Plasma by THz (PbT)

Report activity 2023

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Plasma by Terahertz (PbT) project proposes an R&D activity through a collaboration of TERA-Lab at the Department of Physics, INFN Section Roma1 (**ROMA1 unit**), and SPARC_LAB LNF-INFN (**LNF unit**), for the development of an innovative diagnostic approach for the plasma density detection based on the exploitation of plasma optical criticality as measured by Terahertz radiation. This innovative technique will be used for measuring the properties of plasmas generated in the plasma laboratory (*Plasma_Lab*) of the SPARC_LAB facility. It is particular important in view of the EUPRAXIA facility that will be developed at LNF-INFN.
The time schedule of the 3-years long project is presented in the following table.

Unit	Description	Deadline
ROMA1	THz-TDS multishot technique	31/12/2022
LNF	Design/Building of a dedicated multidiagnostic plasma chamber	31/12/2022
ROMA1	THz-TDS single shot technique	31/07/2023
LNF	Adapting single and multishot THz technique to the multidiagnostic plasma chamber and tests	31/12/2023
LNF/ROMA1	Multidiagnostic tests to the SPARC Linac	31/12/2024

2st YEAR (2023) Milestones for LNF Unit

In the second year, the characterization of plasma sources used to implement a diagnostic system based on THz radiation has been performed. The plasma sources consist of gas-filled discharge capillaries (Fig.1a and Fig.1b), where the plasma will be formed by means of HV electrical discharge. In the *Plasma_Lab*, a dedicated experimental setup has been built to test the plasma sources (Fig.1c). The gas ionization is produced inside of a cylindrical hydrogen-discharge plasma capillary, where the neutral gas will be ionized by using a high-voltage discharge applied by mean of two copper electrodes. The main component of the plasma module for plasma-based accelerators is a hydrogen-discharge cylindrical cross section capillary (the capillary's channel is typically 30 mm in length and 0.5 mm in radius). A central single gas inlet (or two gas inlets, depending on the desired longitudinal profile) feeds the channel with hydrogen gas. According to the Paschen's law, the plasma density can be imposed by using appropriate values of the neutral gas density before the ionization. In our system, the neutral gas pressure inside the capillary's channel is established by mean of an electromechanical regulator in the range 10-50 mbar. This pressure is not changed during the measurements. Also, a high-speed electromechanical valve is placed at 5 cm from the capillary to control the gas injection frequency that changes from 1 to 10 Hz. In fact, the electrovalve is open for 3 ms per second (the duty cycle is 0.3% at 1 Hz) to preserve the vacuum inside the test chamber where the plasma source is mounted, that has to be around 10^{-7} mbar before every shot.

