Scientific Report for Short Visit Grant

Dr. Roberto BENOCCI

SUBJECT: **Super-intense laser-matter interactions SILMI / PESC**
Investigation of phase transition of carbon in the Mbar regime

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Invited by:
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PURPOSE OF THE VISIT: Investigation of the transition between solid-insulator to liquid semi-metal in carbon compressed at megabar pressures by laser driven shocks. According to Grumbach and Martin [1], a transition to a liquid semimetallic or liquid metallic phase at high temperatures is expected. Carbon phase diagram is shown in figure 1. In order to determine the position of the melting line in the P - T plane carbon is compressed and heated to solid, liquid semimetallic and liquid metallic phase respectively, as close as possible to the phase transition points. This is acheived by laser-driven shock wave compression of carbon deposited on silica or LiF transparent substrates (see figure 2). GEKKO laser beams hit the first carbon layer and a shock-wave propagates through the material. Streak cameras and VISAR diagnostics image the interface between first and second layer. Target behaviour in the experimental condi-

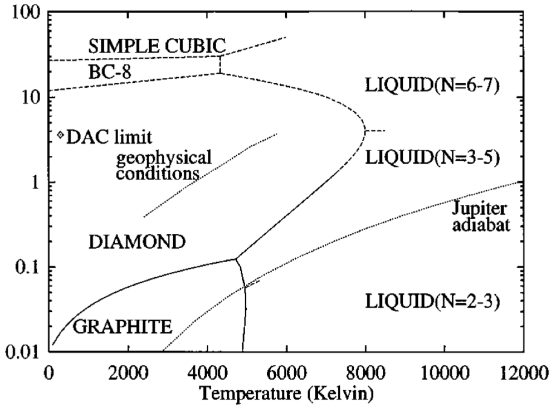

Figure 1: Grumbach and Martin's proposed carbon phase diagram in the Mbar region

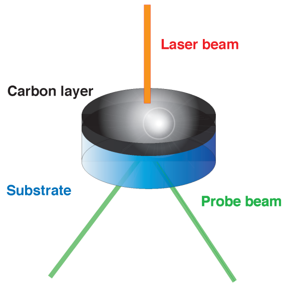

Figure 2: Sketch of a target

tion has been investigated through a hydrodynamical-radiative simulation code, MULTI [2]. The code simulates 1D laser-driven shocks in a very wide range of experimental conditions.

WORK CARRIED OUT DURING THE VISIT: Firstly effective thickness of the carbon layer of the targets was determined, using an optical profiler. This measurement was necessary to check the actual condition of the targets after the transport. Besides, MULTI code simulations were used to choose the best shot parameters, according to target characteristics and experimental set-up. A first calibration shot was performed to estimate the total energy losses of the laser beam due to frequency doubling and the use of KPP technique to get super gaussian spatial profile. Three beams of the GEKKO laser were dedicated exclusively to our experiment and we performed ten shots during the week, including the calibration. Each shot required careful target preparation (done by the target laboratory inside the facility), target alignment in the interaction chamber and diagnostics adjustments and optimization. The following table summarizes the main characteristics of the shots performed.

Energy	**target characteristics**
54.9 J	Carbon ($\rho = 0.2 g/cm^3$) on LiF substrate
101 J	Carbon ($\rho = 0.2 g/cm^3$) on LiF substrate
531 J	Carbon ($\rho = 0.2 g/cm^3$) on LiF substrate
225 J	Carbon ($\rho = 0.2 g/cm^3$) on LiF substrate
26 J	Carbon ($\rho = 0.2 g/cm^3$) on LiF substrate
73.5 J	Carbon ($\rho = 0.2 g/cm^3$) on LiF substrate
308 J	Carbon ($\rho = 0.2 g/cm^3$) on LiF substrate
438 J	Carbon ($\rho = 1.2 g/cm^3$) on silica substrate
183 J	Carbon ($\rho = 1 g/cm^3$) on silica substrate

