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Electromagnetic and geometric characterization of accelerated ion beams by laser ablation

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ABSTRACT

Laser ion sources offer the possibility to get ion beam useful to improve particle accelerators. Pulsed lasers at intensities of the order of 10^8 W/cm^2 and of ns pulse duration, interacting with solid matter in vacuum, produce plasma of high temperature and density. The charge state distribution of the plasma generates high electric fields which accelerate ions along the normal to the target surface. The energy of emitted ions has a Maxwell–Boltzmann distribution which depends on the ion charge state. To increase the ion energy, a post-acceleration system can be employed by means of high voltage power supplies of about 100 kV. The post acceleration system results to be a good method to obtain high ion currents by a not expensive system and the final ion beams find interesting applications in the field of the ion implantation, scientific applications and industrial use. In this work we compare the electromagnetic and geometric properties, like emittance, of the beams delivered by pure Cu, Y and Ag targets. The characterization of the plasma was performed by a Faraday cup for the electromagnetic characteristics, whereas a pepper pot system was used for the geometric ones. At 60 kV accelerating voltage the three examined ion bunches get a current peak of 5.5, 7.3 and 15 mA, with a normalized beam emittance of 0.22, 0.12 and 0.09 π mm mrad for the targets of Cu, Y, and Ag, respectively.

1. Introduction

Ion sources of high current and good geometric quality are very interesting for many applications. They can be used in the industrial field or for scientific experiments, i.e. they can feed large accelerating machines like the LHC; they can also be applied to improve biomedical materials [1,2], innovative electronic materials [3], new radio-pharmacy production [4,5], hadrontherapy applications [6] and the oxidation resistance of many materials [7].

Today, the use of laser sources facilitate the production of ion beams by solid target allowing the extraction of a large variety of ions. Currently, to produce ions electron beams, directed on a solid target in order to etches materials, are utilized [8]. Another method exploits the electron cyclotron resonance (ECR) applied to gases. However, this last cannot be applied to solid materials if they are not previously evaporated [9]. For this reason the ECR is useful for extreme applications.

Instead, pulsed laser ablation (PLA) technique allows to get ions from solid targets, without any previously preparation. The ion energy after the ablation is very low, less than 1 keV [10,11]. Moreover, the whole energy can be easily increased by post acceleration [12]. Therefore, an intense laser beam focused onto metal targets generates laser-induced plasma [13] and then ions also form refractory materials [14,15].

At intensities of the order of 10^8 W/cm^2 and ns pulse duration, laser interacting with solid matter in vacuum produces hot plasmas at high temperature and density, of the order of tens eV with 10^{17} electrons/cm^3 [16]. The laser-induced plasma plume and consequently the contained ions move along the normal to the target surface. Thermal interactions, adiabatic expansion in vacuum and Coulomb interactions are responsible of the primary ion acceleration in plasma [17]. The post acceleration increases the energy and, at long distance from the source, it can select the specific charged particles.

Due to the expanding plasma properties, which is essentially composed by energetic charges moving hydrodynamically, the accelerating field application can induce breakdowns without extracting or separating any charge. Therefore, the post acceleration technique can be applied to plasmas of moderate density owing to their low electric conductivity which avoids breakdowns. The conduction level is also influenced by the value of the particle energy [18]. Therefore, to extract charges from plasma it is necessary to choose very low density plasmas in order to overcome the conducting phase and to avoid short-circuits. In addition, the pres-

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ence of high energy particles can also inhibit the breakdowns since electric fields have a low influence on the particle trajectories.

Unfortunately, the percentage of ionization of material in LIS sources is not very high, but sufficient to get ion beams of high intensity. Besides, the apparatus we present, applying a high laser repetition rate and a high power vacuum system, the output ion beam can become nearly continuous. The maximum percentage of the ionized material is found near the target of the source and it is of about 16% with respect to the total ablated material [11]. The ionizing process is due to the absorbed laser energy via bremsstrahlung [12]. The recorded plume temperature can get values of hundred thousand Kelvin [13]. Nevertheless, the final ion beam energy depends on the particle charge state, on the intrinsic particle energy and on the applied potential, which provide the accelerating field. Generally, the maximum potential value applicable to accelerator apparatus mainly depends on the chamber volume and as well as on its geometry. Therefore, in this work we present, the enlargement of the acceleration without increases the potential value of the power supply, 1° stage, but development a second accelerating gap connected to a further power supply, 2° stage. Then, we realized an ion accelerator composted by two independent accelerating sectors. In this device we used an excimer laser to get PLA from three different metal target, Cu, Y and Ag. By a suitable Faraday cup and a pepper pot system, we characterized the extracted charges and the geometric quality of the beams.

