tained with similar quality to those of polymer based arrays representing the standard in such field, [11].

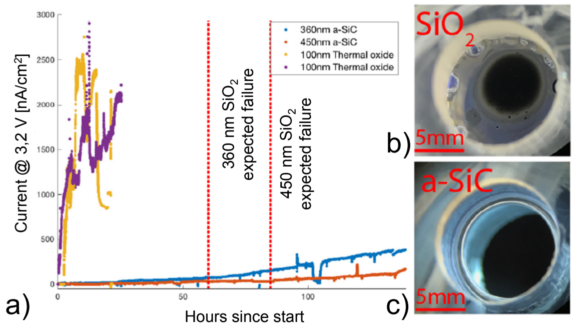

Figure 4: *(a) Leakage current and photos of* SiO_2 *(b) and SiC (c) probes after accelerated aging test, [11].*

Moreover SiC devices have not a limited device lifetime of a few years. Through accelerated aging tests the outstanding long term stability of insulating silicon carbide films has been proved. These tests consist of heating up the system and read the leakage current through a 1 MΩ resistor in series with the sample when 3.2 V are applied to the overall system. Thicker SiC films (360 nm and 450 nm) were aged for several days and, unlike thermal oxide samples that soon reach the failure region, they maintain a leakage current bellow 300 nA/cm^2 for up to 140 h of aging.

Automotive applications

One of the primary uses of silicon carbide is high performance "ceramic" brake discs. The silicon combines with the graphite in the composite to become carbon-fiber-reinforced silicon carbide (C/SiC). These brake discs are used on some sports cars, supercars, and other performance vehicles.

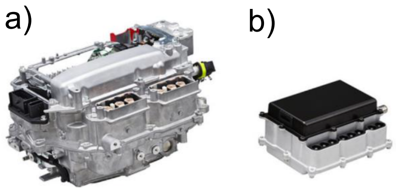

Figure 5: *Comparison of a Boost + Inverter + Generator with Si (a) and SiC (b), [13].*

Another use of SiC is as an oil additive. In this application, SiC reduces friction, emissions, and harmonics. An innovative application concerns its usage in Hybrid- and Electric Vehicles HEV and EV, respectively. It can be used as the Main Inverter that drives the electric motor, but it can be useful for regenerative braking and feeding energy back to the battery. It can be also used as high-power DC/AC or DC/DC. In the first case it replaces the belt-driven auxiliaries such as water pump, PTC Heater HVAC in electric power driven devices, while in the last case is need to charges the conventional 12 V power supply net from the high-voltage battery, replacing the former belt driven alternator. It can be also found in AC or DC electric accessory load On-board charger and battery where the adoption of SiC leads to a reduction of battery size and weight with an increase in efficiency and autonomy (+5% to 10%) as can be seen also in Fig. 5, [12].

Fast Power MOSFETs and diodes

Thanks to its electrical properties SiC can be use for the production of fast power MOSFET that found important applications for examples in "green" technologies. A 650 V SiC fast power MOSFET prototype has been realized by STMicroelectronics [14] with the aim to develop a new power inverter that is a mandatory elements in all grid-connected applications in order to amplify the low DC voltage generated by module array of which any photovoltaic system is made and the higher AC level required by the grid.

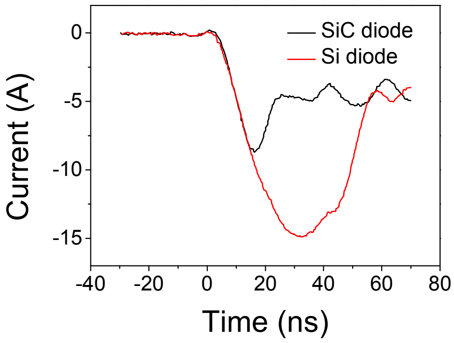

Figure 6: *SiC and Silicon diode response using a* $di/dt = 800\ A/\mu s$

The adoption of these MOSFETs in each stage between the PV panels and the grid, leads to the reduction in the size of passive components, saving cost and board space and open the way to the development of new inverter topology. It should be noted that that these fast power devices have to be used with very fast diode in order to avoid system failure. Again the best solution seems to be the use of SiC based technology as can be seen from Fig. 6. It compares the recovery response between a SiC diode (STPCS1006D) and a ultra-fast silicon diode (STTH8L06D) with the same forward parameters using a di/dt = 800A/μs, 5 A. SiC has the advantage of having a very low recovery current if compared with silicon using the same forward and breakdown voltage. The higher value of silicon diode (about 3 times higher) would lead to the failure of the power MOSFET. Now these are commercial technologies, MDmesh Power MOSET by STMicroelectronic, and represents the faster power MOSFET and diodes on the market.

