IOPscience iopscience.iop.org

Home Search Collections Journals About Contact us My IOPscience

MeV ion beams generated by intense pulsed laser monitored by Silicon Carbide detectors

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2014 J. Phys.: Conf. Ser. 508 012009

(http://iopscience.iop.org/1742-6596/508/1/012009)

View the table of contents for this issue, or go to the journal homepage for more

Download details:

IP Address: 203.64.11.45
This content was downloaded on 14/02/2017 at 08:20

Please note that terms and conditions apply.

You may also be interested in:

Silicon carbide detectors for diagnostics of ion emission from laser plasmas
Paolo Musumeci, Maria Cutroneo, Lorenzo Torrisi et al.

Transmission property and its applications of MeV ion beams with various capillaries
N Fujita, K Ishii and H Ogawa

Charged-particle acceleration through laser irradiation of thin foils at Prague Asterix Laser System
Lorenzo Torrisi, Maria Cutroneo, Salvatore Cavallaro et al.

Optimization in Spot Sizes of Focused MeV Ion Beam by Precise Adjustment of Lens-Current Excitations
Atsushi Kinomura, Mikio Takai, Takahiro Matsuo et al.

Ion energy analyser for laser-produced plasma
S S Chowdhury, R M Clement and H T Miles

Suprathermal electrons in kJ-laser produced plasmas: M- shell resolved high-resolution x-ray spectroscopic study of transient matter evolution
F P Condamine, M Šmíd, O Renner et al.

Comparison study of the charge density distribution induced by heavy ions and pulsed lasers in silicon
Tian Kai, Cao Zhou, Xue Yu-Xiong et al.

Comparative analysis of large plasma focus experiments performed at IPF, Stuttgart, and IPJ, wierk
H. Herold, A. Jerzykiewicz, M. Sadowski et al.

MeV ion beams generated by intense pulsed laser monitored by Silicon Carbide detectors

L Calcagno[1], P Musumeci[1], M Cutroneo[2], L Torrisi[2], F La Via[3], J Ullschmied[4]
[1] Dipartimento di Fisica, Università di Catania, V. S. Sofia 64, 95123 Catania, Italy
[2] Dip.to di Fisica & SdT., Università di Messina, V.le F. Stagno d'Alcontres 31, 98166 S. Agata (ME), Italy
[3]Istituto Microelettronica Microsistemi-CNR, Stradale Primosole, Catania, Italy
[4] Institute of Physics of the ASCR-PALS, Na Slovance 2, 18221, Prague, Czech Republic

E-mail: lucia.calcagno@ct.infn.it

Abstract. The high energy ions produced with intense pulsed laser were analyzed with Silicon Carbide detectors. In order to realize high performances and radiation resistant detectors, high quality and thick epitaxial layer were grown on a substrate and a Schottky diodes were then realized. These detectors were employed to probe the plasma generated with a 300 ps laser at intensity of 10^{16} W/cm^2 operating at Prague Asterix Laser System Laboratory. They show a fast response and a high sensitivity to high energy ions. Metallic and polymeric thin films were irradiated and the produced plasmas were monitored in forward and backward directions. The analysis of the time-of-flight spectra evidences the emission of protons and ions at different energies. The spectra were deconvolved with a shifted Maxwell Boltzmann distribution. In our experimental conditions we detected protons in the energy range 1.2 - 3.0 MeV and heavy ions between 1.0 MeV up to 40 MeV depending on the target and the laser energy. The results were compared with the ones obtained by Thompson Parabola Spectrometer.

1. Introduction

In the last decade a growing interest was addressed to devices realized on Silicon Carbide (SiC) semiconductor [1,2]. The superior physical properties of this material allow to realize devices operating in harsh environments, at elevated temperatures, at high power and under high radiation fields. In that context, SiC radiation detectors have attracted a large attention due to the improvement of processes allowing to grow thick and high quality epitaxial layers [3,4]. The detectors realized on SiC show very interesting features when are used to diagnose the laser plasma [5,6].