MAIN RESULTS: from a preliminary analysis it was possible to evidence some hints of a transition of Carbon to a conductive or semi-conductive phase.Reflectivity variations were found in high energy shots, as well as the emissivity changes reported above. At the shock breakout a sudden decrease in the light reflected from the interface carbon/substrate was observed in all shots. Only in high energy shots VISAR (Velocity Interferometer for Any Reflector) images show sharp peaks of reflected light immediately after shock breakout as can be seen in figure 3. The movement of the fringes is due to either the sudden acceleration of the interface at the shock breakout and the variation of the complex refractive index $\hat{n}$. Other exemples are shown in figure 4. The state in the phase diagram (P,T plane) will be determined from SSOP (spectrometer coupled with a streak camera), SOP and VISAR data. The temperature can be estimated fitting the emission spectrum with Planck curves. Particle and shock velocities can be determined analysing SOP and VISAR images. Once that the velocities are known, the pressure can be evaluated with the aid of Hugoniot and other hydrodynamical relations. MULTI code simulation will give an overall check of the consistency of the results as well.

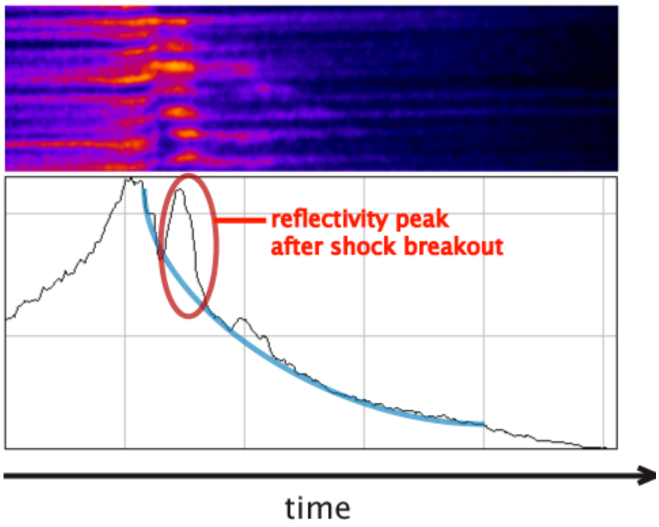

Figure 3: VISAR image showing reflectivity peak (shot energy $E = 225J$)

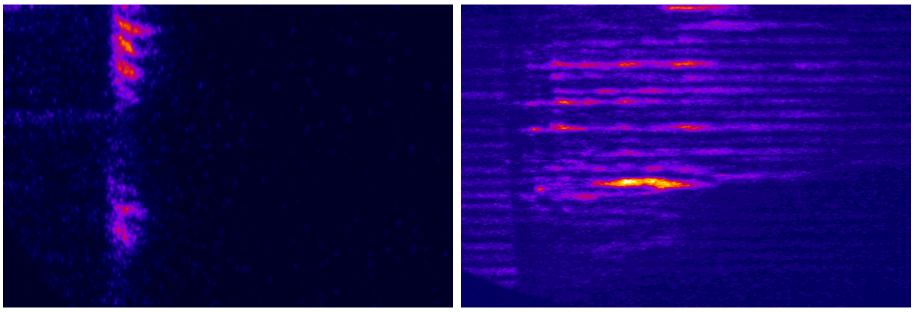

Figure 4: Reflectivity variation due to phase transition in high energy shots ($E = 438J$ and $E = 183J$ respectively)

FUTURE COLLABORATION WITH HOST INSTITUTION: Our common interests have already led to several meetings between the Italian and Japanese teams, and finally to the realization of an experiment, jointly realized by the Prof D. Batani's Milan group and the Osaka groups of Prof H. Nishimura and Prof K. Shigemori, performed at the Institute of Laser Engineering, Osaka University in July 2009 to study the isochoric heating of Deuterium-Clorine compound targets and this last experiment in November 2009 on the phase transition on Carbon at high pressure. In particular, our collaboration will be addressed to make studies on both inertial confinement fusion in the "fast ignition" (FI) approach and to continue the ongoing research on highly compressed materials. Both, the Italian researchers and the Japanese ones involved have been already actively studying this theme and they have a prominent role in the international scientific community working in this field.

PROJECTED PUBLICATIONS/ARTICLES: We expect to submit a paper on the results of this eperiment by May 2010.

References

[1] M. Grumbach and R. Martin, Phys. Rev. B: Condens. Matter **54**, 15730 (1996).

[2] R. Ramis, R. Schmalz and J. Meyer-Ter-Vehn, Comput. Phys. Commun. **49**, 4775 (1988).