A Multipurpose TIM-Based Optical Telescope for Omega and the Trident Laser Facilities

J. A. Oertel, T.J. Murphy, R.R. Berggren, R.F. Horton[#], J. Faulkner, R. Schmell, D. Little, T. Archuleta, J. Lopez, and J. Velarde

Los Alamos National Laboratory, Los Alamos, New Mexico 87545

[#]Science Applications International Corporation, Albuquerque, NM 87106

We have recently designed and are building a telescope which acts as an imaging light collector relaying the image to an optical table for experiment dependent analysis and recording. The expected primary use of this instrument is a streaked optical pyrometer for witness plate measurements of hohlraum drive temperature. The telescope is based on University of Rochester's Ten-Inch Manipulator (TIM) which allows compatibility between Omega[1], Trident[2], and the NIF[3] lasers. The optics capture a f/7 cone of light, have a field of view of 6-mm, have a spatial resolution of 5 to 7-μm per line pair at the object plane, and are optimized for operation at 280-nm. The image is at a magnification of 11.7x, which is convenient for many experiments, but can be changed using additional optics that reside outside the TIM.

I. INTRODUCTION

In the inertial confinement fusion (ICF) program, optical diagnostics have been important instruments for the measurement of laser plasma instabilities, direct-drive laser imprint, neutron burn history and radiation drive. Our primary motivation for designing and building an optical telescope was to measure the radiation drive temperatures in a tetrahedral hohlraum. Hohlraum temperatures for inertial confinement fusion can reach temperatures exceeding 200 eV, pressures of 100 Mb and have been measured by several methods.[4] One of the most precise and technically mature methods of measuring radiation temperature is by streaked optical pyrometery, a technique that has been around for nearly twenty years.[5,6]

In this measurement technique, laser radiation drive interacts with the hohlraum wall and launches a shock wave. A section of the hohlraum wall is cut out and replaced with a wedged or stepped low-Z witness plate, usually aluminum. The shock-heated witness plate emits a flash of light that breaks out with a velocity relative to the hohlraum temperature as $T_R = 0.0126 v_s^{0.63}$. Where T_R is the hohlraum temperature and v_s is the shock velocity.[4] The brief flash of light from the witness plate is imaged and magnified onto the slit of a streak camera, with an optical fiducial added for timing.

Although our primary reason for constructing this telescope is to measure a hohlraum temperature, we also want to have a flexible instrument that can be used for any experiment requiring high resolution imaging of optical radiation from 200-nm to 1-μm. An overall layout of the telescope and other hardware is shown in Figure 1.

The text below is organized into four sections. Section II details the optical telescope and how the optical cell interfaces into an Omega Ten-Inch Manipulator (TIM). Section III discusses the components outside the vacuum chamber including the optical table, final focusing optics, filters, and the streak camera. Section IV briefly mentions system performance, overall specifications and alignment. Finally, section V summarizes the diagnostic.

