Study of Equation of State of Boron and Carbon compounds under laser-induced extreme conditions

<u>A. Milani[1,2]</u>, Bo Xu[3], D. Batani[1], K. Batani[4], D. Singappuli[1], D. Mancelli[1], A. Amouretti[5], W. Kang[6], N. Ozaki[5], K. Shigemori[7], Liang Sun[8]

[1]*CELIA, CNRS-University of Bordeaux, Talence 33405, France*
[2]*School of Electrical Engineering and Telecommunications, University of New South Wales, Sydney, Australia*
[3]*Hunan University, China*
[4]*Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland*
[5]*Graduate School of Engineering, Osaka University, Osaka, Japan*
[6]*Peking University, Beijing, China*
[7]*Institute of Laser Engineering, Osaka, Japan*
[8]*HPSTAR, China*

Cubic boron nitride (c-BN) has emerged as a promising alternative to diamond (HDC) as an ablator material for Inertial Confinement Fusion (ICF) capsules. Both materials share exceptional properties crucial for ICF applications: low atomic number, high density, high bulk modulus, superior chemical resistance, and high melting point. Uniquely, BN offers an additional advantage as a real-time fusion diagnostics tool through gamma-emitting nuclear reactions induced by neutrons and protons interacting with boron and nitrogen nuclei. However, the experimental database characterizing the behavior of these materials under high compression conditions remains significantly limited. This experimental campaign was therefore aimed to obtain Equation of State (EOS) data points for cubic boron nitride (c-BN, density 3.48 g/cm^3) and amorphous carbon (AC, density 3.16 g/cm^3), with the latter expected to exhibit properties similar to diamond. The experiments were performed using the GEKKO laser system at the Institute of Laser Engineering (ILE), Osaka, employing both second and third harmonic beams, focused on a large spot size of 600 µm diameter, producing intensities ranging from 10^{13} to 10^{14} W/cm^2 and leading to ablation pressures of the orders of tens of Megabars. The impedance mismatch technique was employed to determine the EOS points by measuring shock velocities in both the reference material (quartz) and the sample materials. Velocity Interferometer System for Any Reflector (VISAR) systems and Streaked Optical Pyrometers (SOP and SSOP) were utilized for precise shock velocity and temperature measurements. The experimental data for boron nitride showed good agreement with DFT ab initio calculations, while simpler semi-analytical EOS models (FEOS) failed to accurately reproduce the measurements. Amorphous carbon results demonstrated excellent agreement with semi-analytical models for diamond. These results significantly expand the experimental database for these materials and support their consideration as viable ablator materials for ICF capsule designs.

Keywords: laser, shockwave, inertial confinement fusion, megabar pressure, Equation of State

References:

[1] Zhang et al., *Equation of state for boron nitride along the principal Hugoniot to 16 Mbar*, Matter Radiat. Extremes 1 September 2024; 9 (5): 057403

[2] Brygoo et al., *Analysis of laser shock experiments on precompressed samples using a quartz reference and application to warm dense hydrogen and helium*, J. Appl. Phys. 21 November 2015; 118 (19): 195901

ACKNOWLEDGEMENTS

Co-funded by the European Union under the Marie Skłodowska-Curie Grant Agreement No 101081465 (AUFRANDE).
This work has been carried out within the framework of the COST Action CA21128- PROBONO "PROton BOron Nuclear fusion: from energy production to medical applications", supported by COST (European Cooperation in Science and Technology - www.cost.eu).