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Measurements of electrical resistivity of heavy ion beam produced high energy density matter: Latest results for lead and tungsten

Serban Udrea[a,*], Vladimir Ternovoi[b], Nikolay Shilkin[b], Alexander Fertman[e], Vladimir E. Fortov[c], Dieter H.H. Hoffmann[a], Alexander Hug[a], Michail I. Kulish[b], Victor Mintsev[b], Pavel Ni[a], Dmitry Nikolaev[b], Naeem A. Tahir[d], Vladimir Turtikov[e], Dmitry Varentsov[d], Denis Yuriev[b]

[a] *Institute of Nuclear Physics, Technical University Darmstadt, Schlossgartenstr. 9, 64289 Darmstadt, Germany*
[b] *Institute of Problems of Chemical Physics, Prosp. Akad. Semenova 1, 142432 Chernogolovka, Russia*
[c] *Institute of High Energy Densities, Izhorskaya 13/19, 125412 Moscow, Russia*
[d] *Gesellschaft für Schwerionenforschung, Planckstr. 1, 64291 Darmstadt, Germany*
[e] *Institute for Theoretical and Experimental Physics, Bolshaya Cheremushkinskaya 25, 117218 Moscow, Russia*

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Abstract

The high-intensity heavy ion beams provided by the accelerator facilities of the Gesellschaft für Schwerionenforschung (GSI) Darmstadt are an excellent tool to produce large volumes of high energy density (HED) matter. Thermophysical and transport properties of HED matter states are of interest for fundamental as well as for applied research. During the last few years development of new diagnostic techniques allowed for a series of measurements of the electrical resistivity of heavy ion beam generated HED matter. In this report we present the most recent results on electrical resistivity of HED matter at GSI. The experiments on which we report have been performed with targets consisting of tungsten wires and lead foils, respectively. Uranium and argon beam pulses with durations of a few hundred ns, intensities of about 2×10^9 and 1×10^{11} ions/bunch, respectively, and an initial ion energy of 300–350 A MeV have been used as a driver. An energy density deposition of about 1 kJ/g has been achieved by focusing the ion beam down to 1 mm FWHM or less.

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1. Introduction

High-intensity heavy ion beams are an excellent tool to produce large volumes of high energy density (HED) matter [1–3]. Presently, the accelerator facilities of the Gesellschaft für Schwerionenforschung (GSI) Darmstadt can provide heavy ion beams of very high intensity, as for instance uranium beams with up to 5×10^9 ions/bunch and argon beams with up to 1×10^{11} ions/bunch. For HED experiments these beams are delivered in pulses with durations down to 125 ns FWHM. Focusing such beams to 1 mm FWHM or less may provide for an energy density deposition of more than 1 kJ/g in solid samples with volumes of the order of 1 mm^3. The investigation of the thermophysical and transport properties of the HED states reached by these samples due to heavy ion beam irradiation is the main goal of the experiments performed at the High Temperature (HHT) laboratory of the Plasma Physics department of GSI.

During the last few years a first series of measurements of the electrical resistivity of heavy ion beam generated HED matter has been performed using a two-point difference technique specially developed to comply with the experimental infrastructure at the HHT laboratory [4,5]. Recently, improvements of the infrastructure at HHT

*Corresponding author.
E-mail address: S.Udrea@gsi.de (S. Udrea).

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allowed for measurements using the more precise four-point technique [6]. The latest results obtained by this method are presented in this report.

2. Experimental setup

The experimental setup mainly consists of a pulsed current generator for driving the test current through the target, two oscilloscopes for the voltage and current signals, respectively, a fast pyrometer for time-resolved measurements of the temperature and an assembly comprising a laser backlighter and a streak camera to monitor the target expansion. Details for all these components have been presented in Refs. [7,8].

Two target types have been employed: wire and foil. The first type consisted of a 0.1 mm diameter tungsten wire with the section exposed to the ion beam having a length of about 4 mm.

The design of the tungsten targets has been similar to that described in Ref. [7] and used for aluminum targets (Fig. 1). The main difference consisted in thin copper pipes which have been used to make the connection to the irradiated tungsten target, thus the resistance of the connections was significantly reduced as opposed to using a long, bent wire.

The lead targets have been cut out of 0.1 mm thick foil. The shape has been that of an H. Just the central part with a length of 3 mm and a width of 0.6 mm has been heated by the ion beam. The rest was used for electrical connections: two "pins" for the test current and two "pins" for the measurement of the voltage drop across the target. The H-shaped foils have been fixed between two PMMA blocks, which have been provided with copper foils to ensure the electrical contacts.