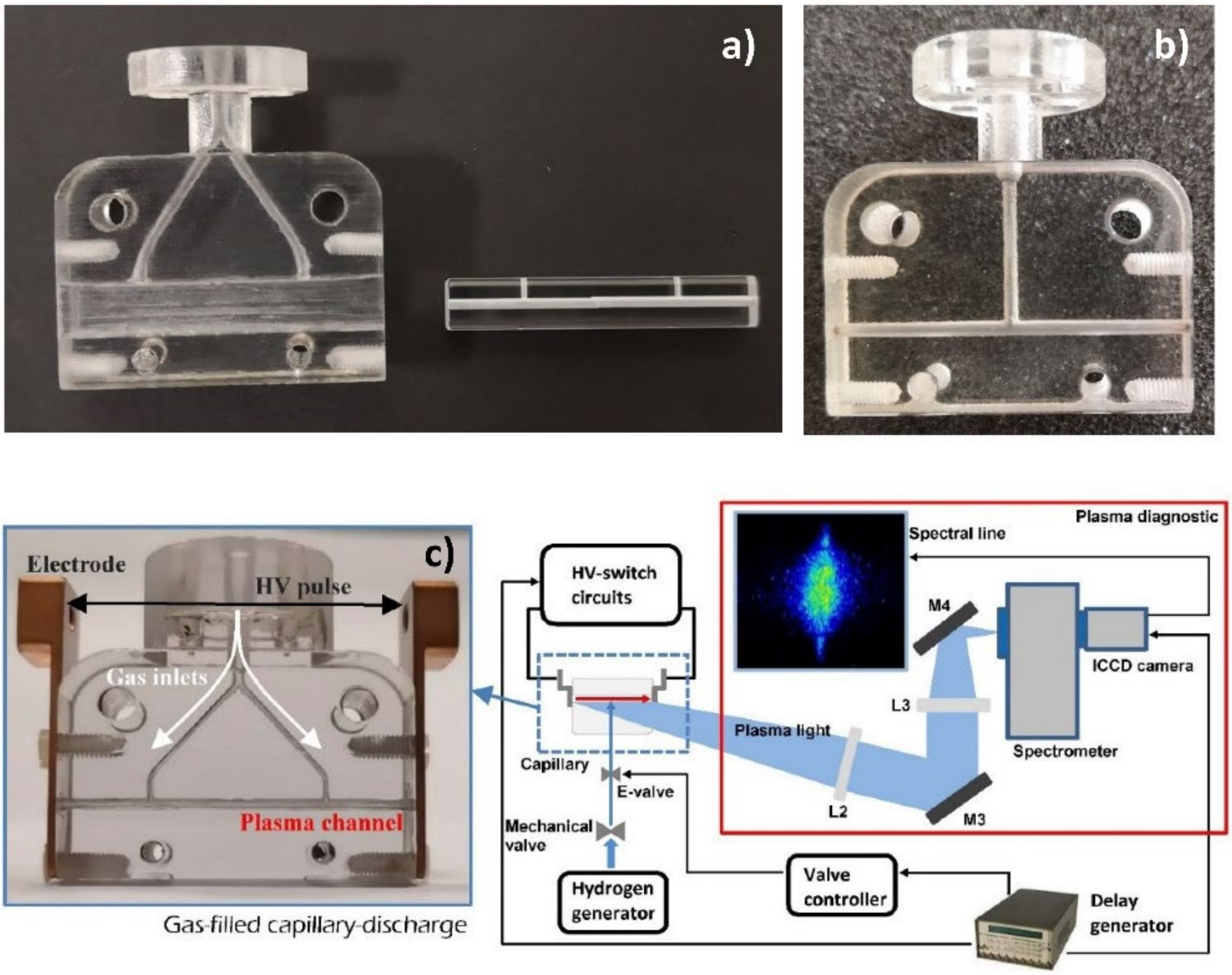

Figure 1. Plasma module used at the *Plasma_Lab* to test plasma sources for installing the THz diagnostic system. a) 3 cm long gas-filled capillary-discharge composed of an inner core of sapphire material and 2 gas inlets. b) 3 cm long gas-filled capillary-discharge composed of 3D-printed plastic material with a single inlet. c) Overall apparatus used for plasma formation inside the source and to measure plasma properties. The plasma diagnostics is based on the Stark broadening technique, for which the emitted plasma light is collected into an imaging spectrometer allowing to measure the enlargement of wavelengths of the Balmer series (2).

The HV-switch circuit provides the power supply to ionize the gas in the capillary and a delay generator (Stanford Research DG535) is used to synchronize the gas injection, the plasma diagnostics and the discharge ignition at the electrodes of the capillary. In order to produce a uniform ionization of the gas along the longitudinal direction of the capillary, the delay between the gas injection and the discharge ignition has to be accurately chosen based on the channel dimensions. During the operations, plasma currents of 350 A were measured when the applied voltage was 15 kV. The system of lenses used to collect the emitted plasma-light produces a capillary image onto the entrance slit of an imaging spectrometer (SpectraPro 275 of Acton Research Corporation). The spectrometer has a focal length of 275 mm and it is equipped with two different gratings of 2400 and 1200 g/mm. A fast-gated and intensified camera (Andor iSTAR 320) is used as a detector for the spectromete

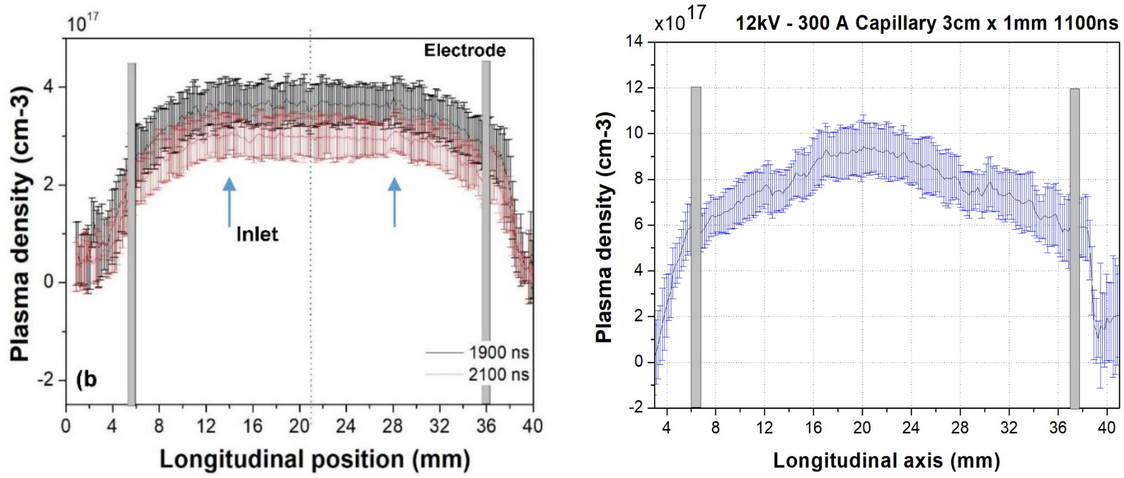

Figure 2. Characterization of two different capillaries. a) Longitudinal profile for 3 cm long/2 inlets/2 mm diameter gas-filled capillary obtained by using 10 kV voltage and 250 A ampere current pulse. b) Longitudinal profile for 3 cm long/1 mm diameter/1 inlet gas-filled capillary obtained by using 12 kV voltage and 300 A ampere current pulse.