ORION laser target diagnostics
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I. INTRODUCTION

The ORION laser facility has been designed to provide a world class high-energy density physics platform to help support Atomic Weapons Establishment’s (AWE) primary mission of stockpile stewardship. This new facility will be available to both the AWE and academic scientific communities for fundamental research accessing new and exciting physics regimes.

The ORION laser combines ten long pulse laser beams operating in the nanosecond regime with two short pulse sub picosecond chirped pulse amplification beams. The long pulse beams are capable of delivering up to 500 J at 351 nm in a 1 ns square-pulse while the short pulse beams will both be capable of delivering 500 J at 1053 nm in a 0.5 ps pulse. This combination of long and short pulse lasers will allow experimentalists to access new temperature and density domains. Novel scientific opportunities such as high density and temperature material properties, high density plasma effects, x-ray heated plasmas in Hohlraums, short pulse physics, etc., will be investigated by utilising this facility.

Experimentalists using the ORION laser facility will have a suite of 45 x-ray, optical, and particle diagnostics available to help diagnose the plasma conditions within the target chamber. The ORION target chamber is fitted with Laboratory for Laser Energetics standard ten inch manipulator (TIM) diagnostic inserters allowing the fielding of the diagnostics. This paper will provide an overview of several of the diagnostics.

II. X-RAY DIAGNOSTICS

ORION has numerous x-ray sensitive detectors and diagnostics at its disposal. Between them these detectors cover the spectral energy range from the ultraviolet (sub keV) to hard x-ray and gamma energies (∼20 MeV). These include the filter fluorescer diagnostic, a number of spectrometers – twin crystal, precision optical spectrometer, transmission grating, x-ray ultraviolet grating, time integrated, transmission crystal and hard x rays, a gated x-ray detector pinhole camera array, multi and single channel x-ray pinhole cameras, high-energy x-ray spectrometer with interchangeable detectors (HEXID), gamma and Laue cameras, Dante/photoconductive detectors (PCDs) arrays, KB x-ray microscope, gated x-ray detector, x-ray streak cameras with crystal spectrometers and imaging snout, thermoluminescent dosimeter array, and a broad band x-ray diffraction diagnostic. In the following paragraphs brief descriptions are given for a selection of these diagnostics.

A. Filter fluorescer diagnostic

The filter fluorescer diagnostic (FFLEX) (Figure 1) is an absolute time-integrated hard x-ray spectrum diagnostic covering the energy range 20 keV to 100 keV. It is used to measure the x-ray emission of a laser irradiated target and thus determine its temperature. Eight channels are used to measure the hard x-rays produced by propagation of hot electrons generated via collisionless absorption at the laser-target boundary in the target material.

Each channel consists of pre- and post-filters combined with a fluorescer to define the spectral window for the channel. The x rays are detected by a photomultiplier tube coupled with a NaI scintillator to produce a signal that is recorded by an oscilloscope. Scattered high-energy radiation is mitigated...
by using filters, lead shielding, and specific scintillator thicknesses.

B. High energy resolution x-ray spectrometer with interchangeable detectors

In recent years multi-channel spectrometers\textsuperscript{2,3} have been developed to measure the soft x-ray spectrum from laser produced plasmas. The high energy resolution x-ray spectrometer with interchangeable detectors (HEX-ID) (Figure 2) is a further progression of these diagnostics which takes advantage of advances in x-ray detection technology. It comprises four channels consisting of a combination of a filter, a crystal, and a detector. This enables the diagnostic to cover a spectral range of 1 to 10 keV with a resolution of $E/dE \sim 800$ (Figure 3). The diagnostic has a range of interchangeable x-ray detectors with which it can be fielded, these being image plates, CMOS x-ray sensors, and PCDs. The selection of detector is dependent on the desired dynamic range, spatial, and temporal resolutions. The HEX-ID is a TIM deployed diagnostic for use with long pulse and short pulse laser shots.

C. Dante diagnostic

For the ORION project a Dante diagnostic (Figure 4) has been designed for use in measuring time resolved laser plasma target temperatures. This is achieved through the measurement of low energy ($<2$ keV) x rays emitted from long pulse laser interactions. The design of the diagnostic has incorporated the capability to extend the measurement spectral range to 4 keV.

The diagnostic is comprised of ten channels with the option for up to a further eight to be added at a later date. Each channel consists of a filter and x-ray diode (XRD) combination which define the spectral range of each channel. Several of these channels also incorporate a mirror assembly to further define the spectral range covered by these channels. A new XRD (known as the DiABLO) has been designed (Figure 5) which is based on the XRD's used in the Dante diagnostic for ORION's predecessor laser facility – HELEN.

This detector has been designed to operate inside a vacuum and incorporates a larger photocathode and modern high voltage and signal connectors. The XRD, filters, and mirrors have all been absolutely characterised using the characterisation beamlines at the National Synchrotron Light Source at the Brookhaven National Laboratories.\textsuperscript{4}

III. OPTICAL DIAGNOSTICS

The ORION laser facility has a comprehensive suite of optical diagnostics (Figure 6) consisting of passive shock breakout (PaSBO), active shock breakout (ASBO), velocity interferometer from the surface of any reflector (VISAR), probe beam detector, streaked optical pyrometry (SOP), full aperture SRS/SBS backscatter, and long and short pulse near backscatter imagers. These are used to provide measurements of various materials in a warm dense matter state ($\rho \sim$ solid, $T \sim 0.1–10$ eV). Temperature, density, shock speed, and
emissivity are all properties which can be measured optically to characterise the target plasma.

A. Fast probing and tomography – Short pulse probes

ORION is equipped with two <0.5 ps, 100 mJ, 4Ω (264 nm), polarization controlled probe beams derived from the main short pulse system. These can be used for deep-UV (264 nm), polarization controlled probe beams derived from the target, either self-emitted or the target, either self-emitted or back-scatter diagnostics. The electron spectrometer is discussed in further detail below.

B. Passive imaging – SOP and PaSBO

SOP and PaSBO have been used to measure the self-emission from targets to determine temperature5–7 and shock speed8,9 without the use of a probe laser. Pyrometry is however greatly enhanced by the use of an active reflectivity probe to correct for the imperfect blackbody nature of the plasma.7,10

C. Active probing – VISAR and ASBO

VISAR and ASBO are two well established optical diagnostics for monitoring the expansion of a plasma and/or the propagation of a shock through a target.11,12 If calibrated they can also be used as single-colour reflectivity diagnostics to aid in pyrometry.7,10

IV. PARTICLE DIAGNOSTICS

ORION has several particle diagnostics which include neutron total yield, CR39, Faraday cup system, low energy electron spectrometer/EPPS, EMP detector, neutron time of flight, thomson parabola, radiochromic film, electron spectrometer, proton/ion magnetic spectrometer, and the SGEMP Cavity. The electron spectrometer is discussed in further detail below.

A. Electron spectrometer

ORION’s electron spectrometer (Figure 7) is designed13–15 to cover the electron spectrum from 50 MeV to 1 GeV and utilises a magnetic field to deflect electrons. The electron interaction produces x rays which are recorded on the image plate along with Brehmsstrahlung radiation. Processing the data to remove the background and taking lineouts across the image plate allows us to infer the electron spectrum.

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* Excluding short-pulse probes or back-scatter diagnostics

FIG. 5. Schematic of the DiABLO XRD.

FIG. 6. Outline schematic of ORION optical diagnostics.

FIG. 7. Outline schematic of ORION electron spectrometer.