Conclusions

SiC seems to be the most promising material for applications including high frequency, high power, high voltages and high temperature operation creating many opportunities for chemists, physicists, engineers, health professional, industry and technologies. It should be noted that despite the large commercial development of silicon carbide, the growth processes, not yet fully optimized, do not allow a wider diffusion, especially in the academic and research fields where very strict quality standards are required. For example the cost of a single crystal n-type 4H-SiC wafer, 3" inches diameter with a thickness of 250 μm is about 225 \$ [5] that is very high if compared with that of a silicon wafer with similar characteristics, i.e. about 21 \$, [6]. Moreover if the concentration of defects in the silicon is practically negligible, in the case of SiC only lately a micropipe density less than $1/\text{cm}^2$ has been achieved and this reduces the maximum wafer size achievable 150 mm, [7]. Despite this, in literature it is possible to find a wide production showing the usage of SiC for radiation detection [1–3]. In Fig. 7 is reported a typical configuration of a SiC Schottky barrier detector and some experimental prototypes through which it is possible not only the detection of low fluxes radiation source (monitoring of radioactive nuclides, RBS analysis) but also the diagnostic of plasma generated in the interaction between an intense laser pulse and a solid or gas target.

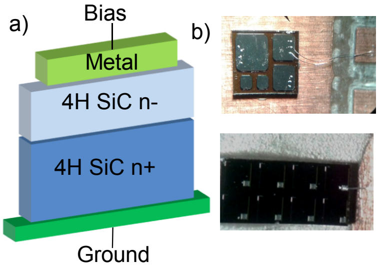

Figure 7: *(a) Typical SiC Schottky barrier detector and (b) photos of some prototypes.*

The interest in this material is growing also for X-rays, UV and neutron detection and and it is not difficult to imagine that in the next future there will be greater competitiveness of prices leading to a better diffusion of this technologies.

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Ion beam from laser-generated plasma and applications

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Abstract

This paper resumes some applications in the field of laser generated plasma, in order to produce good quality beam, all possible range of avialable ions and big current, laser ion sources are employed for give ions at the accelerator system. The beam divergence can be by-passed using Direct Plasma Injection Schema (DPIS). This schema was successfully employed in conjunction with an Radio Frequency Quadrupole (RFQ) system. Obtaining Al ions with current of about 50 mA. Coupling Laser Ion source with classical source, creating in this way an hybrid source, during the ECLISSE project was possible to increase the charge state value of the produced ions from 10+ up to close 34+, was a very interesting result for the possibility to coupling with an accelerator. Other application is in the field of material modification where the plasma can be used in order to implanted ions at different depth using post acceleration system and the multi charge states that are present inside the plasma.

Keywords: Laser, plasma, ion source, implantation, accelerator.

Introduction

Laser ion sources (LIS) have the possibility to produce beams with high charge states ions from any kind of solid material using high intensity lasers. Coupling the Laser ion sources to the high energy accelerator complex including several acceleration steps shown that the results are very interesting. However the multiple charge-state beams from the laser ion source have wide energy spreads and it is quite difficult to suppress space-charge effects in a low energy transport line, which usually consists of an extraction system and focusing elements, such as magnetic lens, between the source and the first stage accelerator. In order to overcome the low energy beam transport, a new injection method called Direct Plasma Injection Scheme (DPIS) can be used [1]. One of the system that can be couled with this scheme is the Radio Frequency Quadrupole (RFQ) Linac, a linear accelerator that accelerate, and focalize the beam for possible subsequent acceleration stages. In this scheme, the target, from which the particles are produced, is located in a vacuum chamber placed in front the entrance of RFQ. The chamber is electrically isolated from ground so that a high voltage can be applied to adjust the initial beam velocity to the RFQ design. A high energy laser hit the target producing a plasma in which the ions have several charge states (energy, charge state and plasma temperature depends strongly from the laser parameters) and a large fraction of the plasma goes directly into the RFQ channel where the ions are extracted from the plasma, accelerated by the DC potential, trapped by the RFQ focusing force, and then accelerated up to the design energy. The characteristics of laser-generated plasma are useful for other types of applications such as the creation of hybrid sources for particle injection in accelerators other than RFQs, such as cyclotrones. Generally a source of particles for the cyclotron is a plasma obtained from evaporation in ovens, or thanks to microwaves in Electron cyclotron resonance ion source (ECRIS). The possibility to produce intense metal ion beams, pulsed or dc mode, by means of an hybrid source, consisting of a LIS as the 1st stage and of an ECRIS as the 2nd stage, was under study at the Laboratori Nazionali del Sud (LNS) with the project ECLISSE [2]. In this study the low charge state plasma produced in the interaction expands inside a plasma produced by microwaves (generally O_2, N_2 or Ar). The expansion inside this plasma allows laser generated plasma to increase its charge state several times and using an extraction voltage of tens of kV it is possible to extract the beam and inject in superconductive cyclotron. Also in this application the possibility to produce all kind of ions is very important in order to obtaine very high energy beam of , for example, the high melting point materials (Ta, W, Re). Other application can be found for the laser generate plasma is the ion implantation using post acceleration systems. Generaly the implantation is performed using monoenergetic ion beam, having the fixed beam energy, the ions are implanted at the same depth. Here is the advantage of plasmas, that have several charge states that using a post acceleration voltage can create a beam with several energies [3]. Each charge state will be implanted at different depth. Using lasers in repetition rate, generally in the order of tens Hz, permits to extract a near constant ion beam from the plasma. The post acceleration voltage that we use is 30 kV in order to produce beam with energy 30 keV/z, where z is the charge state of the post accelerated ion.

