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CVD Diamond Detectors for Fast VUV and SX-Ray Diagnostics on FTU

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Single crystal diamonds appear to be promising for VUV and soft X-ray (SX) radiation detection. The wide bandgap (5.5 eV) results in very low leakage currents and high sensitivity to radiation with wavelengths shorter than 225 nm (visible-blind detectors); furthermore, the high charge carrier mobility allows very fast time responses. More importantly, diamond is optimally suited for harsh environment applications, like those found in and around thermonuclear fusion experiments. For this reason, two diamond detectors, one optimized for extreme UV detection, the other for SX detection (0.8–8 keV) were successfully installed on JET since 2007 [1].

We report on the performances of photodetectors based on Chemical Vapor Deposition (CVD) single crystal diamonds installed on one of the equatorial ports of the FTU tokamak during the last six months of operation of the machine. The CVD diamond detectors were developed and grown at "Tor Vergata"University in Rome, using a p-type/intrinsic/Schottky metal contact configuration. They behave like photodiodes allowing operation above room temperature with no external applied voltage (thanks to the Schottky barrier, about 1 V [2]), or with <10 V external bias. The thickness of their active layer can vary from less than 2 µm up to few tens of µm, while still retaining excellent structural properties, in particular their radiation hardness.

Several detectors were installed on FTU, two at the time, with different thicknesses and type of electrical contacts. The results allowed to highlight some important issues with the mounting design, but essentially confirming the validity of the choices originally made for the JET installation. The final configuration consisted in one diamond 2.0 µm thick and 2.2 mm^2 of effective collection area for UV detection, and another one, 15 µm thick and the same area, for the SX radiation (although the effective depletion thickness is limited to about 4 µm when no external bias is applied). The Schottky junction consist of a 5 nm metal layer (Pt and Cr respectively) deposited on the top surface. A 6 µm thick mylar filter was also positioned in front of the SX detector to cut off the radiation below 1 keV. Both detectors were placed in the machine high vacuum, viewing the plasma through one of the large equatorial ports at about a 2.5 m distance from the center. They were operated in current mode with low-noise current preamplifiers as front-end electronics, which allow acquisition rates up to 500 kHz. Typical transimpedance gains of 10^5 to 10^7 V/A were used, providing excellent signal-to-noise ratios. The responsivity curves (A/W vs incident photon energy) were easily calculated from tabulated atomic scattering factors [3], taking into account the proper diamond detector geometry, including the metal contact layer. Calculations previously performed for different diamond samples had been experimentally validated, showing excellent agreement [4], therefore we expect the calculated curves obtained for the detectors actually employed on FTU to be equally reliable.

Beautiful examples of plasma fast events have been collected in the course of the last two experimental campaigns on FTU in several different plasma conditions, confirming the fast response capabilities of diamond detectors. During the Runaway Control and Mitigation experiments, for example, the so-called Anomalous Doppler Instabilities were observed as sharp peaks followed by exponential decays, perfectly correlated in time with other magnetic diagnostics and fast EC polychromator signals. Given the extremely cold edge plasma conditions, the observed peaks can possibly be interpreted as the Ly-α emission caused by fast electrons hitting the wall, as a result of the RE beam instability, and degassing it. Other interesting observations relate to pellet ablation. The diamonds radial line-of-sight is 300° downstream from the pellet injection port. Also in this case, the initial rise of the diamond UV signal can be attributed mostly to Ly-α radiation. By zooming in on the ablation phase, multiple bumps can be seen, which may correspond to the pellet crossing of rational magnetic surfaces. The initial delay relative to the fast H-α monitor located at the same port of the injector is of the order of 1 ms, and it coincides with the drop of temperature registered by the polychromator edge channel. In some cases, the pellet produces a stabilization of pre-existing modes, in others it de-stabilizes them. The diamonds follow the MHD activity or not depending on its localization relative to the emitting region. It is especially clear, for example, when an internal mode slows down and locks. Core temperature oscillations following ECH modulation were also observed.

The CVD diamond detectors were installed on FTU in view of their possible use for replacement of the Si photodiodes currently adopted for Soft X-Ray tomography (SXT). While the different responsivity curves do not allow a 1:1 comparison in every case, the results indicate the potential for diamonds to perform the same tasks, over a spectral range that can be suitably tailored to differentially cover the lower and the higher energies, with similar upper limits. In fact, in the course of the experiments, it was realized that the relatively flat response of the UV diamond sensor over the range 10 - 2000 eV opened the possibility of using these detectors as bolometers. Therefore, the comparison of the UV and SX signals was extended to selected channels of the FTU bolometry system [5] with similar line of sights. Despite the rather crude estimate of the diamonds light collection area, a very good agreement is observed in cold plasmas, and a systematic underestimate of the emitted power when the plasma temperature exceeds about 1 keV, as expected. A more thorough evaluation of the mounting geometry will be undertaken as soon as the diagnostic will be demounted from the FTU machine, but it is important to note that no calibration procedure is needed for good accuracy. These encouraging results have prompted launching an R&D program for the development of full-fledged diamond bolometers, which will be especially well suited for the coverage of the divertor and edge regions in high performance devices. The diamonds intrinsic limitation is, unfortunately, the rapid drop of the atomic absorption coefficient at energies above 10 keV; therefore, the necessary flatness in the response curve for their use as bolometers in the central part of the plasma column, can no longer be ensured at high peak temperatures. There is, however, a similar energy limitation for the gold-foil conventional bolometers. The low-energy sensitivity, on the other hand, is limited to 5.5 eV for the diamonds, which are, as stated before, visible-blind, while the bolometer surfaces have been blackened in order to absorb photons in the visible range as well. The visible light emitted power, however, is only a small fraction of the total, even in a medium size tokamak such as FTU.

References

[1] M. Angelone, M.Pillon, M. Marinelli, *et al.*, *Nuclear Instrum. and Methods A* **623**, 726 (2010)
[2] S. Almaviva, M. Marinelli, E. Milani, *et al.*, *J. Appl. Phys.* **107**, 014511 (2010)
[3] B.L. Henke, E.M. Gullikson, and J.C. Davis. *Atomic Data and Nuclear Data Tables* **54(2)**, 181 (1993)
[4] I. Ciancaglioni, M. Marinelli, E. Milani, *et al.*, *Journal of Applied Physics* **110**, 054513 (2011)
[5] L. Di Matteo, Technical Report RT_2009-38-ENEA, 2009

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