Plasma by THz (PbT)

Report activity 2022

LNF unit Angelo Biagioni (Loc. Resp.), Maria Pia Anania, , Enrica Chiadroni, Gemma Costa, Lucio Crincoli, Riccardo Pompili

ROMA1 unit Stefano Lupi (Nat. Resp.), Massimo Petrarca, Annalisa D'Arco, Sen Mou

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

1st YEAR (2022) Milestones for LNF Unit

In the first year, in parallel to the work at ROMA1 unit, a dedicated innovative plasma chamber has been designed for installing the THz source/receiver system (studied by the ROMA1 unit) and testing of the gas-filled discharge capillaries, which will be preliminary characterized by the conventional Stark broadening technique and then using the innovative method based on the THz radiation. This plasma chamber will be implemented in the *Plasma lab* at LNF-INFN. The design of the chamber includes supports for different capillary dimensions and materials (to be studied at ROMA1 being compatible with THz radiation), and viewports for passing through of THz radiation to allow the interaction with plasma in the plasma source.

- **Plasma chamber design**

The design of the plasma vacuum chamber for installing the THz diagnostic system and measuring the properties of plasmas for acceleration is shown in figure 1. It is suitable for hosting two plasma sources and includes five viewports to be used for passing through the THz radiation and the plasma light needed to characterize plasmas produced inside the gas-filled discharge capillary.

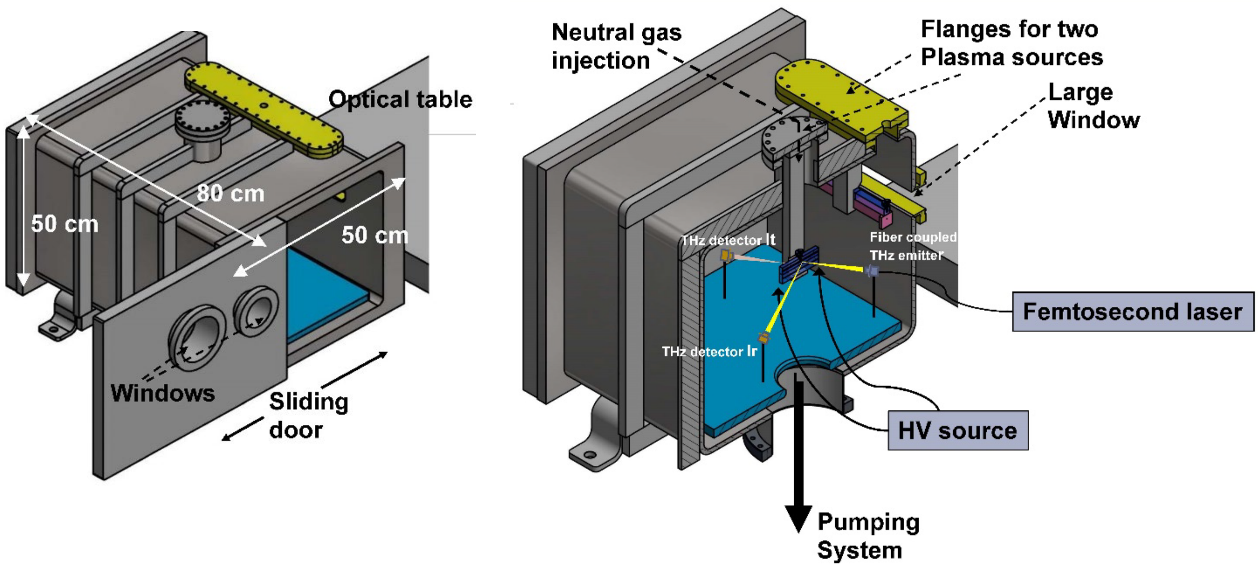
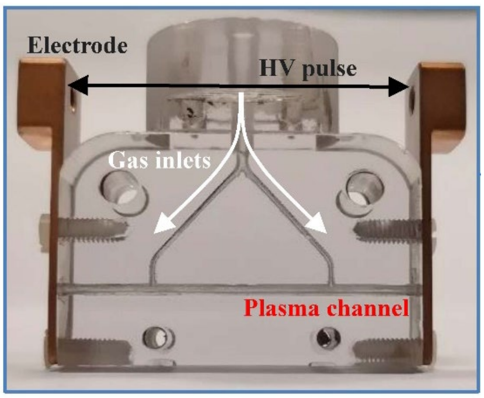


Figure 1. Plasma diagnostic chamber. The image on the left shows the dimensions and the sliding doors usable for easy access to chamber. On the right image, there is a scheme of the THz diagnostic layout, in addition to the HV source used to produce the plasma.

