29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. ***26B****, P-1.208 (2002)*

A laser-triggered high voltage discharge to produce long plasma channels for plasma accelerators

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Abstract. We describe a new technique for producing plasma channels for plasma accelerators. It is based on a laser-triggered high voltage discharge between two specially shaped electrodes. The fast discharge ionizes and heats a plasma line in a background gas that evolves to a guiding channel in a few ns. By increasing the discharge voltage, the length of the channel can be increased to, at least, a few centimeters in moderate plasma densities. This technique presents no jitter, does not require special laser beams or optics and the repetition rate of the channel is only limited by the capacitor bank charging time. We present the first experimental results using this technique, where plasma line lengths of up to 1.5 cm where achieved and shadowgraphy images strongly suggest that these plasmas may evolve to guiding structures capable of guiding intense and short laser pulses.

1 Introduction

Laser-plasma particle accelerators [1] have been the subject of experimental research by several groups worldwide, leading to accelerating fields and energy gains in excess of 100 GeV/m and 100 MeV [2] respectively.

The extension of the acceleration length is one of the key issues of a practical GeV laser-plasma particle accelerator. This goal can be achieved by channelling a focused high power laser pulse through a low mode waveguide [3-7]. There are several desirable characteristics that such a channelling scheme should exhibit. First, it should not require a significant amount of laser power to create the channel. The channel medium should not be subject to degradation over a significant number of shots, and its creation must be kept within a low jitter relative to the laser pulse. For this reason, it is also fundamental to have access to the plasma in order to monitor its evolution. Finally, the scheme should allow the entrance and exit of laser and electron beams, and ideally it should be scalable to channels tens of centimetres long. These requirements have led us to introduce a novel design, which addresses all of them: we use a capacitive discharge; the channel medium is a gaseous plasma, which presents no degradation, and a small part of the main laser pulse itself is used to trigger its creation with virtually no jitter. Given the geometric characteristics of the set-up, access to the plasma is also easily obtained, and the channel length can be readily varied.

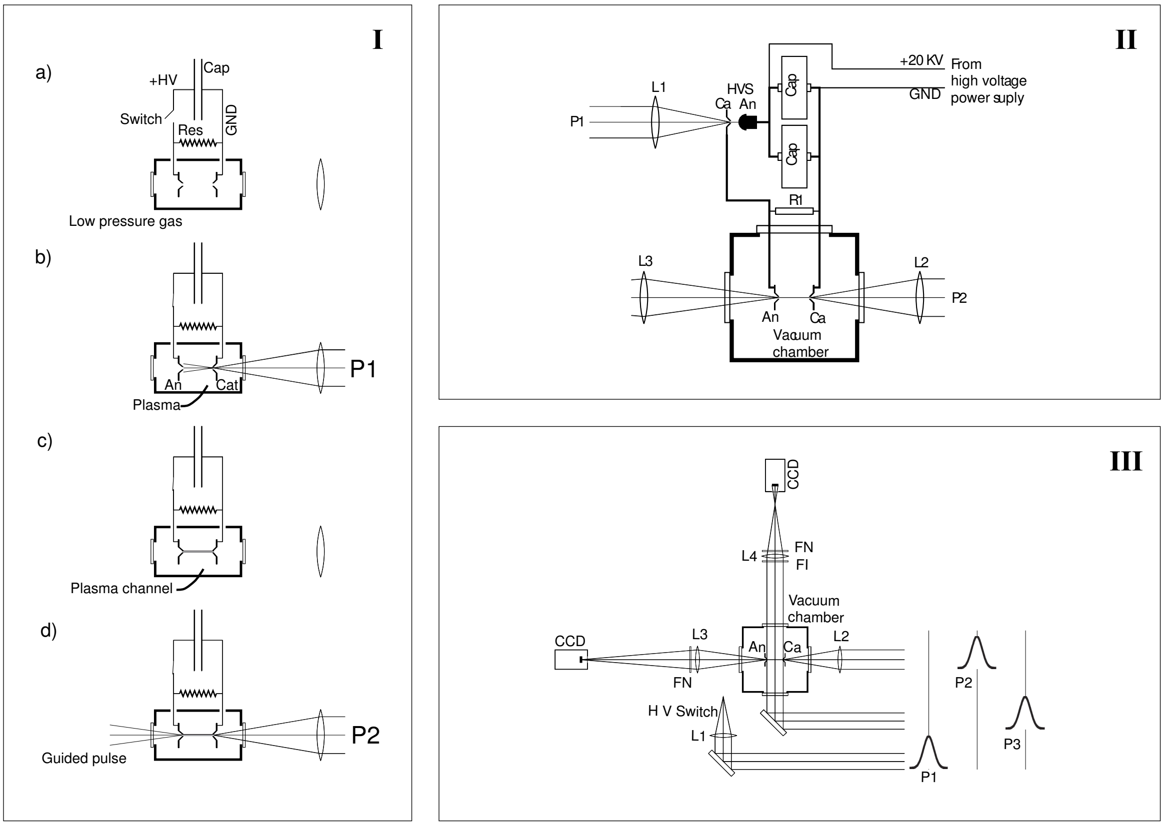

Figure 1: I channeling scheme, II electrical setup, III optical setup.

2 Experimental setup

The scheme for producing laser triggered plasma channels is presented in Fig.1.I. Inside a vacuum chamber filled with He at low pressure ($\simeq 100mbar$), we have two metallic electrodes, each one with a stamped cone and an aperture drilled through the apex (150 μm diameter in this experiment). Their separation can be varied to match the desired channel length.