DPIS-Radio Frequency Quadrupole

We took in consideration the RFQ of the Brookhaven National Laboratory where the DPIS scheme was studied by coupling a Nd: Yag laser with a RFQ that operates at a frequency of 100 MHz and from an input energy of 20 keV/u to 270 keV/u, where with u is indicare the atomic mass unit.

Table 1: *Parameters of RFQ LINAC*

Parameter	**Value**
RFQ Type	4 rods
Length [m]	2.0
Input Energy [keV/u]	20
Output Energy [keV/u]	270
RF Frequency [MHz]	100

The concept of DPIS is shown in Fig.1 [4]. The laser ion source is directly connected to the RFQ linac without low energy beam transport line. Kashiwagi et al (2008) shown that using DPIS with Nd:YAg laser with pulse duration of 6 ns and energy of 1.89 J irradiating an Al target it is possible to obtaine high current of ions up to 50 mA.

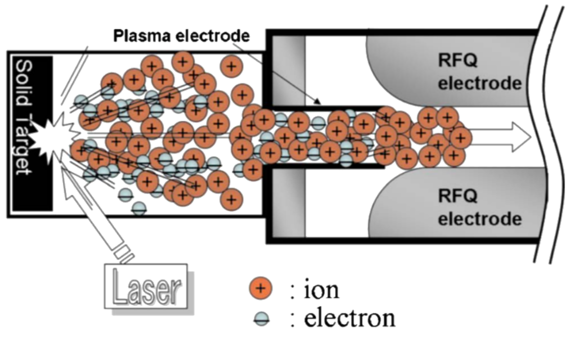

Figure 1: *DPIS with beam extraction in the RFQ cavity*

Changing the position of extraction and voltage it is possible to observe the behavior of current, in particular were studied the results at 0, 5, and 10 mm from the cavity edge and voltage from 40 and 70 kV. Fig.2 shows the measured beam current dependence on the beam extraction voltage and the plasma electrode position. The beam current indicates the peak current.

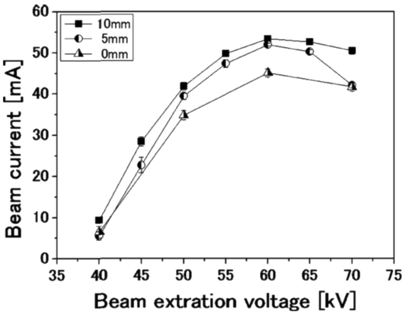

Figure 2: *The accelerated beam current dependence on the extraction voltage and the plasma electrode position 0, 5, and 10 mm from the cavity edge [4]*

The results shown that with a distance of 10 mm from the cavity edge the ion current reach value above 50 mA with 60 kV of extraction. The maximum current was obtained at 60 kV at each electrode position. The reason is that the energy of $^{27}Al^{9+}(z/A = 1/3)$ meets the injection condition 20 keV/u at 60 kV because the operating condition of the linac was tuned for charge to mass ratio z/A of 1/3.

