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CVD Diamond Detectors for Fast VUV and SX-Ray Tomography (part1)

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Among the various compact diagnostics systems, the hybrid CMOS-based and gas electron multiplier (GEM) detectors of multiple sizes, types, and combinations can offer a real "swiss-knife" solution for out-vessel diagnostics of ionizing radiation in experiment of Magnetic and Inertial Nuclear Fusion. They were developed and used, for many years, by the LabNIXT group of ENEA Frascati on many experimental setups (NSTX, FTU, KSTAR, EAST, VEGA, GEKKO, etc.). In particular, the hybrid detectors based on silicon or other semiconductors are realized with a single or multiple chips bump-bonded with a semiconductor layer. Interaction of ionizing radiation in this configuration produces some characteristic tracks inside the detector. The produced charge is collected and recorded as a cluster of pixels. For each cluster, a variety of physical and morphological parameters can be defined. These detectors can be used, with different settings, to discriminate alpha, beta, gammas, hard-X, and neutrons. The hybrid detectors can be coated with one (or more) layers of converter material to observe thermal or fast (with diamond) neutrons. The triple GEM detector is an outstanding candidate for detecting plasma volumes emitting X-ray photons in the 2-30 keV energy range, thanks to its high dynamic range, sensitivity, high rate, energy resolution, and noise-free detection. A hybrid GEM detector that couples the GEM versatility and the hybrid detectors compactness (GEMPix) can be proficiently used for 2-D imaging in all the experimental situations where higher spatial resolution is required, keeping the intrinsic gain. Radiation hard chips for C-MOS and GEM will be required for experiment with a strong radiative background, like ITER.

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CVD Diamond Detectors for Fast VUV and SX-Ray Tomography (part2)

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The excellent photon detection properties of Chemical Vapour Deposition (CVD) single crystal diamonds proved them highly suitable for Vacuum Ultra-Violet and Soft X-ray radiation in-vessel diagnostics of magnetically confined plasmas in a variety of applications [1]. Their radiation and temperature hardness, small size, and high-vacuum compatibility can be exploited for core and divertor tomography/bolometry for energies from 5.5 eV up to 30 keV; their fast response (in the ns range) can be applied to monitor fast plasma events, such as ELMs, MHD instabilities, ablation of pellets. The high-quality CVD diamond detectors developed and grown at "Tor Vergata" University in Rome have long been in use at JET and were more recently tested on FTU. Their deployment on DTT is under design, and their application on ITER can also be proposed.

[1] F. Bombarda et al., 2021 Nucl. Fusion in press https://doi.org/10.1088/1741-4326/ac233a

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Compact diagnostic systems for X-rays, gammas, and neutrons: a "swiss-knife" detectors portfolio ranging between magnetic con-

finement fusion, thermal and fast neutrons detection, and laser produced plasmas experiments

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Between the various compact diagnostics systems, the hybrid CMOS-based and gas electron multiplier (GEM) detectors of multiple sizes, types, and combinations can offer a real "swiss-knife" solution for the experimental investigation of ionizing radiation. They were used, for many years, by the LabNIXT group of ENEA Frascati on many experimental setups (FTU, KSTAR, EAST, VEGA, GEKKO, etc.). In particular, the hybrid detectors based on silicon or other semiconductors are realized with a single or multiple chips bump-bonded with a semiconductor layer. Interaction of ionizing radiation in this configuration produces some characteristic tracks inside the detector. The produced charge is collected and recorded as a cluster of pixels. For each cluster, a variety of physical and morphological parameters can be defined. These detectors can be used, with different settings, to discriminate alpha, beta, gammas, hard-X, and neutrons. The hybrid detectors can be coated with one (or more) layers of converter material to observe thermal neutrons. Moreover, by combining chemical-vapor-deposited diamond and the hybrid detectors' ASIC, a fast neutron measurement is also possible in harsh environments. The triple GEM detector is an outstanding candidate for detecting plasma volumes emitting X-ray photons in the 2-30 keV energy range, thanks to its high dynamic range, sensitivity, high rate, energy resolution, and noise-free detection. The GEM camera system is a micropattern proportional gas detector that consists of an ionization gap. X-ray photon conversion occurs, three consecutive foils that act as an amplification stage, and finally, a dedicated printed circuit board that can be easily mounted outside the port of a fusion machine. A hybrid GEM detector that couples the GEM versatility and the hybrid detectors compactness (GEMPix) can be proficiently used in all the experimental situations where higher spatial resolution is required, keeping the intrinsic gain. GEMpix has been positively tested also for 2-D imaging of laser produced plasma in VEGA (Spain) and Gekko XII (Japan) Laser Facilities