II. THE TELESCOPE

The f/7 telescope is based on a Burch reflecting microscope design and has the advantage that all optical surfaces are spherical. The six TIMs, located around the Omega target chamber, allow researchers the flexibility to place a variety of diagnostics inside the vacuum chamber without having the diagnostics permanently fixed. The telescope optical elements are mounted in a 90-cm long cylindrical optical cell which has a conical light shield, a removable alignment pointer and is attached to a TIM boat by a three point kinematic mount. See Figure 2. The TIM-boat, a permanently mounted fixture inside the TIM, travels into the target chamber and can be precisely located anywhere along the TIM axis. As seen in Figure 3, the optical elements of the telescope consist of a blast shield, meniscus lens, primary mirror, and secondary mirror. The 90-mm diameter, 12-mm thick blast shield is located 450-mm from target chamber center (TCC) and has a 3ω (351-nm) rejection filter coating on the rear surface. The meniscus lens, designed to remove spherical aberrations induced by the flat blast shield, is 90-mm in diameter, has a thickness of 16-mm and has both surfaces with a radius of 742-mm. Because it has zero power, it introduces negligible color aberrations. All of the transmissive optics in the system, including the blast shield and the meniscus lens are made of a high quality fused silica to transmit UV light. The primary and secondary mirrors are made of ZERODUR®[7], are separated by 544-mm and have a UV enhanced aluminized surface coating. This allows alignment at visible wavelengths while maintaining high reflectivity at 280-nm. The concave spherical primary mirror is 160-mm diameter, 25-mm thick, has a center hole clear aperture of 40-mm and a radius of curvature of 825-mm. The convex spherical secondary mirror is 40-mm diameter, 23-mm thick, 278-mm radius of curvature and is cemented to the backside of the meniscus lens. Light from the object plane comes out of the telescope collimated, passes through a high quality quartz vacuum window at the rear of the TIM and enters a light-tight enclosure mounted on the East wall of Omega. The window on the rear of the TIM also has a 1ω (1.053-μm) rejection filter to reduce unwanted, unconverted laser light.

III. DIAGNOSTIC COMPONENTS OUTSIDE THE CHAMBER

The components outside the vacuum chamber include the optical table, final focusing mirrors, image rotator, filters, streak camera, CCD camera and optical fiducial system. For our hohlraum temperature measurements, a 3’x 6’ optical table and enclosure are mounted vertically on the Omega East wall with a small hole allowing light to enter from TIM-5. The Omega target bay has an open-beam-transport architecture, so there are copious amounts of scattered 2ω (527-nm) light to filter out. Rejection is accomplished with a filter on the entrance of the light-tight table enclosure. A schematic of the optical table with components is shown in Figure 4. After the collimated beam comes into the enclosure, an un-obscured spherical telescope focuses the light to the image plane at the slit of a streak camera. The first spherical mirror is concave with a 5407-mm radius of and 160-mm diameter. The second sphere, 1000-mm from the first, has a 33807-mm convex radius, and is 125-

mm diameter. This focusing spherical telescope gives a magnification of 11.7x at the image plane. If a future experiment requires a different magnification than that provided by this spherical mirror combination, it is simple to modify the system. By changing out just these two final focusing mirrors, the magnification can be modified and the telescope inside the vacuum chamber is undisturbed. Because we want to perform a rotational scan of the witness plate, an image rotator is located after the final focusing mirrors. This "K" mirror, the reflective equivalent to a Dove prism[8], has a set of three mirror surfaces arranged 60º of each other. Rotation of the "K" mirror at a given angular rate causes the image to rotate at twice this rate. A filter holder mounted on a kinematic mount contains a 280-nm ±25-nm bandpass and neutral density filters. At this same location, an alignment camera can fit into the mount to view the target back through the entire optical system. Finally, the image falls on a variable slit on a Hamamatsu C4187 large format streak camera with an S-20 photocathode. Interfaced to the streak camera, is a Photometerics 1024x1024 CCD camera for final data acquision.

IV. SYSTEM PERFORMANCE AND SPECIFICATIONS

A broadband optical analysis has been performed using the optics code ZMAX[9], including a modulation transfer calculation (MTF). The optical system design is shown to be nearly diffraction limited at 280-nm in Figure 5. Even though the optical system is capable of spatial resolution ≥ 30-lp/mm at the image plane, the streak camera limits the entire system to 10.9-lp/mm.[10] The f/7, 11.7x magnification, system has a field of view of 6-mm and is limited by the 50-mm aperture in the TIM vacuum window. Mirror reflectivity and transmissive optics allows visible light from 200-nm to 1-μm, although for our temperature measurements, bandpass and notch filters have been included to limit the spectrum. The temporal resolution of the Hamamatsu streak camera is scheduled to be measured at the Los Alamos Trident laser, but is specified by Hamamatsu to be 6.8-ps FWHM.