- **Gas-filled discharge capillary design and characterization**

The plasma sources used to implement a diagnostic system based on THz radiation are represented by gas-filled discharge capillaries (Fig. 2), where the plasma will be formed by means of HV electrical discharge.



Gas-filled capillary-discharge

Figure 2. A 3 cm long gas-filled capillary-discharge with two symmetric inlets.

It is composed of two gas inlets for feeding the channel with a neutral gas (hydrogen, argon, nitrogen etc.) set in the pressure range 10-50 mbar through a mechanical regulator. Also, in the experimental setup, a high-speed electromechanical valve is placed at 20 cm from the capillary, outside the chamber, to control the gas injection frequency, which can be changed from 1 to 10 Hz in order to preserve the vacuum level inside the test plasma chamber.

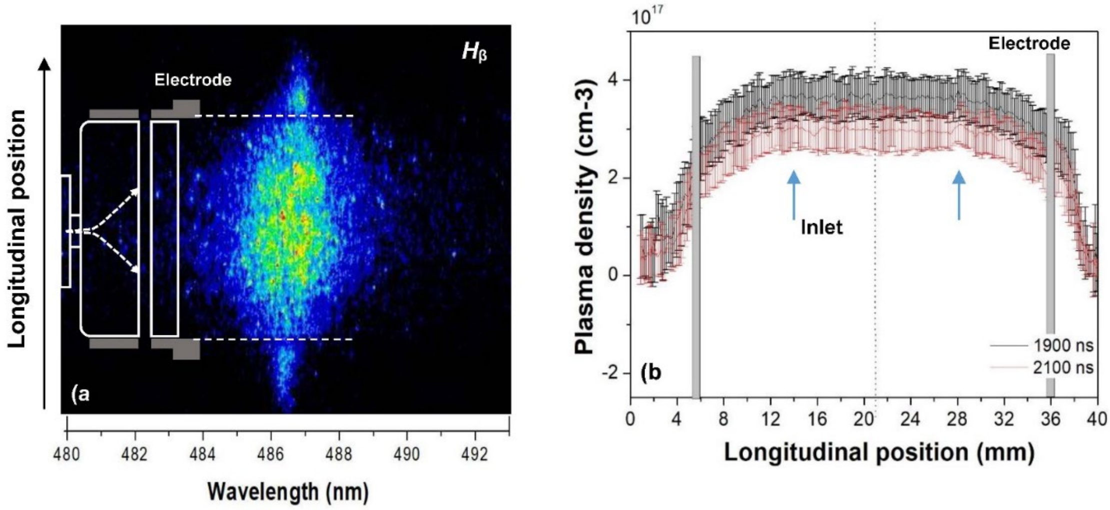


Figure 3. Plasma diagnostics. Hβ Balmer spectral line centered at 486.1 nm acquired by the ICCD camera (a) and corresponding plasma longitudinal profile (b) obtained by measuring the line width along the longitudinal coordinate.

HV circuits provide 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 (THz and conventional techniques) and the discharge ignition at the electrodes of the capillary. The preliminary measurements of plasma density profiles, which will be compared to the results obtained with the THz diagnostic system, have been performed through a spectroscopic analysis of the plasma light emitted during the gas ionization. In such setup, it is collected into an imaging spectrometer (*SpectraPro 275*) equipped with an intensified CCD camera (*Andor Istar 320*) to acquire the spectral lines images shown in figure 3a. The electron density distribution has been obtained by measuring the spectral line width of specific wavelengths of the Balmer series centered at 486.1 nm (*H*β), which can be considered proportional to the plasma electron density according to the equation $n_e = 8.02 \cdot 10^{12} (\Delta\lambda/\alpha)^{3/2}$ cm^{-3}, where α is a tabulated parameter and Δλ is the spectral line enlargement. Some results for a 3 cm long 3D-printed capillary with 1 mm diameter channel and two symmetric inlets to inject hydrogen gas are presented in figure 3.