2. Experimental apparatus

The laser we used to get PLA from solid targets was a Compex 205 excimer laser operating in the UV range, at 248 nm. Its output beam energy is of 600 mJ. Its time duration ranges from 23 to 30 ns, depending on freshness of the gas mixture. The maximum repetition rate is 50 Hz. The laser beam streaks the solid targets to generate plasma in the vacuum chamber. Fig. 1 shows experimental apparatus. The accelerating chamber (AC) contains an expansion chamber (EC) placed tightly closed around the target support (T). It is connected to the AC by an insulating flange (IF). The plasma expands inside the expansion chamber in order to decrease its density. Inside the expanding plasma, no electric field is present, therefore breakdowns are absent. The length of expansion chamber is 18 cm and it has an extremity drilled by a 1.5 cm diameter hole to allow the ion extraction. The target, together to EC, is connected to the first power supply of positive bias voltage. Four capacitors of 1 nF (C_1) stabilize the accelerating voltage during the fast ion extraction.

Owing to the plasma expansion, the charges reach the extremity of the expansion chamber. In this position a pierced ground electrode (GE) is placed at 3 cm distance from the EC drilled extremity. After this electrode an another one, placed at 2 cm from the GE and connected to a power supply of negative bias voltage, is utilized as third electrode and also as Faraday cup (FC) collector. The laser beam is focused on the target through a 15 cm focal distance convergent lens. The beam hit the target with an angle of 70° with respect to the normal to the target surface. During our measurements the laser spot area onto the target surface is fixed at 0.005 cm^2 for all experimental conditions. The third electrode is connected to the oscilloscope by a high voltage capacitor of 2 nF (C_2) and a 20× voltage attenuator in order to separate the oscilloscope from the high voltage. This configuration allows also to suit the cup signals to oscilloscope input voltage. The capacitances of the capacitors utilized to stabilize the accelerating voltage were chosen assuming a storage charge higher that the extracted one.

By theoretical consideration, the maximum accelerating voltage applicable in this configuration could be increased up to 160 kV. Instead, we performed our preliminary experiments with a maximum voltage of 40 and 20 kV for the first and secondary power supply, respectively.

At 40 kV the stabilized capacitors C_1 stored a charge of about 160 μC, while at 20 kV the capacitor C_2 stored a charge of about 40 μC. As it is possible to see in the next section, the total charge extracted in this experiment was slightly larger than 10 μC, value lower than the storage ones.

In this experiment we used the Faraday cup collector also as substrate support for the samples to be implanted. Therefore, it was not possible to insert the suppressing electrode on the cup collector and as a consequence, secondary electron emission, caused by high ion energy, was not avoided. So, by previous measurements [19], we are aware that the output current values are of about 20% higher than the real one.

The laser energy utilized to produce ion beams was 11.3 mJ and the targets were three disks of Cu, Y and Ag. The Faraday cup was fixed at 23 cm distance from the target surface.

3. Results

In the LEAS laboratory the value of the laser intensity utilised was of the order 10^8 W/cm^2, which is sufficient to generate plasma and to produce ions without forming breakdowns under the used voltage values. The output current was recorded by the FC at different accelerating voltages for the 1° and the 2° stage. The waveform of the time of flight (TOF) signal normally presented the form of the shifted Maxwell–Boltzmann distribution. Seldom some TOF waveform was trimmed owing to the space charge effect. This effect is much evident at low accelerating voltage values especially for that of the 1° stage. It is noteworthy to know that trimmed waveforms were not observed when no voltage was applied, since plasma

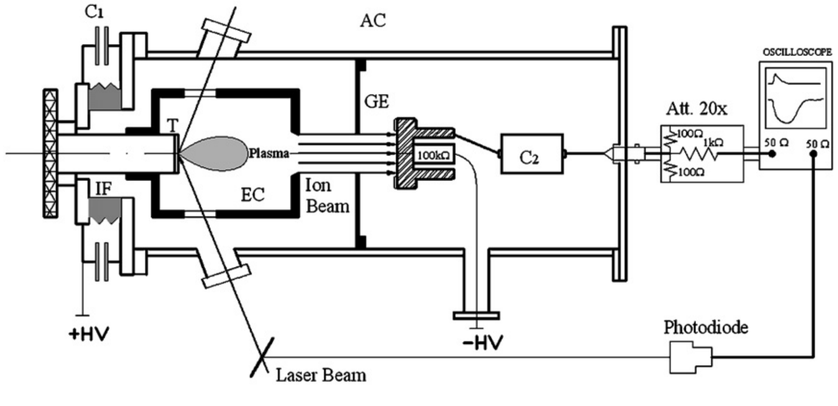

Fig. 1. Schematic drawing of the experimental apparatus.