Rough alignment of the telescope is performed with a precision ground pointer mounted on the end of the conical light shield that is aimed at TCC and viewed with the Omega target viewing system. Once roughly aligned, an alignment Helium-Neon (HeNe) laser is inserted into the opposing TIM-3 with the beam pointed through TCC and out the backside of TIM-5. This permits alignment of the optics on the table with visible light. If an opposing TIM is not available, then a linear fiberoptic array will be placed at TCC. The array is relayed through the system and viewed at the image plane with a camera. This also gives the rotational orientation requirements for the witness plate hohlraum experiments.

V. CONCLUSIONS

We have designed and are constructing an optical telescope to insert into any TIM, primarily for the Omega laser, but also for the Trident the NIF laser systems. The telescope is designed to be a good light collector (f/7), be capable of high spatial resolution (~5-μm), cover wide range of wavelengths (200-nm to 1-μm) and have flexible magnifications. Our motivation was to build a light collection system capable of imaging a radiation shock in order to measure the drive temperature in a tetrahedral hohlraum.

VI. ACKNOWLEDGMENTS

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VII. REFERENCES

[1]Information on the Omega laser system can be found at http://www.lle.rochester.edu/.

[2] Information on the Trident laser system can be found at http://www.harry.lanl.gov/PlasmaPhysics/trident.html

[3] Information on the NIF laser system can be found at http://lasers.llnl.gov/lasers/nif/

[4] R.L. Kauffman et. al., Rev. Sci. Instrum., Vol. 66. No. 1, January 1995, P.678

[5] R.J. Trainer et. al., Phys. Rev. Lett, Vol. 42, No. 17, April 1979, P. 1154

[6] T.H. Lower et.al., Phys. Rev. Lett, Vol. 72, No. 20, May 1994, P. 3186

[7] ZERODUR® is a registered trademark of Schott Glass Technologies Inc.

[8] J.H. Moore, C.C. Davis,M.A. Coplan, “Building Scientific Apparatus”, Addison-Wesley Publishing, 1989, 2nd, ed. P.152

[9] ZMAX is an optical design and evaluation code made by Focus Software, Tuson, AZ

[10] Information from Hamamatsu C4187 specification manual.

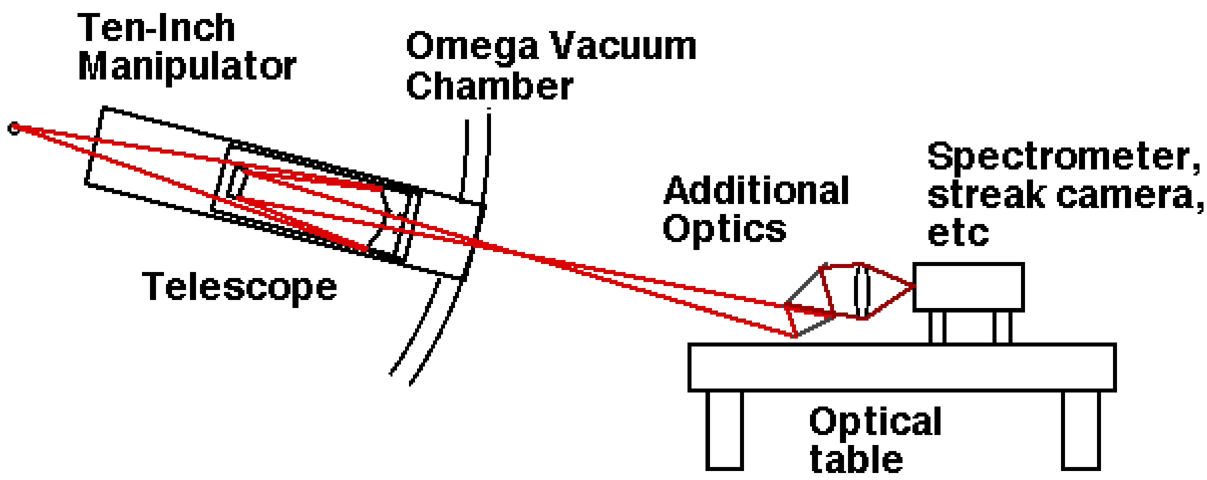

Figure 1. The overall layout of the optical telescope on the Omega target chamber.

