Liquid Carbon reflectivity in the Mbar regime

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The aim of the experiments presented here was producing high-pressures and high-temperatures liquid phases, by means of laser-induced shock compression, and their investigation through reflectivity changes as a possible signature of metallization. The final state reached in compression can be varied tuning the carbon layer characteristics (initial density and thickness) and the laser intensity, with the possibility to determine the reflectivity of carbon and the position on the phase diagram.

We have employed specially designed two-layer targets. A layer of porous carbon was deposited on a transparent substrate, the main laser beam hits the carbon and the rear surface is imaged by the diagnostics. This design has three advantages: (i) the substrate prevents the carbon from releasing into vacuum after shock breakout, keeping the density high; (ii) it reflects the shock wave back due to its higher density, raising the pressure; (iii) the interface between carbon and substrate is accessible to the optical diagnostics. The porous carbon was used to access thermodynamical states lying outside the main Hugoniot curves of ordinary graphite or diamond [1,2].

Two series of targets have been produced. In the first series, disks of fused silica (SiO_2 – 4 mm diameter and 100 μm thickness) were employed as substrates and the carbon layer was deposited with supersonic cluster beam deposition (SCBD) technique. The second series was made with spray coating technique on lithium fluoride substrates of square shape (3x3 mm and 300 μm thickness). Carbon density was 0.5 g/cm^3 and thickness ranged between 5 and 50 μm in both series.

Shock dynamics has been studied with the code MULTI (multigroup radiation transport in multilayer foils) [3]. Simulations have been used: (i) to predict the experimental conditions, in order to optimize the target design, (ii) to suggest the suitable laser energy shot by shot, according to the actual target characteristics during the experiment, and, the most important (iii) for the interpretation of the experimental data. Thanks to the large ratio of focal spot diameter (initial shock size) to the carbon layer thickness 1D simulations provide accurate predictions in our case.

We have used the SESAME equation of state for substrates [4] and porous carbon EOS calculated by MPQEOS [5] with a reduced initial density. [6] The actual time profile of the main laser (measured by the dedicated diagnostic) was included in the simulations and the target was accurately modeled.

Experiments were realized with the GEKKO/HIPER system at the Institute of Laser Engineering (ILE), Osaka University. The HIPER facility [7] is an irradiation system on the GEKKO XII (GXII) Nd glass laser system at ILE [8]. The facility provided one-dimensional compression by smoothed laser beams with short wavelength and high intensity. The laser pulse had a wavelength of 527 nm (second harmonic, 2ω-beam), wais approximately square in time with a full width at half maximum (FWHM) of 2.4 ns and a rise and fall time of 100 ps. The focal-spot diameter was typically 1 mm.

The total laser pulse energy was measured with a calibrated calorimeter. Four diagnostics based on streak cameras with sub-nanosecond time resolution were used at the same time. Two of them collect the self-emission giving space-resolved and frequency-resolved emission intensity (a Streaked Optical Pyrometer – SOP – and a Streaked Spectrograph Optical Pyrometer – SSOP – respectively), while two VISAR (Velocity Interferometer System for Any Reflector) systems recorded the speed and the reflectivity of the rear side of the target.

A serious problem to observe the reflectivity rise in carbon is due to the changes in the substrate becoming either absorbent or reflected. That is why targets with fused silica substrates did not provide useful data. The pressure in this case exceeded the threshold value of 1 Mbar for SiO_2 metallization [9]. For targets with lithium fluoride substrates the threshold value is 3 Mbar, [10] and there is a narrow window available for the observation of the reflectivity rise in carbon.

An evidence of a reflective phase in carbon was observed at pressure of 2.6±0.4 Mbar and temperature of 14,000±2,000 K while no increase in reflectivity is found at 2.0 Mbar and 20,000 K (look at fig. 1).

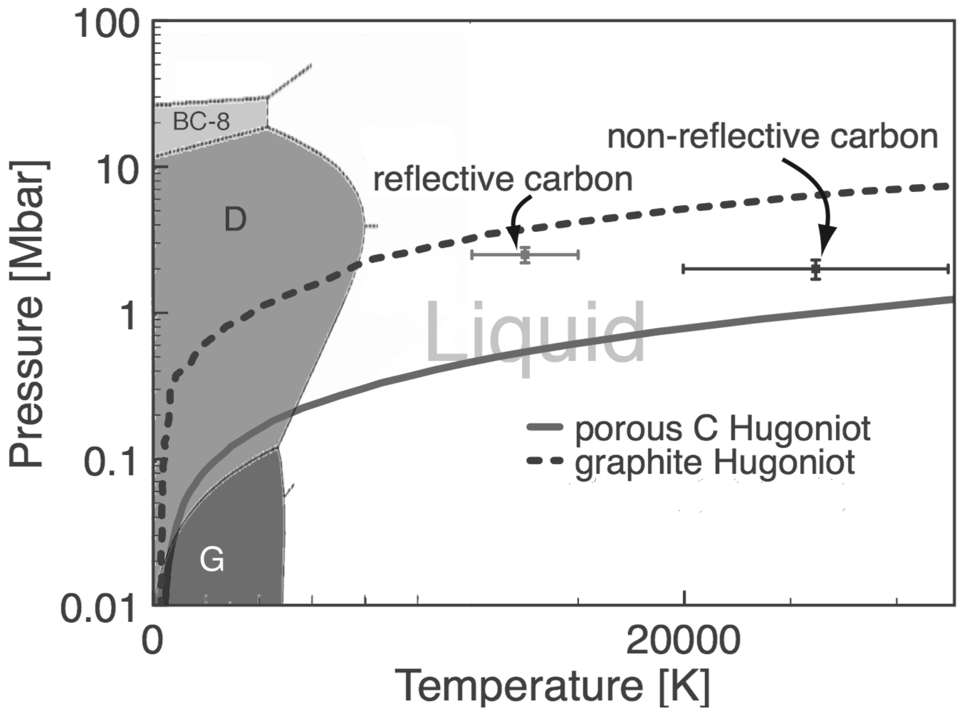

Fig. 1. Phase diagram of carbon in the high pressure and temperature regime, after [11].

Finally we can conclude that: (i) the limits of the carbon-on-transparent substrate design have been explored, (ii) the whole experimental scheme proof has been obtained, and finally (iii) the increase of reflectivity in carbon was observed.

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