Use of THz time-domain spectroscopy for Plasma Diagnostics applications

Workshop Report and Minutes

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The Terahertz band of the electromagnetic spectrum is defined as the range of frequency between microwaves and mid-infrared light, covering the region where electronic and optical technologies overlap. Recently, femtosecond laser pulses have been used to generate extremely broadband (100GHz to 30THz) single-cycle THz pulses. These pulses can be detected coherently with very high sensitivity, and may be used for Time-Domain Spectroscopy (TDS) experiments on a variety of systems.The instrumentation used to perform THz TDS for frequency >100 GHz can be applied to Plasma Diagnostics by redesignign and arranging the system and the optics to channel the beam reflected (or transmitted) by the plasma into the detection section of the instrument. The wide frequency range, 200 GHz up to several THz, covers a very large range of plasma conditions in a Tokamak. In 2010 a Collaboration between ENEA Frascati and Oxford Terahertz Photonics Group has started on the subject. This worskhop will offer the opportunity to discuss objective, potential and possibilities of this research project.

1. Presentations

Marco Zerbini, ENEA-Frascati: “Plasma Diagnostics Applications of THz Time Domain Spectroscopy”

Michael Johnston, Oxford University: “Terahertz time domain spectroscopy: Principles and applications"

Giuliano Rocchi, ENEA Frascati: “Plasma Diagnostics Applications of TDS-THz, Technical Aspects”

Andrea Doria, ENEA Frascati: “THz sources at ENEA-Frascati: features of interest for plasma diagnostics"

2. General comments and talking points:

Importance of beam coherence for interferometry (R. de Angelis). The measurement repeated over very short pulses should solve this issue.
The peak power (or E-field) is the important parameter for non-linearity plasma-wave effects estimate (PB)
The size of detection spot on wafer has been discussed. It is a bit larger than the 4 microns diameter of the laser mode (O. Tudisco).
The THz switch can be figured out as a “spark gap” emitter, within the semi-insulator GaAs material.
The 2-diodes detection is basically based on Faraday Rotation, while the 3-contacts detector is a unique scheme providing the 2 components of the electromagnetic wave at the same time.
The optimization of system and components for lower frequencies (< 1THz) typical of Diagnostic applications can be done by adapting the Optics, increasing the Receiver & Emitter gaps, and extending the pump laser pulse duration (up to 100 fs).
THz TDS has been used for the study of gas explosions, which offers an example of a time scale of phenomena not dissimilar to Tokamak plasmas (milliseconds).
A. Doria presented the mm waves sources available in Frascati like the Cerenkov FEL based on evanescent field in a dielectric. A Ti:Sapphire ultrashort pulse laser is available at the Department Innovazione of the ENEA Frascati, it can be used to established a local test facility.

3. Discussion (Chairman O. Tudisco)

- Optical layout, long distance, low power, Signal-to-Noise ratio (SNR).

for a tokamak diagnostics the terahertz beam has to be parallel over large distances (and not focused on short distances, like in the studies on samples). It puts the issue also if the power is enough and consequently if SNR is adequate. The dynamic range is remarkably high. 6 orders of magnitudes before hitting noise floor have been measured with several minutes of integration time. If a time resolution of a few milliseconds is assumed, the SNR will be divided by thesquare root of the time integration ratio.
Nitrogen or dry air flux for waveguides and optics boxes will be required to remove water vapour

absorption, as routinely done in FTU for ECE diagnostics.

- Mechanical vibrations

With the mechanical scanning of the distance of the reference beam, mechanical vibrations can pose a potential issue, because displacements and frequency of the scan is comparable with those of the vibrations. An ideal solution would be to decouple receiver and emitter heads from Tokamak. But probably this effect can be ignored, as the delay introduced by 100 microns of vibration is negligible compared to the total delay scan. A quantitative estimation can be easily made.

- Refractive Optics in the THz range, chromatic aberrations.

Chromatic aberrations can be corrected, once the spectral range of operation is selected. (difficult to compensate all the aberrations in the full range). PB suggested the use of Elliptic mirrors instead of lenses when possible.

- Pulse distorsion in fiber

The Group Velocity Delay (GVD) introduced by the optical fiber in the laser pulse, will be corrected using the standard technique of double grating pre-compression of the pulse.

- Non linear effects in plasma.