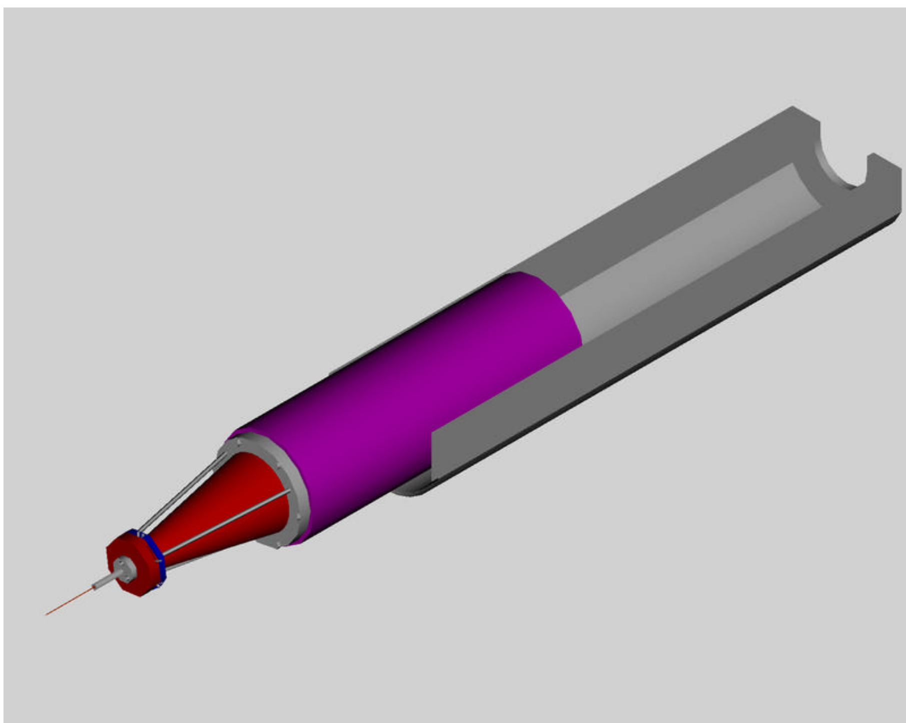

Figure 2. Optical cell placed in TIM-boat.

