Available online at www.sciencedirect.com
SCIENCE DIRECT®
Nuclear Instruments and Methods in Physics Research A 544 (2005) 16–26
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Studies of heavy ion-induced high-energy density states in matter at the GSI Darmstadt SIS-18 and future FAIR facility

N.A. Tahir[a,*], A. Adonin[b], C. Deutsch[c], V.E. Fortov[d], N. Grandjouan[e], B. Geil[f], V. Grayaznov[d], D.H.H. Hoffmann[a,g], M. Kulish[d], I.V. Lomonosov[d], V. Mintsev[d], P. Ni[g], D. Nikolaev[d], A.R. Piriz[h], N. Shilkin[d], P. Spiller[a], A. Shutov[d], M. Temporal[h], V. Ternovoi[d], S. Udrea[g], D. Varentsov[g]

[a]*Gesellschaft für Schwerionenforschung, Planckstrasse 1, 64291 Darmstadt, Germany*
[b]*Institut für Angewandte Physik, Frankfurt University, 60325 Frankfurt, Germany*
[c]*Laboratoire de Physik des Gaz et des Plasmas, Universite Paris-Sud, 91405 Orsay, France*
[d]*Institute for Problems in Chemical Physics, Chernogolovka, Russia*
[e]*LULI, UMR 7605, Ecole Polytechnique-CNRS-CEA-Universite Paris VI, Palaiseau, France*
[f]*Institut für Festkörperphysik, TU Darmstadt, 64289 Darmstadt, Germany*
[g]*Institut für Kernphysik, TU Darmstadt, 64289 Darmstadt, Germany*
[h]*E.T.S.I Industrials, Universidad de Castilla-La Mancha, 13071 Ciudad Real, Spain*

Available online 11 March 2005

Abstract

This paper presents numerical simulation results of heating and compression of matter using intense beams of energetic heavy ions. In this study we consider different beam parameters that include those which are currently available at the heavy ion synchrotron, SIS18 at the Gesellschaft für Schwerionenforschung (GSI), Darmstadt and those which will be available in the near future as a result of the upgraded facility. In addition to this, we carried out detailed calculations considering parameters of high-intensity beam which will be generated at the GSI future Facility for Antiprotons and Ion Research (FAIR facility) that has been approved by the German Government. These simulations show that by using the above ion beam parameter range, it will be possible to carry out very useful studies on the thermophysical properties of high-energy density (HED) states in matter. This scheme would make it possible to investigate those regions of the phase diagram that are either very difficult to access or even are unaccessible using the traditional methods of shock waves. Moreover, employing a hollow ion beam which has an annular (ring shaped) focal spot, it would be possible to achieve a low entropy compression of a test material like hydrogen, which is enclosed in a cylindrical shell of a high-density material such as lead or gold. These experiments

*Corresponding author. GSI Darmstadt, Planckstr.1, 64291 Darmstadt, Germany. Tel.: +49 6159 71 2293; fax: +49 6159 71 2992.
E-mail address: n.tahir@gsi.de (N.A. Tahir).

doi:10.1016/j.nima.2005.01.178

will enable one to study the interiors of Giant planets, Jupiter and Saturn as well as to investigate the problem of hydrogen metallization.

PACS: 51.30.+i; 52.40.Mj; 52.50.Lp

Keywords: Intense heavy ion beams; High-energy density matter; Equation-of-state; Strongly coupled plasmas; Planetary science

1. Introduction

The Gesellschaft für Schwerionenforschung (GSI), Darmstadt is a unique laboratory worldwide that has the capability to generate intense heavy ion beams at a heavy ion synchrotron facility, SIS18 which has a magnetic rigidity of 18 Tm. Currently, this facility can deliver a uranium beam with an intensity $N = 4 \times 10^9$ ions, having a particle energy of a few hundred MeV/u. The particles are delivered in a single bunch which is a few hundred nanosecond long. It is expected that when the upgrade of the SIS18 will be completed, the beam intensity will be increased to 2.5×10^{11} ions per bunch while the bunch length will be reduced to about 50 ns and the particle energy will be 197 MeV/u [1]. The full-width at half-maximum (FWHM) of the Gaussian beam intensity profile along the radial direction, which for the calculational purposes is considered as the effective beam diameter will be 1.0 mm.

GSI is also in the process to establish a new accelerator facility named Facility for Antiprotons and Ion Research (FAIR) that would include construction of a new synchrotron SIS100, which will have a magnetic rigidity of 100 Tm. The SIS18 will be used as injector for the SIS100 and four to eight bunches from the SIS18 will be transferred to the SIS100 consecutively, where the ions will be further accelerated before the beam is finally delivered onto a target. The SIS100 beam will therefore consist of 1–2×10^{12} uranium ions with a wide range of available particle energy (400 MeV/u−2.7 GeV/u). The bunch length corresponding to this energy range is expected to be 90–20 ns.

Recently, a letter of intent (LOI) named high-energy-density matter Generated by Heavy Ion Beams (HEDgeHOB) [2], has been written by the members of the GSI Plasma Physics Group together with more than 100 international collaborators from about 30 universities and scientific institutions from all over the world. In this LOI, two different schemes have been proposed to study the problem of high-energy-density (HED) states in matter using the intense heavy ion beams that will be generated at the FAIR facility. In the first scheme named Heavy Ion Heating and Expansion (HIHEX), the material is isochorically heated by the beam. The heated material can then expand isentropically and depending on deposited energy, will reach different interesting physical states from that of an expanded hot liquid, critical point region and two-phase liquid–gas region to strongly coupled plasmas and warm dense matter (WDM) states. These states are either very difficult to achieve or are unaccessible using traditional methods. An additional advantage of the HIHEX experiment compared to some traditional methods is that it is not limited to a specific type of target material, but any material of interest like for example, metals, minerals or oxides can be studied [3]. In case of the exploding wire experiments which are somewhat similar to the proposed HIHEX scheme, on the other hand, one is limited to use conductor material only [4]. In addition to that, due to the large flexibility in beam spot size and geometry, one may use plane as well as cylindrical geometry in these studies.

The second type of experiments named Laboratory Planetary Sciences (LAPLAS) are designed to achieve low entropy compression of a sample material like hydrogen, using a hollow beam that has a ring-shaped (annular) focal spot. Numerical simulation and analytic modeling have shown that using the beam parameters that will be available at the future FAIR facility, it will be possible to achieve the physical conditions that are expected