Progress on THz Applications for Plasma Diagnostics

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***Abstract*—We discuss an extensive set of experimental results about the spectroscopic properties of different materials in THz spectral range, as part of the development of a THz-based Plasma Diagnostic for Nuclear Fusion Applications.**

I. INTRODUCTION

The Terahertz (THz) band of the electromagnetic spectrum is defined as the frequency range between microwaves and mid-infrared light [1,2]. Since 2010 a successful collaboration between ENEA Frascati and the Photonics Group at Clarendon Laboratory, Oxford University, has been in place to extend the use of THz Time Domain Spectroscopy (TDS) techniques to harsh environment applications in systems with access difficulties, namely Tokamak Plasma diagnostics for Fusion research [3]. The simultaneous use of large portions of the electromagnetic spectrum in the form of THz pulses produced with femtosecond mode-locked lasers provides an appealing tool to diagnose plasma phenomena spanning above and below the plasma frequency [4]. THz pulses can be used as very sensitive and versatile probes of widely varying plasma parameters especially for diagnostic applications in Tokamaks where plasma characteristics are non-uniform and evolve during the discharge. We designed and assembled a table-top free-air THz-TDS setup based on a femtosecond infrared laser pulse (790 nm) and photoconductive GaAs wafer plates [2]. This preliminary system has been designed with a great flexibility, to experiment different solutions for coupling optical systems, path difference scan and Group Velocity Delay (GVD) compensation. Recently we used a commercial Advantest TAS7500TS THz Analysis System to test the long range optics and to measure the spectroscopic properties of materials and components relevant for Plasma diagnostics over an unprecedentedly large spectral range.

II. LABORATORY SETUP

The operation of TAS spectrometer is similar to our plasma-diagnostic oriented system, the main difference is the path difference scanning system. Instead of a Michelson-style scanning mirror TAS uses a pair of Ti:Sapphire linked lasers with a small fixed repetition rate difference to separately drive Emitter and Detector. The scan frequency will result from the beating of the the two repetition rate frequencies (*ECOPS= Electronic Controlled Optical Sampling*). THz Emitter (TX) and Detector (RX) are both single polarization and are housed in a pair of compact aluminium boxes with built-in Silicon lens (refractive index 3.45) to pre-focus the THz radiation. The laser beams are coupled with RX and TX wafers through polarization maintaining optical fibers. The THz beams are well approximated by Gaussian Beam Optics description [5]. The main parameters of the system are:

THz Emitter TAS1110
THz Detector TAS1230 (60 dB dynamic range)
Laser pair Ti-Sapphire λ = 1550nm, power 20 mW
Laser pulse 50 fs (1.5 m fiber)
Repetition frequency f=50 MHz
Spectral range: 200 GHz - 4 THz
Spectral resolution: 7.6 GHz
Scanning time: 8ms/scan

In order to measure reflectivity and transmission of the samples we used an adjustable arrangement with Emitter and Receiver heads attached on two Micro-Controle optical bars, coupled by a goniometer joint to hold the sample and change the reflection angle. TX and RX modules were optically coupled via two TPX lenses with 100 mm focal length [6] collimating the beams originating from the virtual images of the emission and detection gaps created by the Si lenses. The two TPX lenses can be replaced by Off Axis Parabolic mirrors, more critical to align, but operating on a wider frequency range due to the absence of dispersive effects. Measurements have been taken by averaging 16384 scans, providing a good signal-to-noise ratio with only a few minutes averaging time.

III. RESULTS

The most relevant measurements are listed below:

-) Inductive metallic mesh 550 μm [5]
-) Microwave absorber Eccosorb AN-72,
"carbon loaded foam laminate"
-) 0.4 mm GaAs wafer, THz Emitter e Detector substrate
-) Crystal quartz window (4 mm)
-) Wire-grid polariser, 25 μm wires, pitch 10 μm
-) Reflection reference: 45 deg incidence on metal reflector
-) CR110 plastic Eccosorb microwave absorber (reflection)

Spectral transmission is defined as the ratio between transmitted and reference signal, while reflectivity is the corresponding ratio of the reflected component. Note that having used TPX lenses for the optical setup we encounter a strong reduction of SNR for frequency over 1.2 THz, due to the TPX properties. Since the majority of plasma diagnostics applications are in the spectral region below 1 THz this

limitation is not relevant in our case [7].
Fig. 1 shows the measured transmission of 4 different samples, discussed in the caption. It is worth to point out the inductive metallic mesh characteristic, the transmission of which increases almost linearly up to 600 GHz, where a wide resonance peak appears. In this region, as expected, the wavelength is comparable to the 500 µm mesh period [5].