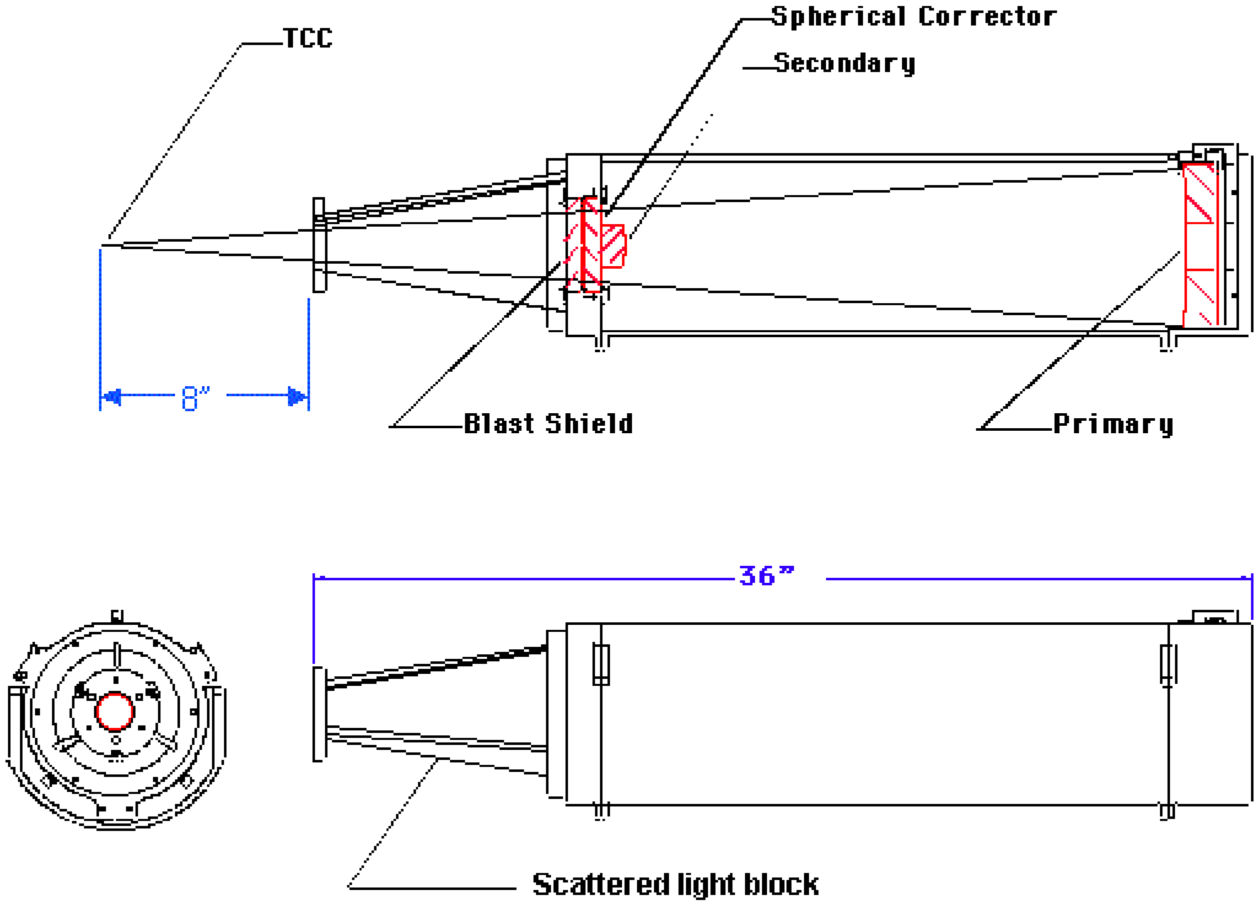

Figure 3. The optical elements inside the cell.

