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High Energy Density Laser Beam Interactions Simulating Astrophysical and Planetary Processes: Dielectrics

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Abstract: An example of results from an innovative electro-optic experimental methodology to determine the equations of state (EOS) and momentum coupling coefficients at high (Hugoniot) pressures (4 – 10 GPa) on unconfined Si (dielectric) targets from high energy laser radiation density in the 100 GW/cm^2 to 10 TW/cm^2 range is presented. This paper describes the basis for the validity of the methodology used for measurements of EOS properties for dielectrics. Nonmetals generally require additional reflective surfaces applied to the rear surface of the (dielectric) targets, and this aspect differs from the methodology for highly polished metals described in a previous paper. However, this Si is a single crystal highly reflective optical window grade material and is an exception, allowing efficient direct reflection of the probe laser beam. Extensive use was made of the Sandia National Laboratories (SNL) NLS (1064 nm) and Z-Beamlet (527 nm) pulsed lasers. Such information is critical to modeling radiation driven proto-planetary and astrophysical interactions as well as for high pressure materials interactions in general.

Introduction

This paper follows a previous one (Remo and Adams 2006a) that describes an innovative electro-optic method to determine the parameters for establishing the equation of state (EOS) of a material. In this paper the experimental results that determine the EOS and momentum coupling coefficients for the optical grade of the element Si at two different intensity are presented and compared to reference results with excellent agreement, thereby supporting the validity of this experimental approach. Future work will compare these results to amorphous Si powders.

Experimental method

The experimental method used to determine the EOS of the dielectrics is similar to but not exactly the same as that for the metals, as described in a previous paper (Remo and Adams 2006a), except for the necessity of placing a reflector at the interface between the rear surface of the target and the BK7 glass substrate as shown in figure 1. The rear surface reflector is a thin Al layer ~ 0.25 μm thick vapor deposited on the BK7 glass substrate. This is necessary whenever a good reflecting surface could not be polished or deposited onto the rear surface of the target. Since the density of the glass is close to that of the target and the thickness of the Al reflector is so small, the mechanical impedance between the target and BK7 is minimal. This indicates that the push out velocity as measured off the reflector is approximately equal to the particle velocity. However, this Si is a highly reflective optical window grade material and is an exception, allowing efficient direct reflection of the probe laser beam without an impedance matching layer. This indicates the observed push-out velocity is twice the particle velocity. Care must be taken when carrying out optical measurements because mounting reflecting surfaces can introduce mechanical changes that significantly effect results. Because this Si has such a good reflecting surface with a high degree of rigidity, several orders of reflection and push-out velocity can be detected from the rear surface reflections. This is not typical of other dielectrics such as graphite which requires a reflecting layer. The parameters used in table 1 are the target thickness, δ(mm), the laser energy deposited on the target front surface, E(J), the laser intensity, I(GW/cm^2), the shock wave transit time, τ_{sw} (ns), the shock wave velocity, v_s (km/s), the push out time, τ_+(ns), the particle velocity, v_p (km/s), the Hugoniot pressure, P_H(GPa),the front surface radiation pressure, P_{rad}(GPa), and the momentum coupling coefficient, C_M(s/m). The front surface radiation pressure, P_{rad}(GPa), is calculated from the intensity, I.

