CVD diamond photodetector for plasma diagnostics on FTU

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Introduction

Diamond is a semiconductor material with outstanding physical properties: a wide bandgap (5.5 eV) that results in very low leakage currents, high sensitivity to radiation with wavelengths shorter than visible band and high charge carrier mobility. Furthermore, thanks to its radiation hardness, diamond is also optimally suited for harsh environment applications, like those found in thermonuclear fusion experiments. In view of the above, diamond detectors appear to be especially promising for VUV and Soft X-ray (SX) radiation detection and two of them were successfully installed on JET since 2007 [1].

We report on the performances of two Chemical Vapor Deposition (CVD) single crystal diamond-based detectors installed in one of the equatorial ports of the FTU tokamak during the last two experimental campaigns of the machine.

Diamond detectors layout

The devices were developed by University of Rome "Tor Vergata"; their design is based on a metal/intrinsic/p-type diamond layered structure and they behave like Schottky photodiodes without an external bias (Fig. 1a, 1b). The diamond detectors were operated in current mode using low-noise preamplifiers, which allow acquisition rates up to 500 kHz; typical transimpedance gains of 10^5-10^7 V/A were used, providing excellent signal-to-noise ratios (Fig. 1c). These detectors exhibited very low leakage currents and very fast time responses (below 1 ns). By using different diamond thicknesses and type of electrical contacts, one detector was optimised for the extreme UV detection (~5.5 eV ÷ 1 keV), the other for SX detection (~1÷3 keV). A 6 μm thick Mylar filter was positioned in front of the SX detector to cut-off the radiation with energy below 1 keV. The responsivity curves (A/W vs incident photon energy) were calculated from tabulated atomic scattering factors, taking into account the proper diamond detector geometry, including the metal contact layer [2]. Both detectors were placed inside the machine high vacuum vessel, using a manufactured flange in the equatorial port 9, at about 2.5 m distance from the plasma centre (Fig. 1d).

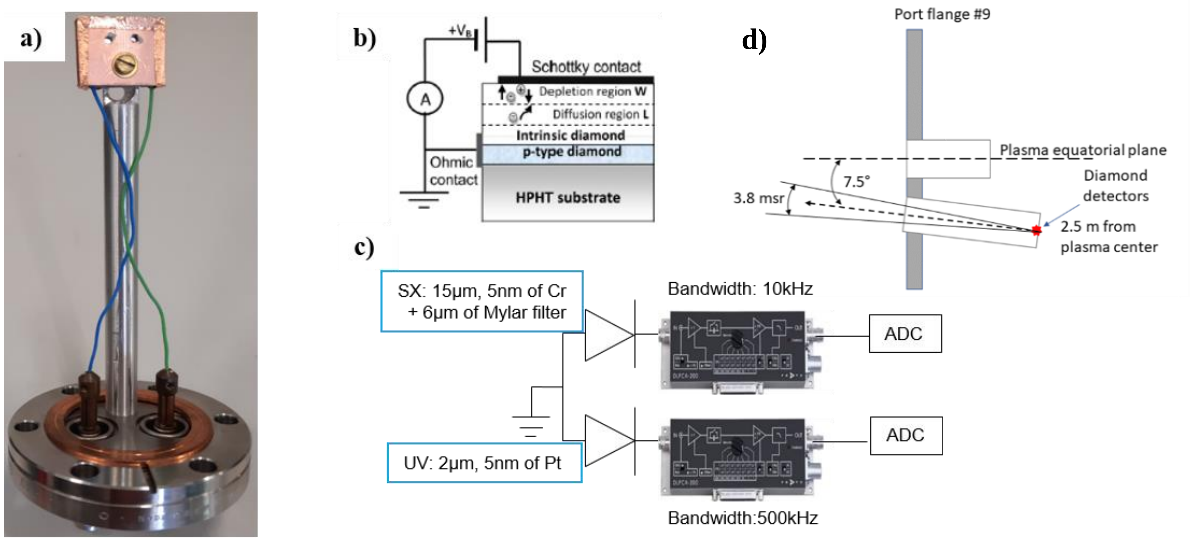

Fig. 1: a) The device installed using a manufactured flange, b) the design of each diamond detector, c) the electronic chain with the low-noise current amplifiers and d) the position of the detectors on the FTU port.