KEYWORDS: Detector design and construction technologies and materials; Micropattern gaseous detectors; Nuclear instruments and methods for hot plasma diagnostics; Hybrid pixel detectors, Neutron detectors, GEM, GEMpix, Timepix

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Compact diagnostics systems for X-rays, gamma and neutrons based on GEM gas detector, C-Mos imagers and CVD Diamond Detectors for Fast VUV and SX-Ray Tomography

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Among the various compact diagnostics systems, the hybrid CMOS-based and gas electron multiplier (GEM) detectors of multiple sizes, types, and combinations can offer a real "swiss-knife" solution for out-vessel diagnostics of ionizing radiation in experiment of Magnetic and Inertial Nuclear Fusion. They were developed and used, for many years, by the LabNIXT group of ENEA Frascati on many experimental setups (NSTX, FTU, KSTAR, EAST, VEGA, GEKKO, etc.). In particular, the hybrid detectors based on silicon or other semiconductors are realized with a single or multiple chips bump-bonded with a semiconductor layer. Interaction of ionizing radiation in this configuration produces some characteristic tracks inside the detector. The produced charge is collected and recorded as a cluster of pixels. For each cluster, a variety of physical and morphological parameters can be defined. These detectors can be used, with different settings, to discriminate alpha, beta, gammas, hard-X, and neutrons. The hybrid detectors can be coated with one (or more) layers of

converter material to observe thermal or fast (with diamond) neutrons. The triple GEM detector is an outstanding candidate for detecting plasma volumes emitting X-ray photons in the 2-30 keV energy range, thanks to its high dynamic range, sensitivity, high rate, energy resolution, and noise-free detection. A hybrid GEM detector that couples the GEM versatility and the hybrid detectors compactness (GEMPix) can be proficiently used for 2-D imaging in all the experimental situations where higher spatial resolution is required, keeping the intrinsic gain. Radiation hard chips for C-MOS and GEM will be required for experiment with a strong radiative background, like ITER.
The excellent photon detection properties of Chemical Vapour Deposition (CVD) single crystal diamonds proved them highly suitable for Vacuum Ultra-Violet and Soft X-ray radiation in-vessel diagnostics of magnetically confined plasmas in a variety of applications [1]. Their radiation and temperature hardness, small size, and high-vacuum compatibility can be exploited for core and divertor tomography/bolometry for energies from 5.5 eV up to 30 keV; their fast response (in the ns range) can be applied to monitor fast plasma events, such as ELMs, MHD instabilities, ablation of pellets. The high-quality CVD diamond detectors developed and grown at "Tor Vergata" University in Rome have long been in use at JET and were more recently tested on FTU. Their deployment on DTT is under design, and their application on ITER can also be proposed.
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Detection of RF emission by runaway electrons

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Detection of plasma waves emitted by runway electrons (RE) provides a sensitive monitor for RE kinetic instabilities, which can reduce energy attained by RE as well as RE confinement. Furthermore, understanding how to stimulate such kinetic instabilities can lead to the development of advanced RE mitigation methods. Emission of radio waves by runaway electrons in the 400 MHz – 3 GHz range has been measured on FTU under different regimes, including low-density plasmas during current ramp-up, in wave dispersion conditions similar to the ones expected for the ITER start-up phase [1].
The team built around FTU measurements has continued its activity during 2020 with measurements on TCV, by and ex-vessel antenna, and with a full experimental campaign on COMPASS, by means of a complex of in-vessel and ex-vessel antennas built in collaboration with the COMPASS team. Preliminary experiments on active wave injection have also been performed on COMPASS. New measurements on TCV, employing an in-vessel antenna, are foreseen in next months. The team also includes theoretical skills for the development of analysis and prediction tools. The experience gained with FTU, TCV and COMPASS experiments and analyses on RE-waves interactions can be capitalized to devise diagnostic and control settings to detect and possibly stimulate RE kinetic instabilities also in ITER.

[1] P Buratti et al 2021 Plasma Phys. Control. Fusion 63 095007ment of analysis and prediction tools.

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Impact of Radiation on Optical Fibres at JET

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Fibres have been installed in the JET Torus hall to determine the impact of radiation on optical fibre during the JET D-T campaign. This talk will show the main affects observed from this work.