The wide band gap allows to blind the visible, near UV and IR light and to operate under high intensity visible light. The high carrier mobility gives the possibility of fabricating fast (ns) devices, the high resistance to radiation allows to operate under high radiation fields. Once more, a further interesting feature of these detectors is the proportionality of response to the ion energy. In fact, the detected ions generate, into the active detector volume, e-h pairs loosing 7.8 eV for pair production. The current signal collected by the electrodes will be proportional to the number of ions, i.e. to their energy loss.

In the last years a large activity was devoted to the production of high energy protons and light ions by a plasma laser because of the many applications in different scientific fields, as new generation

ion source, nuclear and astrophysical field, biomedicine, microelectronics, metallurgy and nuclear fusion technique [7]. In order to demonstrate the capability of laser plasma accelerators, the characterization of the produced ion beams must be performed. In that context we have already shown that SiC semiconductor detectors can be used in the monitoring of ionizing radiation emitted from laser-generated plasmas [8].

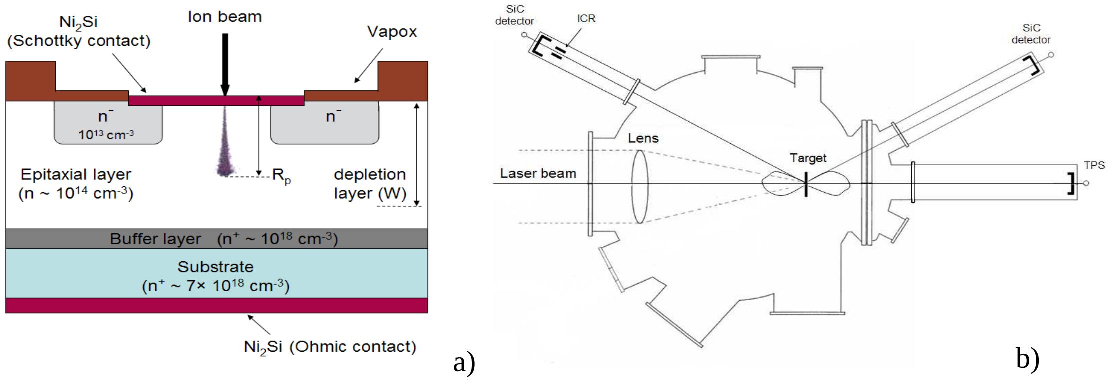
In the present paper we report some results obtained in the characterization of laser plasma by using SiC detectors realized on epitaxial SiC layer. In order to test the detector sensitivity, plasmas obtained in different conditions and from different targets were monitored. To provide the possibility of a better evaluation of the data, the results obtained with SiC detectors were compared with the ones coming from a Thompson Parabola Spectrometer (TPS).

2. Detectors and experimental setup

The SiC detectors were built on a 4H-SiC epitaxial layer grown with chemical vapour deposition technique in HCl atmosphere, which allows to obtain very thick layer (about 100 µm) with low dopant concentration (about 10^{14} cm^{-3}) and with very low defect concentration [9]. Schottky diodes were fabricated on these epilayers. The backside ohmic contact was formed by a rapid thermal annealing of a 100 nm thick Ni film at 950 °C. A Ni layer was then deposited in a Ultra High Vacuum chamber on the front of the wafer and various diodes were realized using standard photolithography. These diodes were then further annealed at 600 °C to optimize the Schottky barrier properties by the formation of a nickel silicide layer (Ni_2Si), with a resulting thickness of 200 nm. In Fig.1a a schematic section of the employed Schottky diode is shown, in which the track and the range (R_p) of a generic incident ion beam is also reported.

The application of a reverse bias creates a depletion layer (w) that lies entirely in the lightly doped SiC epitaxial layer. In our experiments we use a reverse bias of 600 V which produces a depletion layer of about 75 µm, thus allowing the measurement of the energy loss of ions whose penetration range (R_p) is less than 75 µm. This range value corresponds to proton energy of 3.2 MeV [10].