Results from FTU

Several examples of plasma events have been collected, confirming the fast response capabilities of diamond detectors. The so-called Anomalous Doppler Instabilities were observed as sharp peaks followed by exponential decays, perfectly correlated in time with other diagnostics. In Fig. 2a the diamond photodetector signal is compared to the MHD pick-up coil signal and to the suprathermal electron cyclotron emission from a channel of the ECE grating polychromator. Furthermore, there are interesting observations related to pellet ablation, especially on the initial rise of the diamond VUV signal and on the ablation phase. In Fig. 2b the diamond photodetector signal is compared to a core channel of the ECE polychromator and one channel of the saddle coils, during a D pellet injection. Diamond detectors often but not always followed the MHD activity, depending on its localization relative to the emitting region; core temperature oscillations following ECH modulation were also observed. In Fig. 2c an example of rotating 2/1 tearing mode slowing down and locking as seen by the diamond photodetector is shown and compared to other FTU fast diagnostics. Fast events occurred at the plasma edge, such as MARFE, were also observed (Fig. 2d).

Diamond-based Bolometry

The relative flatness of the detector's response over a wide range of energy, as described by the calculated responsivity curves, has suggested their possible use as bolometers. For this reason, comparison of the diamond signals was extended to selected channels of the FTU bolometry system [3] with similar line-of-sight (Fig. 3).

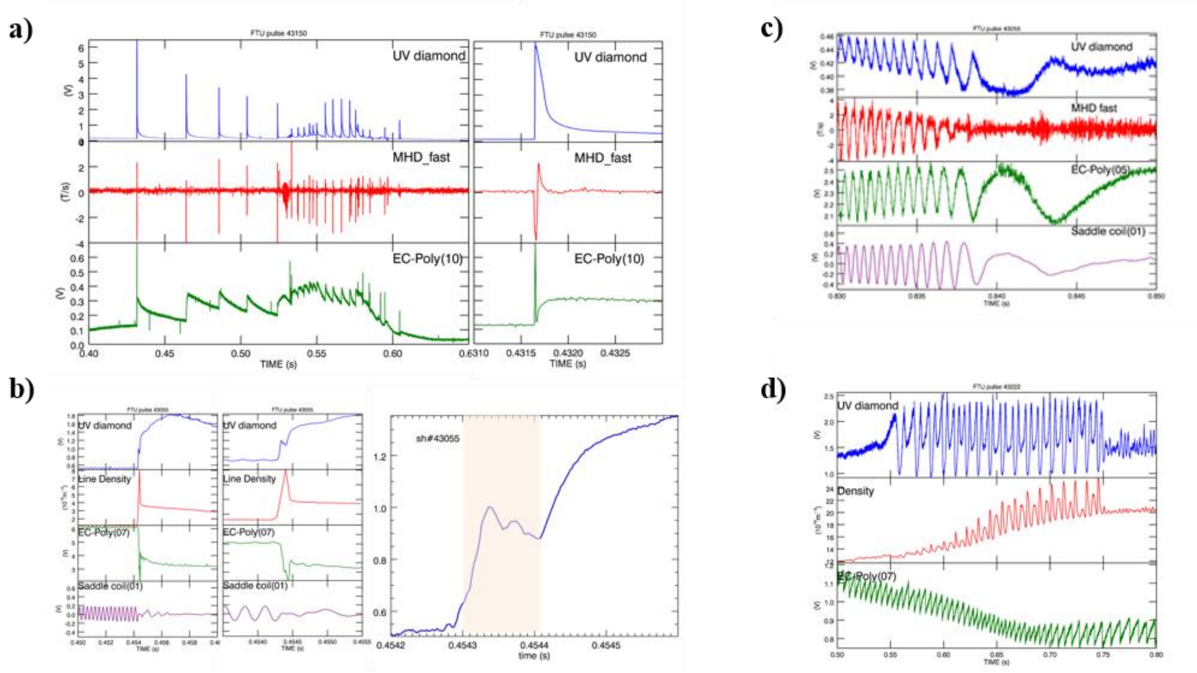

Fig. 2: Examples of plasma phenomena observed by the diamond detectors on FTU: a) Anomalous Doppler Instabilities, b) Pellet ablation, with an expanded view on the right that highlights the rise of the diamond signal and the ablation phase of the pellet, c) rotating 2/1 tearing mode slowing down and locking and d) MARFE.

In Fig. 3a, a pretty good agreement is observed during the initial current ramp-up phase, when the plasma is still relatively cold, and a systematic underestimate of the emitted power density measured by the diamonds during the current flat-top, when the plasma temperature exceeds about 1 keV, as expected.

