission). The calorimeters were of the absorbing glass type, with NG-1 used for both 1064 and 532 nm.

The combined beams were mixed in the second KDP crystal to generate 355 nm. Following the mixer crystal, all main beam optical components and most of the diagnostic optics were fused quartz (Suprasil) for low loss UV transmission. The first element, a trichroic beam dump, removed the residual 1064 nm and 532 nm components from the laser beam. Its coating reflected 1064 nm and 532 nm and transmitted 355 nm light. Following this, a diagnostic beamsplitter sampled both incident and target-reflected light for analysis in the IBD and RBD. It was uncoated to reduce the possibility of damage. The target chamber windows, f/2.2 target illumination lenses, and debris shields were anti-reflection coated.

Beam Diagnostic Assemblies.

The Target Bay beam diagnostics included an IBD for both 1064 nm and 355 nm, 355 nm TBD and RBD packages, and a crystal alignment package (CA). These packages contained:

- (1064 nm IBD) - calorimetry, near-field camera, far-field multiple image camera, alignment TV, streak camera;
- (355 nm IBD) - calorimetry, equivalent plane multiple image camera, alignment TV, streak camera fiducial optics;
- (355 nm RBD) - calorimetry, equivalent plane multiple image camera, alignment TV, streak camera;
- (355 nm TBD) - target plane multiple image camera, alignment TV and backlighting optics, energy transport streak camera.
- (CA) - high gain photomultiplier sensitive to 355 nm and a mode-locked oscillator (AMQ) for generating 355 nm.

Incident Beam Diagnostics - 1064 nm. The 1064 nm IBD package (Fig. 2), located behind the first turning mirror, was the primary alignment diagnostic for the laser. The adjustment of the beam path through the disk amplifier stages was accomplished by steering the laser far-field spot to the crosswire located in this IBD. We used a silicon target vidicon focused at the crosswire to detect the laser spot. Spatial filter pinholes were centered and focused by viewing their backlighted images with the same TV.

The telescope at the entrance to this package reduced the collimated 28 cm diameter Argus output beam to a converging 5 cm beam with an effective focal length of approximately 5 m. Beamsplitters sampled portions of this beam for measurement of energy in a calorimeter and of

focal spot profile in a multiple image camera. The temporal profile was also determined using an intensified streak camera with an S-20 photocathode.

These optics were not modified in preparation for the smaller beam diameter (8 cm) used in the 532 and 355 nm experiments. The effective diffraction limit increased by 3x as a result, but made no practical difference to the accuracy of the system alignment.

Incident and Reflected Beam Diagnostics - 355 nm. Each surface of the wedged, uncoated quartz beamsplitter directed 4% of the incident, converted laser beam energy into the IBD and of the energy reflected from the target into the RBD (Figs. 3, 4). The wedge separated the beams reflected from the two surfaces in the IBD and only the first surface reflection was used. In the RBD, both reflections entered the calorimeter, but only the first surface reflection was used in the other diagnostics. Splitters directed 50% of the beam energy into 2" calorimeters with UG-11 filters and GG-19 absorbing glass detectors.

The input to each 355 nm diagnostic assembly was a reducing telescope consisting of a 1 m positive and .5 m negative lens pair, yielding a 4 cm diameter converging beam focusing to a crosswire 5 m away. The negative lens in each case was mounted on a slide to ease the focus adjustment. A 4% beamsplitter directed a portion of the sample beam to a multiple image camera located in a plane equivalent to the crosswire. Magnification of the target plane by the RBD optics was approximately 42x. The IBD focal spot was also about 41 times the spot size at the target.

We often positioned the f/2.2 target illumination lens away from best focus in order to obtain the required intensity on the target surface and adjusted the negative telescope lenses to record a plane equivalent to the target plane with the RBD and IBD multiple image cameras.

In the IBD, the remainder of the diagnostic beam reached the crosswire location. An insertable mirror directed the beam to the TV. With this mirror removed, the light was refocused to a uv-sensitive (fused-quartz window) streak camera in the RBD layout. In the RBD, a splitter directed 4% of the beam energy to the crosswire and TV while the remainder went to the streak camera. Path lengths were adjusted so that the propagation time from the main beamsplitter through the IBD optics was the same as that from the main splitter to the target, back to the splitter and through the RBD optics. The incident beam record was used as a fiducial for the study of the reflected beam intensity.

Transmitted Beam Diagnostics - 355 nm. The layout of the TBD was similar (Fig. 5) to that of the other diagnostic assemblies. Since adjustment was not required of the TBD camera, which was always focused at the desired point of laser-target interaction through the north f/2.2 lens, the reducing telescope was fixed. An additional kinematically mounted mirror was used to direct an alignment beam "backward" through the target chamber.