The lead targets have been irradiated by uranium ion beams with an intensity of 2×10^9 ions/bunch, a pulse duration of approximately 200 ns FWHM and an initial ion energy of 350 A MeV. These beams have been focused down to a focal spot of less than 1 mm FWHM leading to deposited energy densities of about 1 kJ/g. The tungsten targets have been irradiated by argon ion beams with an intensity of 9×10^{10} ions/bunch, a pulse duration of approximately 250 ns FWHM and an initial ion energy of 300 A MeV. These beams have been focused down to a focal spot of about 1 mm FWHM leading to a similar energy density deposition.

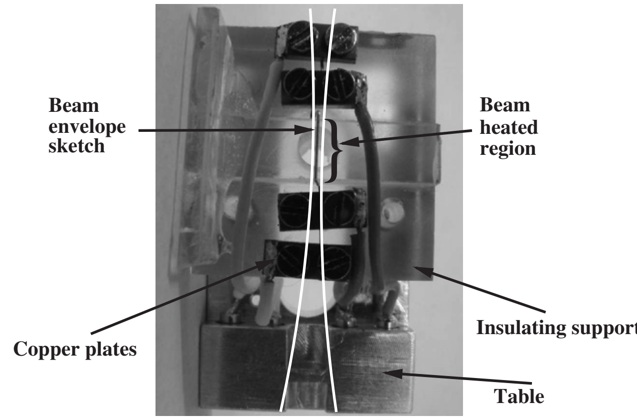
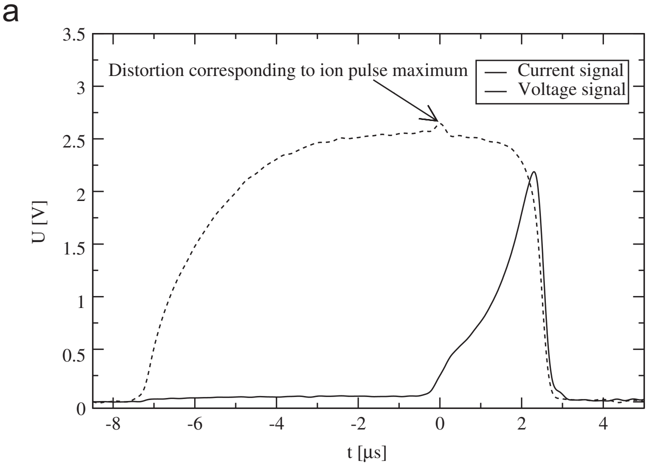


Fig. 1. Typical target assembly for wire targets. The target wire, fixing copper plates, insulating support and table are pointed out.

a



b

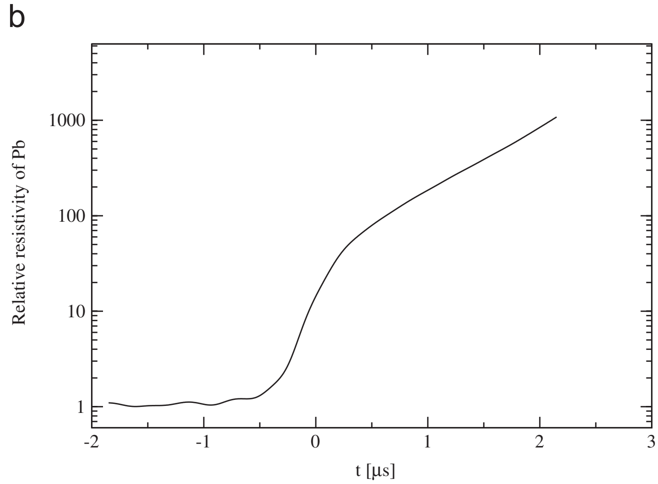


Fig. 2. (a) Typical experimental signals for lead targets. (b) Relative resistivity $\rho(t)/\rho_0$ of the irradiated lead target.

3. Results and discussion

In Fig. 2 typical experimental signals for the lead foil targets are presented together with the corresponding relative resistivity computed as

$$\rho(t)/\rho_0 = \frac{W(t)}{W_0}\frac{R(t)}{R_0}.$$

In this expression ρ_0 is the resistivity of the foil before irradiation, $R(t)$ is the resistance of the sample as a function of time as inferred from the current and voltage measurements, R_0 is the initial resistance, $W(t)$ is the thickness of the expanded target as estimated from the streak record and W_0 is the initial thickness of the foil. The expression of the relative resistivity is valid under the approximation that the expansion takes place mainly perpendicular to the