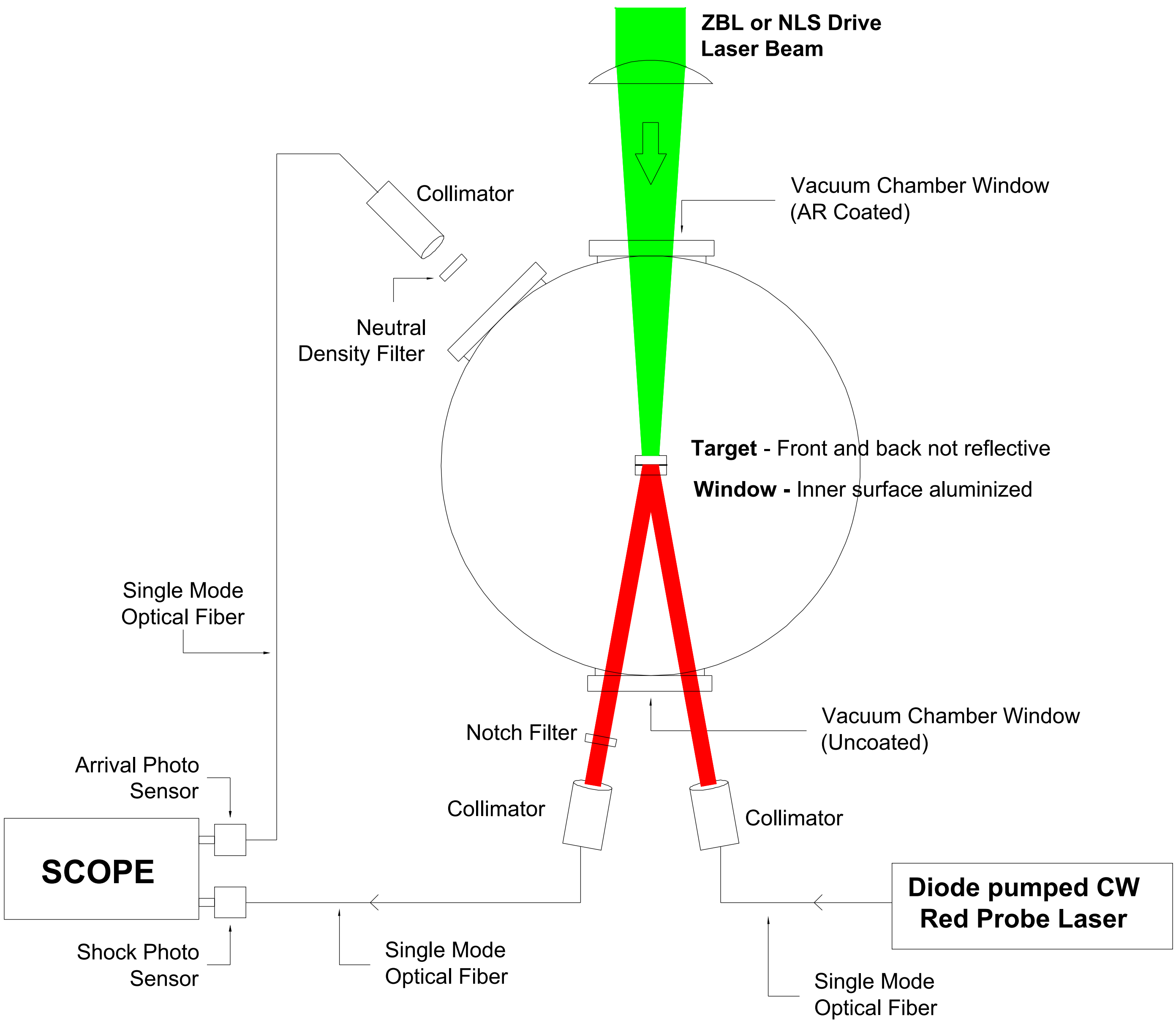
δ(mm)	**E(J)**	**I(GW/cm^2)**	**τ_{sw} (ns)**	**v_s (km/s)**	**τ_+(ns)**	**v_p (km/s)**	**P_H(GPa)**	**P_{rad}(GPa)**	**C_M(s/m)**
NLS laser; λ = 1064 nm									x10^{-5}
1.21	9.9	560	139	8.71	7	7.1	145	30	0.26
1.21	9.4	460	140	8.64	7	7.1	144	26	0.31
ZBL laser; λ = 527 nm									
1.21	120	4370	134	9.03	6	8.3	175		
Reference values (Pavlovski 1968)				**8.5**		**0.20**	**4.0 (transformations from elastic to plastic states)**		
				6.7		**0.66**	**11.2 (beginning of phase transformation)**		

Table 1. Si, ρ = 2.34 g/cm^3 Parameters at the top of the table are described in the text. The first set of data corresponds to NLS shots. The second set of data corresponds to a ZBL shot. The units for C_M are in 10^{-5} s/m as listed.