The streak camera in this package was a target, not a laser beam, diagnostic. It was used to study the shock wave propagation through the target by temporally resolving the visible light emitted from the back of the target.

Active Mode-Locked, Q-Switched Alignment Oscillator. In order to align

crystals and targets without requiring multiple oscillator/preamplifier shots spaced ten minutes apart, we added a 5 pps AMQ oscillator similar to the Argus master oscillator (Fig. 6). The emitted 1064 nm beam was a train of 300 ps wide Gaussian pulses, spaced 7 ns apart, contained in a Gaussian envelope of 70 ns width. The peak output power was 1 MW in a spatially Gaussian beam with a 1.2 mm diameter beam waist. In this intense beam, we placed a small KDP crystal pair to triple the laser frequency. The resulting 355 nm beam was expanded to 4 cm diameter and inserted in the Argus beam line between the doubler and mixer crystals with a kinematically mounted mirror. A YAG preamplifier before the crystal pair increased the intensity, but reduced the pulse rate to 0.2 pps. This was occasionally used to help view the expanded beam.

A small mirror, inserted in the diverging 355 nm AMQ beam before the expanding telescope, provided the backlighting beam which entered the Argus beam path in the TBD, propagating backward through the target chamber toward the laser, to backlight the target for RBD alignment.

A similar small mirror, mounted before the tripler crystals, provided a diverging 1064 nm beam. Space was left at the end of the optical table for kinematic bases upon which an alignment crosswire and an insertion mirror for the AMQ 1064 nm alignment beam could be placed. This beam, boresighted with the main laser beam, generated a detectable amount of 355 nm light in the 10 cm aperture crystals. The detector was usually a high gain, uv sensitive photomultiplier with a UG-11 filter, although an intensified viewer was also used.

ALIGNMENT

Crystal Installation. In order to achieve efficient frequency conversion, the optical axis of each crystal must form the correct angle with the beam propagation direction and the orientation of the plane containing these two directions with respect to the polarization of the incident beam must be correct. Alignment of the mixer crystal was more critical than the doubler because the acceptable angular error for the optical axis of the mixer crystal (9.9 mm Type II) was smaller ($\pm .13$ mr) than for the doubler (Type II, 11.9 mm, $\pm .25$ mr). Lack of long term crystal alignment stability required fine tuning of the crystals before each target shot.

The polarization of the output 355 nm light from the crystal pair was selected to be 140° ccw from the horizontal to match our earlier 1064 nm and 532 nm target irradiation experiments. This completely determined the orientation for each of the crystals.

In preparation for installing the crystals, the "ordinary" axis of each was determined. (This axis is parallel to the direction of polarization for which light rays will travel through the crystal in a direction perpendicular to their wavefront. Light polarized orthogonal to the ordinary axis is "extraordinary" because the wavefront normal and ray directions are not the same.) The crystals were cut so that a beam meeting the crystal surface with nearly zero angle-of-incidence made approximately the correct phase matching angle (doubler angle, 59.140° ; mixer angle, 58.390°) with the optical axis. The preliminary ordinary axis determination consisted of inspecting the green (532 nm) fringes

generated when these crystals were illuminated through a diverging lens with a 1 MW pulse of 1064 nm light near normal incidence. The ordinary axis was oriented parallel to these straight fringes.

Upon installation (Fig. 7), the ordinary axis of the mixer crystal was adjusted to be perpendicular to the desired output polarization direction (14° ccw). With the Type II/Type II crystal configuration used in these experiments, the required orientation for the ordinary axis of the doubler was parallel to the mixer extraordinary axis. We then used a half-waveplate placed before the doubler crystal to adjust the polarization angle of the incoming 1064 nm light with respect to the doubler crystal ordinary axis. At the intensity used in these experiments (2.5 GW/cm^2), a 45° polarization angle would have supplied the mixer with excess green and insufficient infrared light for maximum conversion to 355 nm. The required ratio of 532 nm to orthogonally polarized 1064 nm power for efficient mixing is 2:1, which at this peak intensity, is achieved by rotating the plane of polarization to an angle of 35° with respect to the doubler ordinary crystal axis. However, with this configuration, only 1/2 of the 1064 nm energy leaving the doubler is properly polarized for generating 355 nm light. For a rectangular temporal pulse shape, the energy ratio would be 1:1, but the variation of conversion efficiency due to the temporal pulse shape changed the optimum energy mix ratio to 1.4:1. A polarization angle of 31° was appropriate.