Hybrid Sources

The electron cyclotron resonance coupled to a laser ion source for charge state enhancement (ECLISSE) is hybrid ion source where the first stage of the source is a LIS which gives intense beams of electrons and of multiply charged ions ($z/m = 1/10$ or lower) to the ECR-generated plasma, where its charge state is increased. In Fig.3 a cross section of the plasma chamber (called SERSE [5]) is shown with the laser beam that was injected into the beamline from the 0° port of the 90° analysis magnet, on-axis with the extracted beam (the interaction between the laser beam and the beam of highly charged ions extracted from the source is negligible). The Nd:YAG laser has been aligned along the normal to the target surface, by means of a He-Ne laser. A focusing lens (4 m focal distance) is placed in air at about 20 cm from the window placed on the 0° flange of the magnet, and a circular beam spot dimension variable from 1 to 3 mm^2 is obtained on the target. Generally, the employed laser repetition rate was 30 Hz or 1 Hz. The optical path of the laser beam was about 8 m and the free path after the lens about 4 m, passing through many beamline elements (slits and extractor electrodes) to hit the target, slightly off-centered, so that its rotation may permit to launch the laser beam over an annular shape.

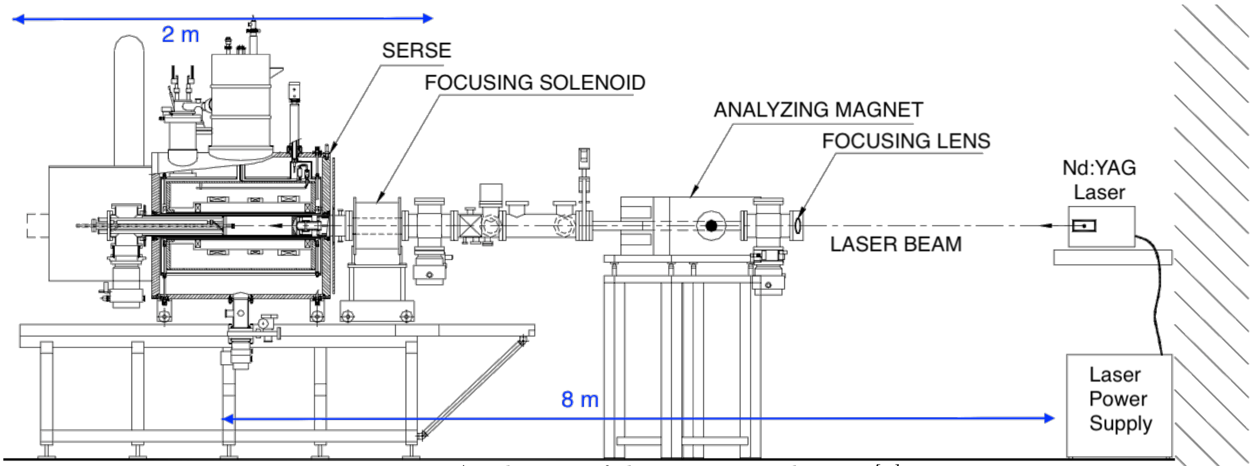

Figure 3: *A side view of the experimental setup [2]*

By using a Nd:YAG laser, 9 ns impulse duration, 900 mJ maximum pulse energy, and 30 Hz repetition rate, it is possible to get on the target an intensity of the order of 10^{10} W/cm^2 on the target, with this laser parameters, Gammino et al. (2004) shows the possibility to obtained high charge state enhancement coupling the plasma generated by laser with the ECRIS system. The plasma generated by laser with a maximum charge state up to $Q = 10+$ for heavy ions, such as Ta or Au, was produced in front to an argon plasma produced by ECRIS. The experiments performed with Ta plasma produced by laser, shown up to 8 charge states, after the transition through the argon plasma, it enhanced the number of charge states up to 34+. Like shows in Fig.4 we were able to get 40 μA Ta^{25+} and Ta^{26+}, 12 μA of Ta^{31+}, 1 μA of Ta^{33+} [2].

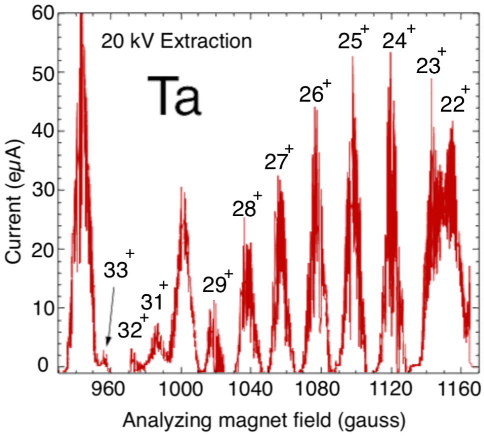

Figure 4: *Ta Charge state distributions after magnetic selector and 20 kV of extraction.*

The Fig.4 shown the results for Ta plasma, at the exit of microwave chamber there is a magnetic 90° selector that, changing the magnetic field, allows to study the produced charge states and the beam current.