Figure 1. Experimental configuration for electro-optic real-time shock wave and particle velocity measurements using a reflecting interface on the rear target surface.

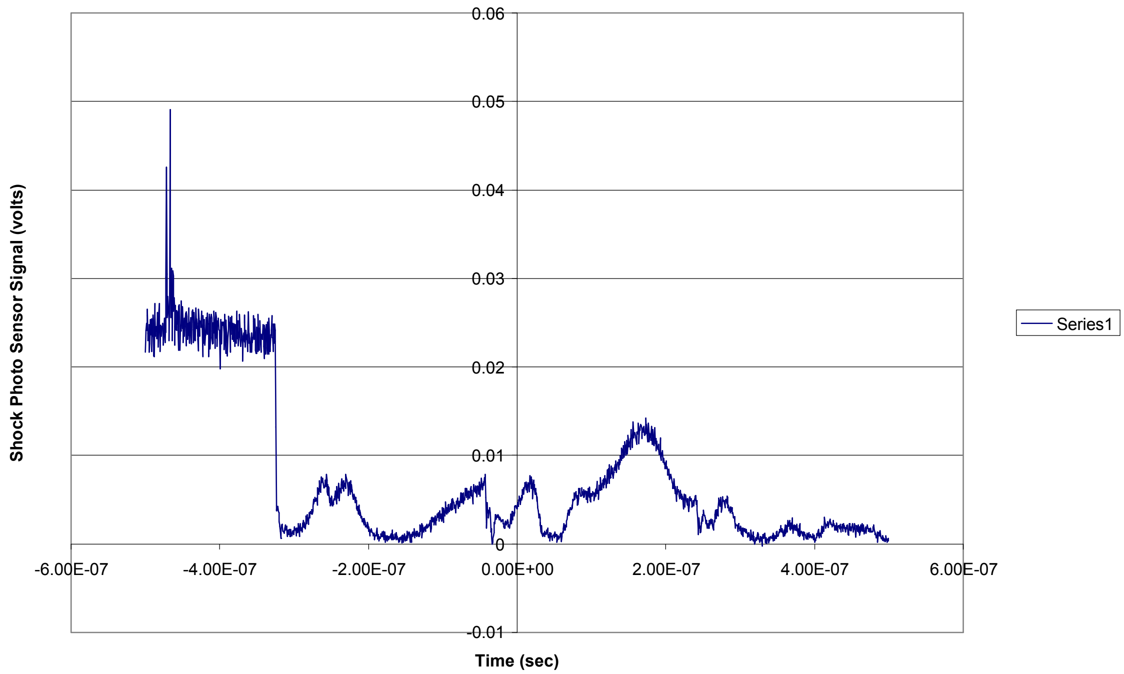
Figure 2. Electro-optic real-time measurements for the shock wave arrival (139 ns) and push-out time (7 ns) for the NLS laser irradiation of a Si target at 560 GW/cm^2.

Figure 3. Elecro-optic real-time measurements for the shock wave arrival (134 ns) and push-out time (6 ns) for the ZBL laser irradiation of an Si target at 4.37 TW/cm^2.



ZBL or NLS Drive
Laser Beam
Collimator
Vacuum Chamber Window
(AR Coated)
Neutral
Density Filter
Target - Front and back not reflective
Window - Inner surface aluminized
Single Mode
Optical Fiber
Notch Filter
Vacuum Chamber Window
(Uncoated)
Arrival Photo
Sensor
Collimator
Collimator
SCOPE
Diode pumped CW
Red Probe Laser
Shock Photo
Sensor
Single Mode
Optical Fiber
Single Mode
Optical Fiber

Typical Si Target Reflectivity Response for NLS Laser (1064 nm) Irradiation



Typical Si Target Reflectivity Response for ZBL Laser (527 nm) Irradiation