Final adjustment of the crystal orientation was accomplished by placing a diverging lens before each crystal in turn and taking Polaroid pictures of the fringe pattern generated by 700 ps, 1 J laser pulses. Comparison of the fringes with a crosswire set before the camera helped the ordinary axis adjustment. A rough adjustment of the angle-of-incidence was achieved by centering the bright central fringe on the crosswire. This technique was used in the second harmonic target experiments and during measurements of conversion efficiency (reported at CLEO '81) as the final angle-of-incidence adjustment. Special care was taken to align both the crosswire and the diverging lens with the laser path. However, we found a discrepancy between the aligned angle-of-incidence determined by the negative lens technique and that determined for maximum conversion efficiency by measuring the output of the crystal as a function of angle with several high energy laser pulses. The $\sin^2(x)/(x)^2$ fringes were recorded for a series of shots with energies between 0.2 J and 350 J and the fringe location was compared to the reference crosswire shadow. The angular separation of the minima decreased with increasing intensity as expected, but there was no shift of these minima with respect to the crosswire. Densitometer traces corrected for the film $D/\log E$ response curve generally showed that the maxima were displaced by angles ranging from .15 to .2 mr in a direction away from the crystal optical axis at all intensities. Since the alignment procedure had required centering the crosswire between the dark fringes, it was inherently flawed. Further tests with a small, collimated, high repetition rate probe beam exhibited no asymmetry when the crystal was angle-tuned.

Our conclusion that the diverging lens technique does not result in correct alignment of large aperture crystals was confirmed when the 355 nm target experiment crystals aligned with a photomultiplier and nearly collimated beam resulted in conversion efficiencies equivalent to

the maximum obtained with a similar crystal configuration in the conversion efficiency experiments.

Final tuning of the angle-of-incidence was part of the preshot alignment.

Initial Alignment. As a first step in the installation of the optical components for the 355 nm target experiments, we rough-aligned all of the main beam elements and some of the diagnostics with the 1064 nm cw beam from the main alignment laser. The primary alignment marks were two crosswires located about 2 m from the target on each side of the target chamber. However, the dispersion in the several optical components, resulting in frequency dependent shifts in the beam position, required that the beam be centered on these crosswires with 355 nm light. The next step, therefore, was to align the small 1064 nm AMQ beam collinear with the main beam path. We iterated the crystal pair tuning for maximum output with the the beam pointing and centering so that the 355 nm generated by the 1064 nm beam was centered on the chamber crosswires (Fig. 8). The beam intensity ($.3 \text{ MW/cm}^2$) from the target alignment oscillator generated 532 nm and 355 nm energy in the main frequency conversion crystals sufficient for alignment purposes. The 355 nm beam was detectable with an intensified viewer or UV-sensitive photomultiplier filtered by a UG-11 filter.

Kinematically mounted crosswires located before each of the turning mirrors were adjusted to the beam center and the TBD TV crosswire centered on the transmitted beam focal spot. Two other kinematic crosswires were then added. One was a "1064 nm" crosswire after the mixer crystal to mark where the 1064 nm beam center was located when the 355 nm beam was aligned. This was used with the cw YAG alignment oscillator before each shot to check the adjustment of the last turning mirror. The other was a "355 nm" crosswire before the mixer collinear with the two chamber crosswires which could be used with the first chamber crosswire to point the 4 cm AMQ 355 nm beam after the f/2.2 target illumination lenses were inserted.

The collimated 4 cm diameter, 355 nm beam was inserted between the doubling and mixing crystals with a kinematically mounted, insertable mirror and centered on crosswires located before and after the target chamber. The collimation was checked by inspection of the fringes in the reflection from a 1 cm thick wedged, uncoated shear plate. With the wedge vertex located at the top, and the reflected beams located in the same horizontal plane as the laser beam, horizontal fringes indicated a collimated beam. Using this beam, the crosswires, reducing telescopes and TV cameras in the IBD and TBD assemblies were centered and focused. The RBD crosswire, telescope and TV were centered and focused by placing a plane mirror between the main beamsplitter and the target chamber, normal to the beam.