One of the electrodes (cathode) is connected to the capacitor bank GND pole. The capacitor bank is composed of up to six low inductance, 1.7 nF ceramic capacitors that can be charged up to 50 kV. The second electrode (anode) is connected to the positive pole through an ultra-fast switch.

In order to obtain a HV rise time in the electrodes much faster than the discharge initiation time an ultra-fast switch based on a high-pressure laser-triggered spark gap is used, Fig.1.II. Under static conditions a high ohmic resistor between the switch anode and the GND capacitor bank pole is required to keep the switch anode at GND potential.

When the HV switch is closed a relatively slow discharge takes place between the electrodes. However, if a plasma is produced at the anode aperture by a laser pulse (P_1) before this process starts, the discharge will be much faster, and the discharge initiation will exhibit a lower jitter.

After the plasma is created a high current traverses and heats it. The hot electrons in the middle of plasma leave the plasma axis followed by the ions due to the space

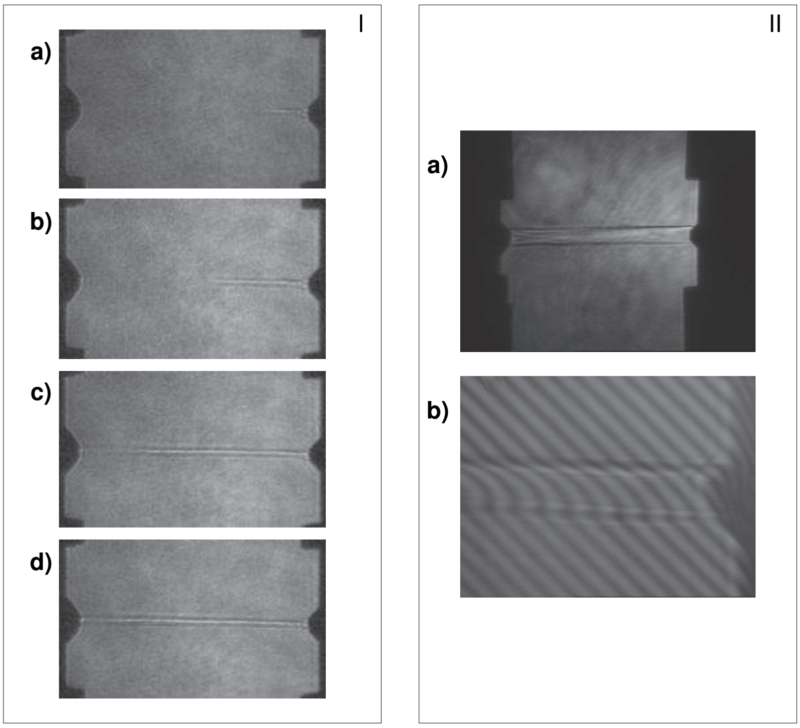

Figure 2: I shadowgrahy images of plasma produced by fast discharges, II shadowgraphy image of plasma produced by a slow discharge and interferometry image of part of the same plasma.

charge field. The plasma electron density becomes smaller in the axial region leading to a guiding channel.

In Fig.1.III the optical setup is presented. The L^2I Terawatt (800 fs, 1 J, 3.6 cm diameter) main laser beam is divided into three beams. Beam 1 is used to trigger the high-voltage switch. It contains 33% of the main beam energy and is focused in the switch anode aperture by a lens, L_1 (20 cm - FL). Beam 2 contains about 43% of the main energy and is used to trigger the discharge, so it is focused on the channel discharge anode aperture by a 25 cm focal length lens L_2. The delay between both beams is fixed to 6 metres (corresponding to 20 ns).

A third laser beam with a pulse energy of 22% of the main beam is used to probe the plasma. The delay between the pulses of beams 3 and 2 can be varied to follow the evolution of the plasma in time. After propagation through the plasma, the probe beam is divided in two by means of a beam splitter, in order to have shadowgraphic and interferometric diagnostics of the plasma. The shadowgraphy is obtained by imaging the beam on the plasma axis in a CCD camera with a magnification of 0.285. The interferograms of part of the channel are obtained by imaging the probe beam on the plasma in another CCD camera with a magnification of 0.92. The interference is obtained by using the reflection of two near uncoated surfaces of two glass wedges. In both diagnostics a 10 nm bandpass interference filter centered at 1053 nm is also used to block the light resulting from the plasma recombination process. The discharge current is followed in time and shape by using a Rogowski coil placed near the cathode feedthrough.

3 Experimental results

In Fig. 2.I we present typical shadowgrams of the plasma for different and decreasing delays between the probe pulse and the current. The four pictures were obtained with the same delay line length between the probe (P_3) and triggering (P_2) pulses. The variation in time was obtained by displacing forward the P_2 focusing length L_2 from the focus by 3,5,7 and 8 mm respectively. The background pressure in the vacuum chamber was 102 mbar. The distance between the electrodes was fixed to 15 mm and the radius of the obtained plasmas was found to be about 100 μm.

For the same parameters the plasma shadowgrams and the currents were found to be highly reproducible for variations of laser energy of up to 15%. On the other hand, the development of the plasma line is strongly affected, in shape and time, by laser pre-pulses. In the presence of pre-pulses a high jitter and slow discharge may start before the triggering of the discharge by P_2, resulting in large, partially ionized and non-uniform plasmas, Fig. 2.II.

4 Conclusions

The preliminary results shown in this paper demonstrate the formation of straight plasma lines using a non-guided and non-contained fast discharge triggered by a laser pulse. The formation of the plasma presents no jitter in the absence of laser pre-pulses. According to the results of other channeling methods [3-7]these plasmas may evolve into guiding plasma structures capable of channeling intense laser pulses.

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