Fast changes in the Electric Field (order of hundreds of V/cm) of the Teraherz wave could induce non-linear effects in the wave-plasma interaction that have to be estimated. A simple plasma-wave interaction model will be developed to this purpose.

- Stability of GaAs under gamma and neutron flux

The presence of neutrons and gammas in the background can be a problem for the GaAs, used both as emitter and detector. The major concern comes from gammas, since the GaAs can absorb and detect them. Fortunately the detection of Terahertz occurs only in a very localized part of the detector (order of tens of microns) so the rest of the detector can be used to estimate the effect of the radiative background. In addition laser light and Terahertz radiation can be bent, while gammas don’t, which makes easier the shielding of the detector.

- Fiber coupled laser

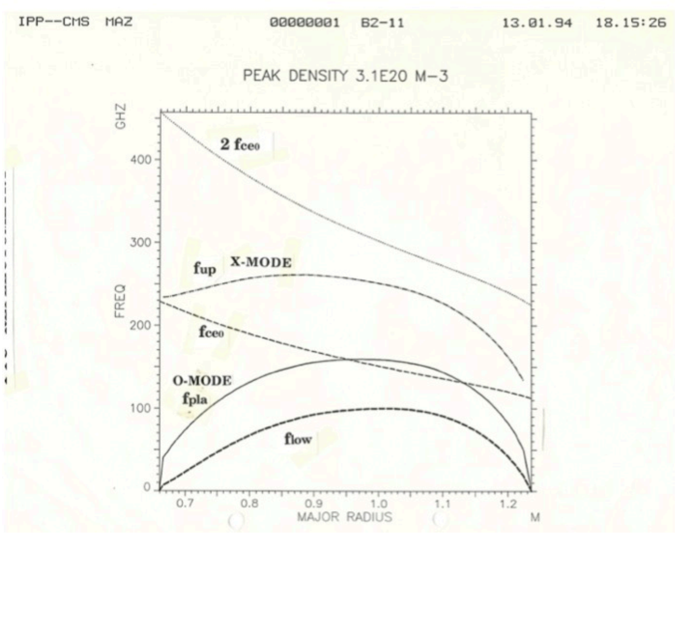
These devices, which will simplify the optical arrangement of the instrumnt, are presently optimised for wavelength > 1000 nm.

- Spectral resolution

It is determinated by the laser optical path scan, it should not be difficult to optimise it for the Plasma measurements requirements (a few GHz)

- Basic frequency propagation pattern in FTU

Below, the hystorical plot of relevant FTU reflectometry parameters, originally produced for the first reflectometry system in early ‘90s.



- A discussion of diagnostic capabilities

Reflectometry
The effect of frequency components non in cutoff, reflected by the Tokamak wall, will have to be studied.

Interferometry (O. Tudisco suggests to find a more accurate name for the measurement)
Vertical or Horizontal port? reflection on the vacuum vessel (horizontal port) is easier to realize, but the data are potentially more difficult to analyse. The use of vertical port will ensure better data, and overcome the problem of electron Cyclotron resonance absorption. Delay and amplitude of the signal can provide useful information about the plasma. The high frequency components can be used Interferometry-style to evaluate the plasma density. The possibility of masuring the temperature, by working near the resonance, has to be assessed (O. Tudisco).
Is the wide band of the spectrum suitable for 1-chord measurements? (P. Buratti)

Electron Cyclotron Absorption (ECA): are the low frequency components of the GaAs spectrum enough for this type of measurement?

Suprathermal electron: density and temperature can be potentially measured, by tuning the system in a low absorption region, then evaluate the extra absorption due to the relativistic downshift.

Polarimetry
By launching in the plasma a 45° polarization to the magnetic field the measurement of the two components, Ordinary and Extraordinary, can provide information about the local magnetic field. SNR is again a fundamental issue.

Cross-polarization scattering (P. Buratti)

4. Future work

The Fiber optics system should be ready in Oxford by March 2012, to be used for feasibility tests. A large sealed pipe for coupling tests in dry atmosphere, a diagnostic-relevant coupling distances has been suggested (M. Johnston).

In parallel the plasma wave interaction will be studied with simulations, to converge to a preliminary diagnostic design which will take into account the open points above listed.

An appropriate acquisition system, suitable to sample the THz pulse shape with the required time respolution and dynamic range will be designed.