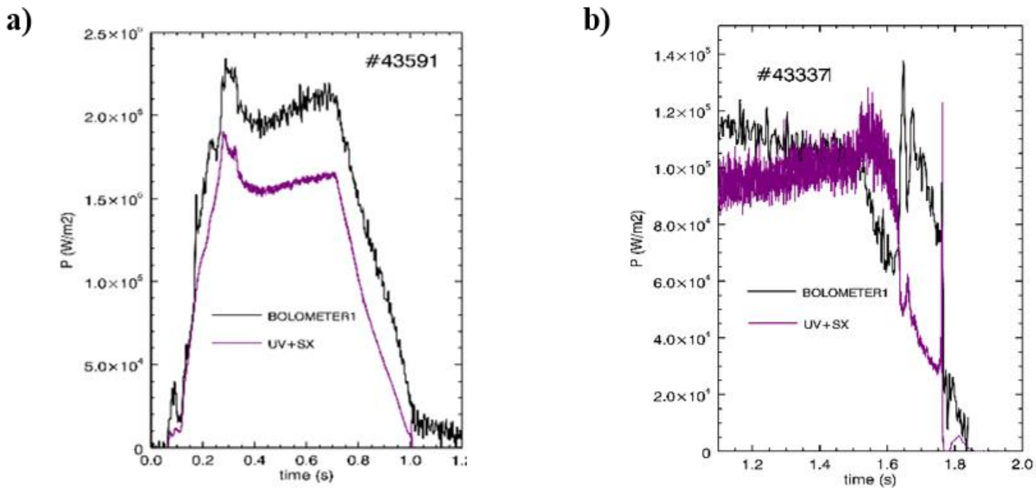

Fig. 3: Comparison between diamond detectors signal and FTU bolometry system during a) a standard discharge and b) the end of a He-doped discharge.

Fig. 3b shows an expanded view of the end of a helium-doped discharge. Helium is injected in the early part of the discharge and by the end no other impurity is present, as documented by the survey spectrometer SPRED. The plasma temperature is too low to cause sputtering from the wall, but in this phase the diamond's measured power density is both higher and lower than the bolometer's, pointing to the different sensitivity to the visible and ultra-soft UV radiation, to which the diamonds are blind while the gold-foil bolometers are not. It is also worth noting how, in #43337 shot, the diamonds' signal appears to be noisier than in the current ramp-down phase: that is the result of the persistent MHD activity throughout the discharge, finally disappearing around 1.6 s. The UV diamond S/N ratio continues to be high even during a subsequent re-ionization spontaneously occurring around 1.8 s, when a plasma current of about 15 kA is produced. While most other diagnostics are outside their range of operation in these conditions, the SPRED spectrometer still recorded a neat He II spectrum (Fig. 4), thus confirming the "reality" of the VUV diamond signal.

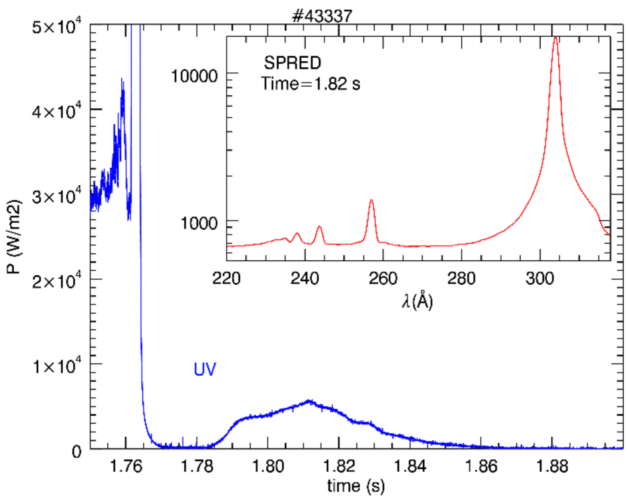

Fig. 4 VUV detector signal during the spontaneous re-ionization at the end of the discharge. In the inset the He spectrum as recorded by the SPRED spectrometer.

Conclusions

Two CVD diamond photodetectors, one optimised for VUV detection and the other for SX detection, were successfully installed on the FTU tokamak. The collected data show that the fast time response and the good signal-to-noise ratio render diamond especially suitable for pellet ablation diagnostics and identification of MHD instabilities in the plasma core. In addition, these devices can monitor low energy fast events occurring at the plasma edge or at the very end of the discharge. Following the encouraging results achieved by comparing the diamond signals to the FTU bolometry system, an R&D program for the development of diamond-based bolometers was launched, aiming at the optimization of the diamond's response over the widest possible energy range, also considering different geometries.

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