In such configuration, at 600 V inverse bias, the detector response has high linearity with the radiation energy, high resolution (FWHM=34 eV), and 100% charge collection efficiency, as demonstrated detecting alpha particles emitted from radioactive sources [11]. The active area of the SiC detector was 2x2 mm^2 and it was glued onto high temperature resistance holder.



a) b)

Figure 1. (a) Schematic cross-section of the SiC detector and of the ion trajectories (R_p is the ion range) (b) Schematic of the experimental setup for the target irradiation in the vacuum chamber at PALS laboratory.

The experimental measurements were carried out with the Iodine laser of Prague Asterix Laser System (PALS) Laboratory operating in single pulse at 1315 nm wavelength, 300 ps pulse duration, 70 µm laser spot diameter, 10^{16} W/cm^2 pulse intensity using laser energies ranging from 500 J to 600 J.

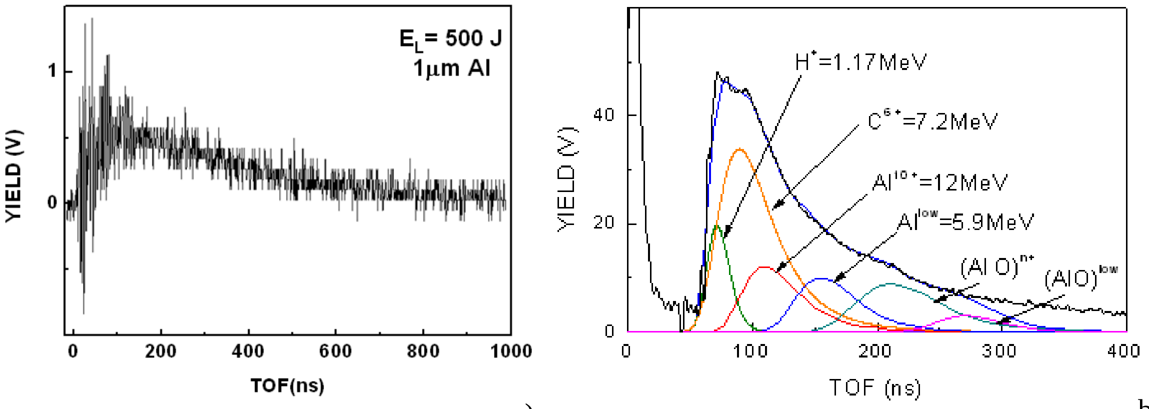
A schematic of experimental apparatus is shown in Fig.1b. Measurements were performed irradiating in normal incidence targets of aluminum (Al) and polyethylene (PE) and monitoring the plasma radiation emission both in forward direction (rear face of the irradiated target) and in backward direction (laser irradiated front face). SiC detectors were located at 30° angle with respect to the target normal in forward and backward direction. A Ring Ion collector (ICR) was also used and it was placed at 30° in backward. The laser focal position (FP) on the target surface was controlled though a X-ray streak camera permitting to measure its distance from the target surface. Micrometric step-motors permitted change of the focal position in order to check the self-focusing conditions for distances of the order of 100 µm in front of the target surface.

Time of Flight (TOF) technique was employed in our measurements and the spectra were recorded with a fast oscilloscope operating to 20 GS/s recording the laser shot as a start signal and the ion peaks as stop signals.

The ions emitted from plasma were also analyzed through a Thomson Parabola Spectrometer (TPS) located in forward direction along the normal to the target surface. The TPS is preceded by two pinholes, the first 1 mm in diameter and the second 100 µm in diameter at a distance of 16 cm, in order to finely collimate the detected ions from the plasma and to exactly determine the incidence direction. The spectrometer uses a 0.06 T horizontal magnetic deflection and + 2.8 kV (from the top) voltage for the vertical electric deflection. The distance between the electric deflectors and the Micro-Channel Plate (MCP) plane detector of the parabola ions is D=16.5 cm, as in similar apparatuses reported in literature [12].

3. Results and Discussion

The TOF spectra are usually composed by a relatively fast photopeak, followed, sometimes, by a signal due to the detection of plasma electrons, and a relatively long and structured peak due to the detection of plasma ions, from light to heavy ones depending on their velocity and charge state distributions. However if the detector is not fast enough, it becomes difficult to distinguish all the contributions in the TOF spectra.



a) b)

Figure 2. TOF spectra detected by a ion collector (ICR) (a) and by a SiC detector (b). The spectra are obtained by irradiating a thin Al target with a laser energy of 500 J. In the spectrum of SiC detector it is also shown the deconvolution obtained with the use of Coulomb-Boltzmann Shifted function (blue line).