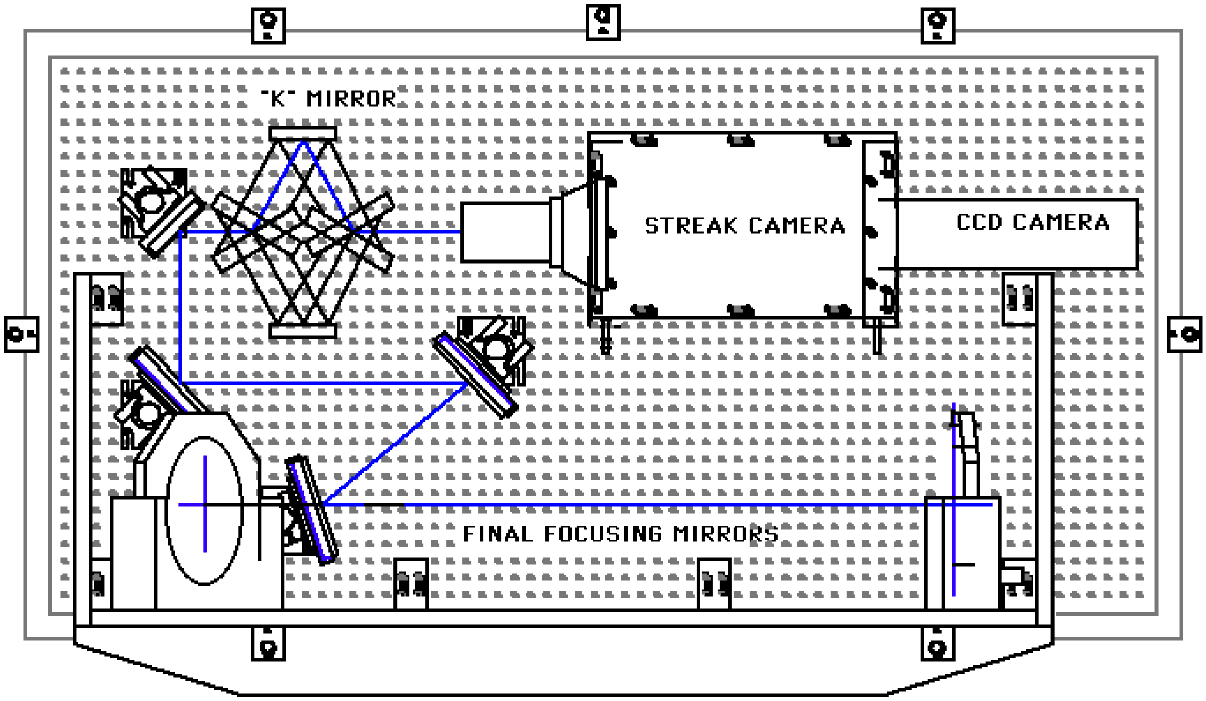

Figure 4. The optical table with components.

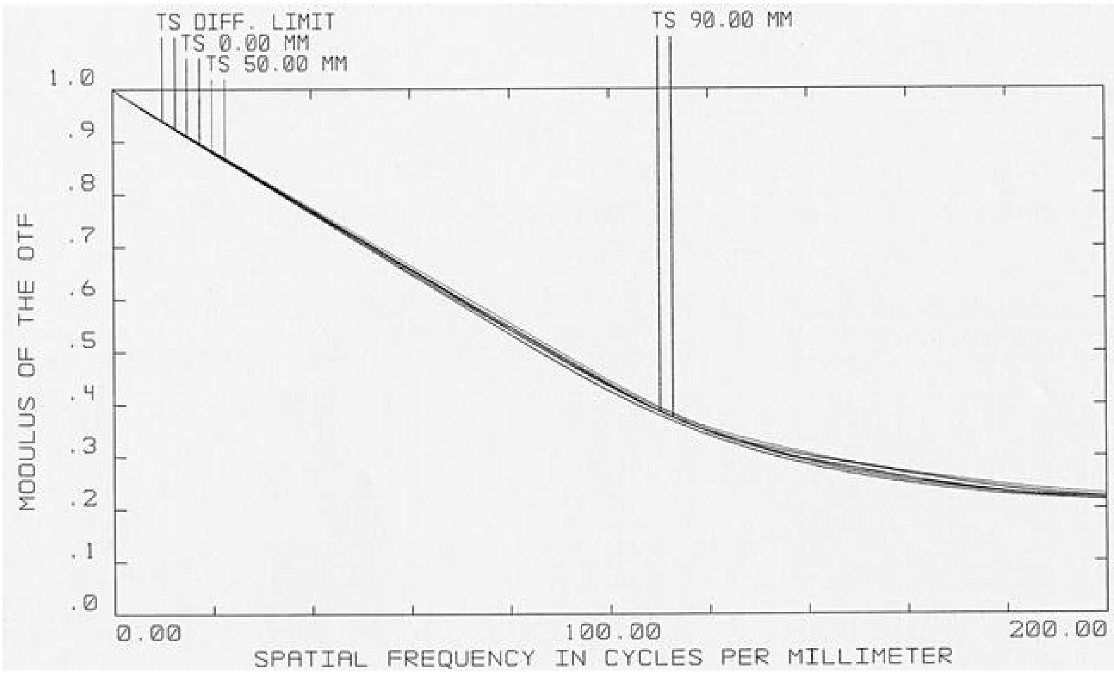

Figure 5. The modulation transfer function at the image plane for 280 nm.