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Multi-energy x-ray imaging systems for long-pulse machines with metal PFCs

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The WEST tokamak is currently being prepared for long pulse operation with a water-cooled full metallic first wall to test ITER-like plasma facing components. Tungsten will be the main impurity source in the vessel and its concentration in the core plasma will limit the device performances as it is expected to be the case in ITER. Heating will be provided by radio-frequency systems, including lower hybrid current drive (LHCD). In this context PPPL has built two complementary cameras for energy and space-resolved measurements of the soft and hard x-rays. These measurements will be used to study the impurity (W) transport, to infer the electron temperature, the fast electron tail density produced by LHCD and runaway electrons, and the beam-target emission of tungsten at the edge due to fast electron losses interacting with the target.
The two cameras share the same compact design and both have horizontal lines-of-sight: while the SXR camera has a symmetric field of view that covers most of the plasma cross-section, the HXR camera is slightly titled to intersect the lower divertor. Both systems are based on a novel 2D pixel array x-ray detector with adjustable threshold energy at the pixel level. This innovation provides a great flexibility in the energy configuration allowing simultaneous space and energy resolved x-ray measurements. The SXR camera uses a silicon detector calibrated in the range 2.3 - 21 keV. The HXR camera uses a cadmium telluride detector calibrated in the range 8 - 100 keV.
A synthetic diagnostic was developed for both cameras to assess their capabilities. SXR emission for a given impurity mix in the plasma was modelled using the collisional-radiative code FLYCHK. HXR emission produced by thermal electrons and fast electrons generated by LHCD was modelled using the suite of codes C3PO/LUKE/R5-X2.
Both diagnostics are installed and will provide measurements starting from the next WEST campaign (March 2022).

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New developments of the T-Monitor diagnostic

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The tritium monitor diagnostic releases tritium deposited on the inner baffle of the divertor by laser-induced desorption. The tritium that is set free is detected by mass spectrometry (QMS= Quadrupole Mass Spectrometry or RGA= Residual Gas Analysis). After the Conceptual Design Review (CDR), the system was moved in the port plug from the top to the bottom half of the central drawer or Diagnostic Shield Module (DSM) in the equatorial port 17 (EQ#17). This relocation makes a deep

revision of the optical design necessary, even more so since the boundary conditions have changed in the interspace and port cell, too.

A glimpse into the physics of the method shall be given, implying strong conditions on the laser specifications. It will be followed by the current status of development for the new position in EQ#17 with the high power desorption laser still located in the tritium building.

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Plasma current measurement at JET using fibre optics current sensor (FOCS)

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The Fibre Optic Current Sensor (FOCS) is a supplementary diagnostic system to be installed in ITER to provide data on the plasma current. The FOCS is not standard for plasma current measurements the and sensor performance in a tokamak environment has to be assessed. Considering this goal, polarisation detection based FOCS systems were installed at JET. The measurements were performed in various machine operating scenarios at currents up to 4.2 MA. Data from Continuous External Rogowski (CER) coils were used as a reference. To have an agreement between two systems, cross-talk between the CER and TF coils had to be taken into account, while FOCS is mostly not affected by this effect. Based on the experimental data we conclude that the FOCS has performance characteristics compatible with the ITER requirements.

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The potential of THz-TDS diagnostics for next step Fusion experiments

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The Terahertz (THz) band of the electromagnetic spectrum is nowadays defined as a range of frequency [0.1-10] THz, between microwaves and mid-infrared electromagnetic radiation, where electronic and optical technologies overlap. The last decade has seen an enormous development of spectroscopy techniques in this area, with the full development of the so-called Time Domain Spectroscopy (TDS). The use of the wide range of frequencies associated with a probing THz pulse generated by a femtosecond pulse laser via spark-gap emitters, permits the determination of several sample parameters simultaneously, both in transmission and reflection. This possibility has obvious potential in the area of Far Infrared and millimeter waves plasma diagnostics One of the most promising diagnostic applications of THz-TDS is interferometry. A THz-TDS spectrometer with emitter and receiver located at the opposite ends of a vertical chord, using several spectral components of the THz beam, will provide the same information of a classic interferometric and in addition a straightforward implementation of the combined measurement of interferometry and polarimetry.

A more challenging diagnostic application of THz-TDS comes with reflectometry. The THz TDS reflectometer will be an evolution of the Ultrashort Pulse Radar technique, with the broadband spectrum required for the diagnostic obtained through a Terahertz switch.

The THZ diagnostic development is now progressing along the lines of transition from table top THz-TDS spectroscopy to plasma diagnostics on a tokamak. This will require a complete change of geometrical arrangements, optical layouts, spatial and temporal scales of the measurements.