The production of Ta ion beams is particularly interesting, as they cannot be produced by evaporation, for this reason is very important the developent of these hybrid sources for the cyclotron and other accelerators.

Implantation using post-acceleration

Ion implantation is a process by which ions of one element are accelerated into a solid target. Ion implantation equipment typically consists of an ion source, where ions of the desired element are produced, an accelerator, where the ions are electrostatically accelerated to a high energy, and a target chamber, where the ions are implanted on a target, which is the material to be implanted. Typilcally the accelerator produce a monoenergetic beam, in this case the implantation take place for all particles at the same depth. Using like source a laser-generated plasma, it is possible to obtaine several charge states and coupling with a post accelerator system it is possible to produce beams with multi-energetic ions. A post acceleration system consist of mainly of a positive bias on target surface and a negative voltage (generally high voltage) in front to the plasma in order to accelerate the positive ion produced by laser-matter interaction. After extraction, ions are accelerated by the intense electric field between the electrodes. If the applied potential difference is V, one would expect that ions reach an energy roughly equal to $Z_i eV$. A Nd:YAg pulsed laser operating with 1064 nm wavelength, 9 ns pulse width and 200 mJ pulse energy, in single shot mode, was employed to irradiate Ge target in vacuum chamber. The ion energy distributions shown in Fig. 5, obtained by varying the IEA deflection bias, indicate that the ions follow a Boltzmann distribution but it is different for each charge state three charge states and it follows a Coulomb-Boltzmann-shifted distribution, as reported in the literature [7].

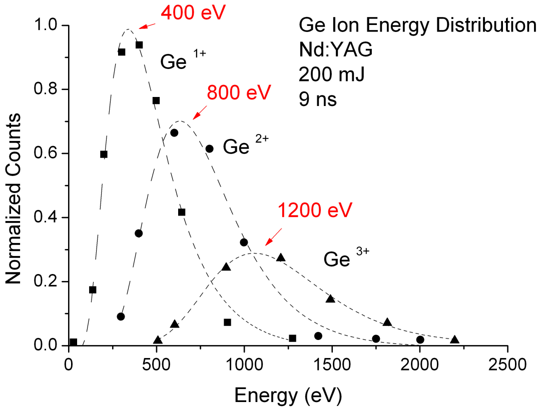

Figure 5: *Experimental ion energy distributions of the three Ge ion species without post-acceleration [6]*

The mean ion energies were about 400 eV, 800 eV and 1200 eV for Ge^{1+}, Ge^{2+} and Ge^{3+}, respectively, as reported in the energy distributions of Fig.5. By using the 30 kV acceleration voltage, the IEA ion energy distributions of the post-accelerated ions have been acquired by changing the E/z ratios around the mean energy of 30 keV, 60 keV and 90 keV for the three charge states of the two ion species. The multi energetic ion implantation in different materials can be followed by using the SRIM simulation program, which allows to determine the range and the straggling of ion implanted in a bulk. In this case three simulations with Ge ions like beam and SiO_2 like substrate were performed. The Ge ions were consireded emitted from a plasma with maximum charge state 3+, using a post acceleration of 30 kV, therefore the three simulated beams will have energy 30 keV, 60 keV and 90 keV respectively. The results of the three simulations are overlapped and shown in Fig.6 were are indicate the average implantation depths in an SiO_2 substrate.

Conclusions

How shown in this report the laser-generated plasma can be apply in many field and with several final applications. The possibility to change many parameter in laser parameters, pulse time, energy, focalization, angle of interaction, give the opportunity to obtain many kinds of ion sources from the single charge beam to full stripped, from low current to very high current etc. In addition there is the advantages to produce ions from all kind of solid target, this allow at this system to be employed in many facility for the described applications.

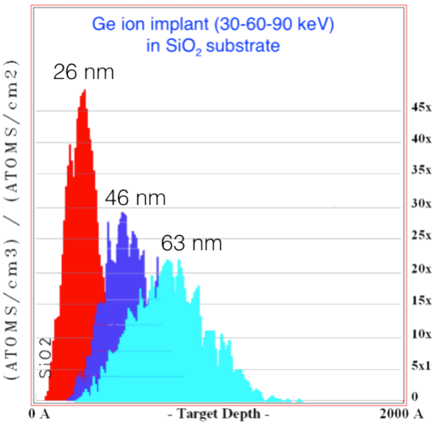

Figure 6: *SRIM simulation relatively to the ion implantation of* Ge^{1+} *of 30* keV*,* Ge^{2+} *of 60* keV*,* Ge^{3+} *of 90* keV

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