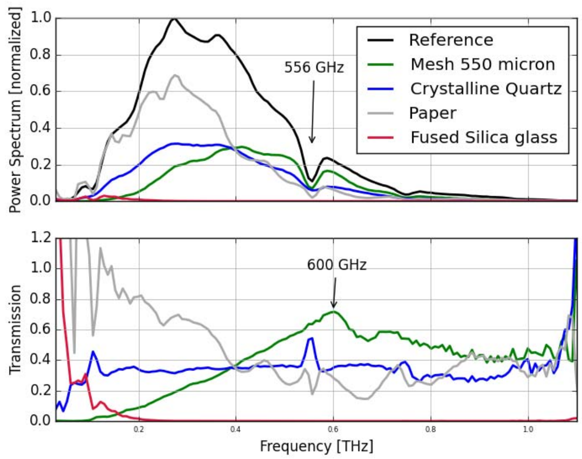

Fig. 1. Measured spectra and corresponding transmissions of plasma diagnostics relevant samples. The water vapour absorption line at 556 GHz is well visible. Oscillations in the lower part of the spectrum are due to low SNR. Crystalline quartz has a fairly uniform transmission, while fused silica glass (not used for mm-waves plasma diagnostics) cuts above 0.1 THz. The metallic mesh is discussed in the text. As reference a plain paper sample spectrum is also showed.

The spectral characteristics of the GaAs wafer (Fig. 2) are of particular interest for our applications, since the THz beam always goes through the material in emission and detection.

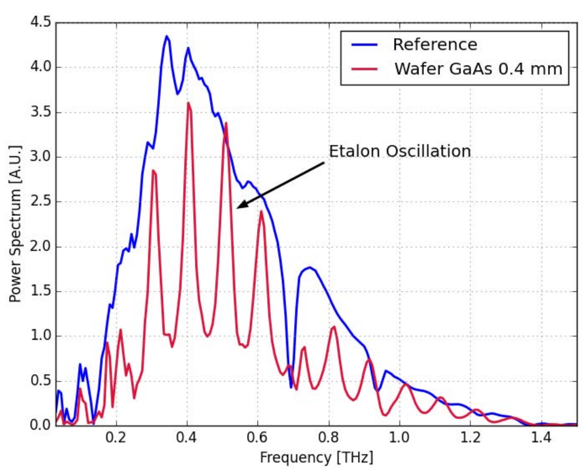

Fig. 2. Transmission and reference spectra of GaAs wafer

The transmission spectrum shows the Etalon oscillating pattern caused by multiple reflections between the two surfaces of the wafer, while the envelope of the oscillations shows a nearly full transmission. By using a simple Fabry-Perot description [8] with d=0.4 mm (wafer thickness) e and n=3 (GaAs refractive index) we estimated an oscillation period *$\delta v=c/2nd \sim 125GHz$,* well in agreement with the measured 130 GHz, considering the 5% uncertainty on the experimental quantities, in particular the GaAs refractive index. Fig. 3 shows the reflection measurements for the CR110 microwave absorber.

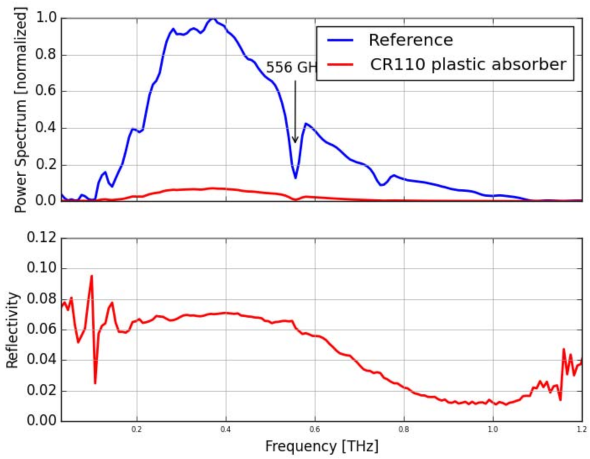

Fig. 3. Reflection measurements for the plastic microwave absorber CR110, with 45 deg incidence angle. The reflectivity is very low (<10%) and shows a clear frequency pattern, well over the SNR, over the considered spectral range.

IV. CONCLUSIONS

We measured transmission and reflectivity of a large variety of materials and components relevant for plasma diagnostics and other applications. We were able to compare the results with the calculations and check the design approximations in the different wavelength regimes. The results will be extremely useful to design and engineer the final THz-TDS plasma diagnostic system.

V. ACKNOWLEDGMENTS

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