The small 355 nm beam from the AMQ was transmitted without collimation to the TBD, where it was directed backward through the target chamber and aligned to the target chamber crosswires. The insertion of this beam did not disturb the alignment of the collimated 355 nm beam optics, although it blocked that beam path. The north f/2.2 lens, which imaged the target on the TBD, was then installed. We minimized lens aberrations by "retro-reflecting" the lens. This was done by inserting a small setup mirror in the lens mount and adjusting the mount so that the

incident and reflected beams were collinear. This setup mirror had been aligned previously to be normal to the optical axis of the lens. The south $f/2.2$ lens, used to direct the laser beam onto the target, was installed, retroreflected, and adjusted so that the light from the collimated alignment beam was visible on the TBD TV. A diffusing screen, placed before the target chamber, improved the quality of the backlighting. A 0.6 mm alignment target was adjusted until it was visible on the TV. Both lenses and the target were then moved until the target was centered in the target chamber as seen by the target alignment optics. The north $f/2.2$ lens was adjusted to focus and center the target on the TBD crosswire. The diffusing screen and target were then removed and the orientation of the south lens adjusted. This lens was translated until the best-focus spot was centered on the TBD crosswire.

With the $f/2.2$ lenses focused on the chamber center, we adjusted the three 355 nm multiple image cameras (MIC) until they recorded far-field images. The RBMIC and TBMIC target image magnifications were determined by backlighting the target from the appropriate direction and recording the image size photographically. The variation of RBMIC magnification with displacement of the south target lens from best focus was calculated, then checked with more pictures. The TBMIC did not vary since the north lens was always focused at the target surface. The IBMIC magnification could not be measured directly. Its value, and the correct setting for the reducing telescope to image the equivalent target plane, were computed. Indirect confirmation was supplied by the comparison of TBD and IBD equivalent plane spot sizes.

We calibrated the various calorimeters in the diagnostic layout by placing a 5" reference calorimeter, filtered for the wavelength in question, in the main beam path just beyond the diagnostic sampling splitter and comparing the responses of the reference and diagnostic calorimeters to a laser pulse.

The retro-reflecting procedure was carried out with all other lenses in the main and diagnostic beams, although in these cases the reflection from the lens surface was usually adequate for alignment. In some cases, it was more convenient to align a He-Ne beam collinear with the 355 nm beam and do the retroreflection with this.

Preshot Alignment. We began the system alignment leading to each target shot by centering the target in the target alignment optics (TAO) field of view. The orthogonal TAO views determine the location of the target within the chamber. Next, we adjusted the target alignment oscillator to provide the collimated 4 cm 355 nm beam, pointing and centering to the "355 nm" and first target chamber crosswires. We backlighted the target for viewing on the TBD TV. The north target chamber lens focus and centering of this image of the target was checked. We then aligned the main beam line using the 1064 nm cw alignment laser and adjusted the small 1064 nm pulsed beam from the target alignment oscillator to be collinear with this line. Then the Target Bay turning mirrors were adjusted to align the fringe pattern of the preamplifier table output crosswire with crosswires before the second and third mirrors and the "1064 nm" crosswire before the 1064 nm/532 nm beam dump. A removable mirror directed this beam into a high gain photomultiplier through UG-11 filters so that only 355 nm light was detected. The angle of incidence for each of the KDP crystals was then adjusted for maximum signal.

We determined spot size in the target plane directly by recording a preamplifier shot on the TBMIC together with a time exposure of the backlighted target. Adjustments in spot size and location were made by moving the south lens. The IBMIC was then set by adjusting the 355 nm IBD telescope lens to a point previously calculated to be appropriate for the offset of the south lens from focus. The RBMIC was focused by using the uncollimated AMQ 355 nm beam transmitted from the TBD side of the target chamber to backlight the target. A final TBD spot size picture was then recorded.

THE EXPERIMENTAL SCHEMATIC

We Checked the Laser Beam Parameter with the 1 ω Incident Beam Diagnostics Package

WITH THE 3ω INCIDENT BEAM DIAGNOSTICS WE MEASURED:

- Incident 3ω energy
- Target plane beam profile
- Incident 3ω temporal profile

02-12-1281-3990

WITH THE $3\omega_0$ REFLECTED BEAM DIAGNOSTICS, WE MEASURED:

- Energy specularly reflected from the target
- Beam profile in the target plane
- Temporal profile of the 3ω reflection

We Used the Transmitted Beam Diagnostic Optics to Help Adjust the Size and Location of the 355 nm Spot in the Target Plane

An Active Mode-Locked Q-Switched Oscillator was Our Primary Alignment Tool

AMQ output

- 10 pps
- Q-switched envelope of mode-locked pulses
 - Pulse width - 700 ps
 - Pulse separation - 7 ns
 - Peak power - 1 MW
 - Beam waist diameter - 0.2 mm

A Pair of KDP Crystals, Properly Aligned, Tripled the Fundamental Laser Frequency