The last statement is demonstrated by the spectrum shown in Fig.2a, which was obtained by an ICR detector when an Al target was irradiated at laser energy of 500 J. The spectrum shows a broad peak between 0-250 ns related to X-rays, UV radiation and fast ions, followed by a broad structure related to slow ions. Indeed, it is very hard to distinguish each component.

The use of SiC semiconductor detector allows to separate the plasma fast protons/ions with respect to the X-UV photopeak in the TOF spectrum. The wide bandgap (3.2 eV) allows a high attenuation of the plasma-emitted UV and soft X-ray radiation (XUV) then the SiC main advantage consists in the possibility to detect simultaneously the hard X-rays and fast ions emitted from the laser-generated plasma. This statement is evidenced by the spectrum obtained by SiC detector reported in the Fig.2b. This spectrum is detected in forward direction and it is relative to 500 J pulse energy irradiating a thin Al foil (1.0 µm) at -100 µm Focal Position, with a target-SiC detector distance of 102 cm. The spectrum shows an intense photo peak at fast time of flight (≈ 20 ns), followed by a large structured peak extending from 60 ns to about 300 ns. This structure is due to the fast protons and to the different charge states of the Al ions. Carbon ion contaminations might also be present. The spectrum reported in Fig.2b was fitted with the Coulomb-Boltzmann-shifted (CBS) function, which allows to deconvolve the experimental spectrum in the different ion species and charge states contributions [13]. The CBS function takes into account thermal and Coulomb interactions between plasma particles. Inside the plasma, in fact, a high equivalent acceleration voltage due to charge space separation effects is developed. It modifies the ion kinetic energy proportionally to the ion charge state. The fit of the experimental spectrum permits to know the most probable equivalent temperature and acceleration voltage of the plasma core. In the same Fig.2b the deconvolution obtained with this CBS function is reported. The proton kinetic energy is evaluated to be close to 1.2 MeV and the maximum energy of the Al ions is 12 MeV. As the acceleration energy is 1.2 MeV/charge state, Al ions with charge state n^+ =10 were produced in the plasma. Carbon ions at a maximum energy of 7.2 MeV (n^+=6) are also present.

We have tested the SiC detector with different type of targets in the same experimental conditions and in Fig.3 the spectra obtained at 600 J of laser energy with Polyethylene (PE) and Al targets, both 10 µm thin, are reported.

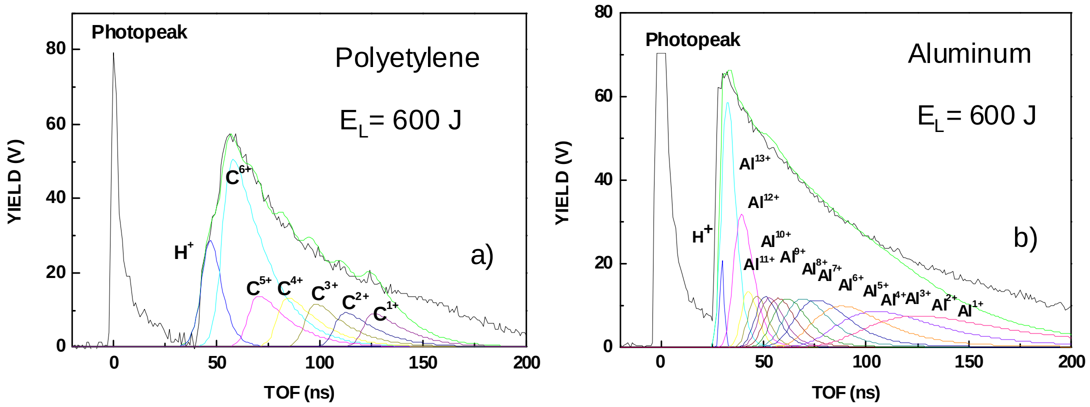


Figure 3. TOF spectrum achieved by a SiC detector with a polyethene (a) and an Al (b) target with a laser energy of 600 J. In both spectra the deconvolution with the use of Coulomb-Boltzmann Shifted function is reported.

The shape of the spectra is the same of the previous one, showing the feature of photopeak followed by the structure related to the ion components. In the same figures are reported the fits obtained with CBS function: we obtain an acceleration energy of 1.5 MeV/charge state and a temperature of 4 keV for polyethylene, while for the Al target we obtain 3.0 MeV/charge state, and the temperatures is 8 keV. This result reveals that in the same experimental condition the irradiation of Al target produces more energetic protons with respect to PE target. This result can be explained on the basis of the highly conductive metallic Al target that acts as an electron injector into the plasma, increasing the electron density. Such electrons increase the electric field of the plasma responsible of the high ion acceleration.

In addition the comparison between the results reported in Fig.2b and Fig.3b reveals that the energy of the produced ions increases with increasing the laser energy, as expected. In fact, the ion energy should be proportional to $I\lambda^2$, being I the laser intensity and λ the wavelength.

The plasma was also characterized by the TPS, which allows to determine the charge-to-mass ratios and the charge state distributions of the Al on the forward emitted plasma. Fig.4a shows the TPS spectrum obtained by the irradiation of an Al thin target with 600 J of laser energy, during the same SiC detection experiment. The spectrum shows a circular zone due to plasma photons and undeflected neutral particles arriving onto the MCP and different parabolas outgoing from this circular zone.

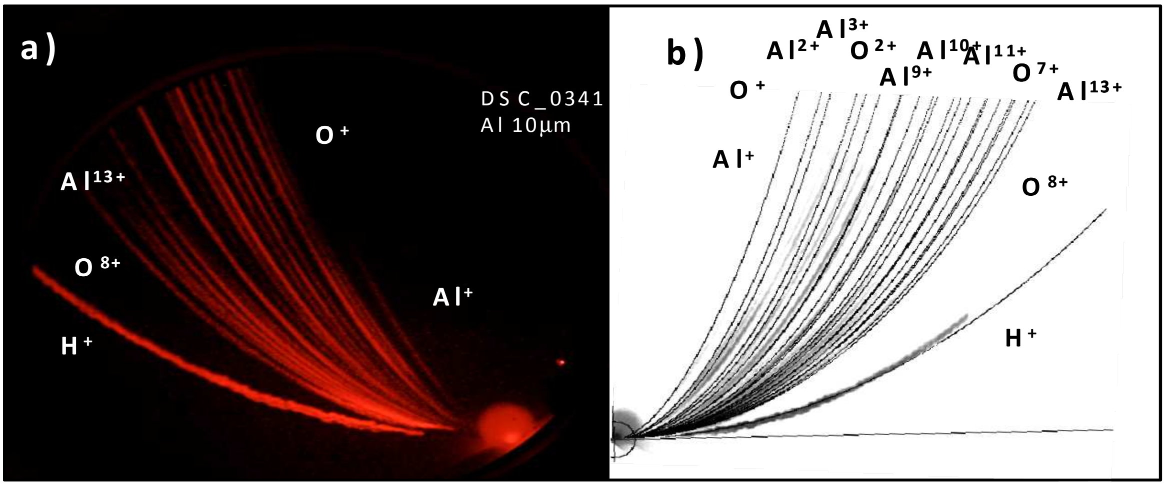


Figure 4. (a) Original image provided from TPS by irradiating the same Al target of Fig.3b and simulated spectra for the same shot obtained by executing Opera 3D-TOSCA code (b).

The experimental TPS parabolas are compared with the simulation data obtained by Opera-3D/TOSCA code [14]. The fixed parameters are the geometrical TPS dimensions, the magnetic field value, and the electric voltage applied to the electric deflector plates. In Fig.4b the simulation data are shown. The lower parabola is related to proton deflections and the others to Al ions from high charge state to the single charge state. The more vertically deflected parabola reveals the lower Al charge-to-mass ratio (on the top) and the less vertically deflected indicates the higher Al charge-to-mass ratio (on the bottom). The points of parabola lying nearest to the circular zone is due to the detection of highest energy ions. The distance between the protons parabola and the center circle is compatible with a proton maximum energy of 2.8 MeV, close to the value obtained with SiC detector (3.0 MeV). TPS measurements show thirteen parables related to all the charge states of Al and some ones associated to oxygen ions. The spectrum reported in Fig.3b was fitted without considering the oxygen ions as their intensity is too low.

The comparison between SiC detector and TPS evidences the high resolution of TPS to low energy ions, while at high energy the parabolas are close to each other because of the low applied magnetic field (0.06 T). Then, different detectors should be employed in order to have a complete energetic characterization of the laser accelerated ions and of the plasma proprieties in terms of maximum charge state, temperature, ion current and kinetic energy.

4.Conclusions

In the present paper we have shown that single crystal Silicon Carbide detector can be used to monitor the ions emitted from a laser generated plasma. The large energy gap of SiC allows well separate the photopeak and the ionic component of the plasma. These detectors were employed to characterize the plasma in different experimental conditions. The plasma emitted by polyethylene target at high laser energy allows to generate proton beams of 1.5 MeV. This energy increases to about 3.0 MeV by the use of metallic treated target. The results reveals that the SiC detectors are very sensitive to high energy ions and they are suitable for a characterization of ion beams generated by laser systems.

Moreover complementary techniques as Thomson Parabola Spectrometer permits a high resolution to low energy ions, evidencing that the use of different detectors gives a more complete characterization of the laser-generated plasma.

Acknowledgments

This work was performed at the PALS Research Infrastucture, benefiting from the Laserlab Europe project, N. pals001823 “High energy proton acceleration from thin advanced targets at PALS” coordinated by prof. L.Torrisi. The authors thanks the Mr. E.Krousky, M.Pfeifer, A.Velyan and J.Skala for the technical and scientific support provided during the experiments. Thanks also to G. Saccà and M. D’Andrea of the Istituto Nazionale di Fisica Nucleare (Sezione di Catania) for the technical assistance for the SiC detector electronics equipment.

References

[1] Park Y S SiC Materials and Devices, Semiconductors and Semimetal Vol. 52, edited by R. K. Willardson and E. R. Weber, Academic, San Diego, (1998)
[2] Matsunami H 2004 Jpn. J. Appl.Phys. 43 6835
[3] Calcagno L, Izzo G, Litrico G, Foti G, La Via F, Galvagno G, Mauceri M and Leone S 2007 J.Appl.Phys. 102 43523
[4] La Via F, Izzo G, Mauceri M, Pistone G, Condorelli G, Perdicaro L, Abbondanza G, Calcagno L, Foti G and Crippa D 2008 Journal of Crystal Growth 311 107
[5] Torrisi L, Foti G, Giuffrida L et al. 2009 J. Appl. Phys. 105 123304
[6] Margarone D, Krása J, Giuffrida L et al. 2011 J. Appl. Phys. **109** 103302
[7] Borghesi M, Fuchs J, Bulanov S V, Macckinnon A J, Patel P K and Roth M 2006 Fusion Sci. Technol. 49 412 .
[8] Cutroneo M, Musumeci P, Zimbone M, Torrisi L, La Via F, Margarone D, Velyhan A, Ullschmied J and Calcagno L 2013 Journal Material Research 28 87
[9] La Via F, Galvagno G, Foti G et al. 2006 Chem. Vapor Deposition 12 509
[10] Ziegler F, Biersack J P and Ziegler M D, 2008 SRIM-The Stopping and Range of Ions in Matter (SRIM, Annapolis, MD)
[11] Nava F, Bertuccio G, Cavallini A and Vittone E 2008 Meas.Sci.Technol. 19 102011
[12] Harres K, Schollmeier M, Brambrik E 2008 Rev. Sci. Instr. 79 93306
[13] Torrisi L, Gammino S, Andò L and Laska L 2002 J. Appl. Phys. 91 4685
[14] Chobam, OPERA-3D/TOSCA, 2012: http://www.cobham.com/about-cobham/aerospace-and-security/about-us/antenna-systems/kidlington/products/opera-3d/statics.aspx