THE APPLICATION OF NATURAL DIAMOND DETECTORS TO 3 MEV PROTON DIAGNOSTICS AT TORE SUPRA

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1. Introduction

Silicon detectors are now commonly used for 3 MeV proton spectra measurements close to deuterium plasmas [1,2]. Relatively low operation temperatures (below 50^{o}C) and radiation hardness (<10^{9} protons/cm^{2}) result in severe limitations of their applicability to hostile tokamak environments, requiring permanent heating up to 200^{o}C at the inner wall and permanent calibration by α-sources. Natural diamond detectors (NDD) have proved to be the most temperature and radiation resistant devices (up to 200^{o}C and 10^{14}cm^{-2}, respectively) with a fast particle energy resolution of 1-5% [3]. However, no direct practical evaluation has been carried out of NDD performance in the vicinity of high temperature, high current, plasma discharges at elevated levels of operating temperature, magnetic field, hard X-rays and numerous sources of external electromagnetic interference (EMI noise). Appropriate testing of NDD and related front-end electronics is thus the general purpose of present work. Experiments with escaping 3 MeV protons were carried out at TORE SUPRA, and compared with the performance of the existing water-cooled silicon detector system.

2. Diamond detectors

The detectors were manufactured in the form of simple metal-semiconductor-metal sandwich structures based on the natural type IIa diamonds mined from Yakutian deposits with the use of standard selection/treatment procedures. After the final selection two NDDs were chosen for testing with the following major features :

• Sensitive area	5 ... 7 mm^{2}
• Operating temperature	up to 200^{o}C
• Resolution [^{241}Am 5.5 MeV α-rays]	250 - 300 keV FWHM

Special small-size rectangular NDD casings were designed with orthogonal directions of incident irradiation and output cable (Fig. 1) to provide simultaneous operation of Si and diamond detectors, the latter being installed behind the Si array plane at the TORE SUPRA Proton Detector Unit [4].

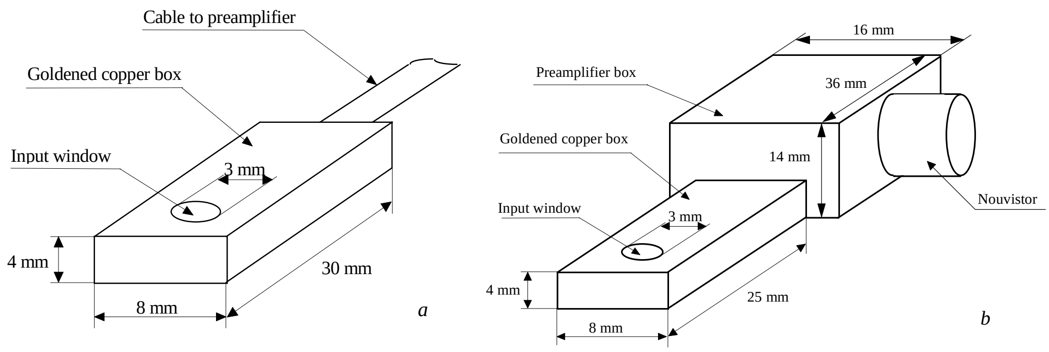

Figure 1. NDD casing design sketches: a - single NDD casing, b - NDD + preamplifier assembly.

3. Electronics

Simple low-noise JFET-input operational amplifiers (LF157, AD743 or similar) with capacitive feedback are suitable for 3 MeV proton induced charge preamplifier circuitry up to 50-60^{o}C operation temperatures. Being installed into the tokamak vacuum vessel, the distance between detector and its preamplifier appears to be one of the most critical factors since the EMI noise influence impose strong limitations on detector performance. Shorter input cable lengths (and consequently capacitance) is also advantageous for better dynamic and noise performance of the charge preamplifier circuits. Ultimately the close coupling of the detector to the preamplifier, with proper shielding and electric isolation for the electronics seems to be the most efficient solution from these points of view.

On the other hand, semiconductor electronic performance is substantially degraded by temperatures over 70^{o}C, X-ray, gamma and neutron irradiation, and thus requires active cooling and extra shielding. However, high reliability and safety are difficult to achieve for complicated systems of in-vessel multi-channel and multi-viewpoint diagnostics. In order to avoid these difficulties two main approaches were developed and tested at TORE SUPRA:

i) NDD plus preamplifier-hybrid assemblies with the front-end amplification stage constructed using small size metal-ceramic vacuum triode («nouvistor»);

ii) distant location of semiconductor front-end electronics (2 m from from the detector position) with total galvanic isolation of power supply, detector bias, analog signal and digital control circuits for the correct EMI noise suppression.

The required functionality of the first design described above is achieved by a compromise of a number of contradictory requirements of device compactness, minimum number of electric connections, enhanced stability to detector electric breakdown, ambient temperature and magnetic field variations. A small size vacuum triode (nouvistor) was used for the front-end amplification stage. It was located close to NDD in a hybrid assembly together with a few passive components. Reduced cathode heating power and proper triode axis orientation (Fig. 1b) were chosen for resistance to the high toroidal magnetic field and high temperature tokamak environments. The triode anode voltage V_b = 100...200 V is suitable for the NDD biasing. A secondary low input impedance amplifier and output 50 Ω cable line driver were installed outside the vacuum vessel 2.5 meters away from the assembly.

The second approach includes three extra isolation circuits as well as a standard charge preamplifier analog output, power supply and NDD bias. It provides high common-mode rejection ratio in a wide range (up to 1 kV) of induced common-mode potential, resulting in considerable improvement of EMI noise suppression. Reduced AC coupling between in-vessel and outer electronics is favourable also for the total system reliability and safety.

Both designs were able to sustain elevated operating temperatures (up to 200^{o}C) and magnetic fields (up to 5T) at the detector location. No remarkable variations and/or long-term drift of the calibration curve, measured with ^{241}Am α-rays, were observed during the temperature and the magnetic field ramp up and down in the ranges 20-150^{o}C and 0-3 T.

4. Results

An example of the escaping proton spectra is shown in Figure 2. The NDD and Si detectors have been installed a few millimetres apart to intercept the same proton flux. Both detectors demonstrate similar spectral evolution throughout the plasma discharge, with the peak energy at 2.7MeV, in agreement with the 300 keV lost in a 6 μm thick stainless steel input vacuum separation window.

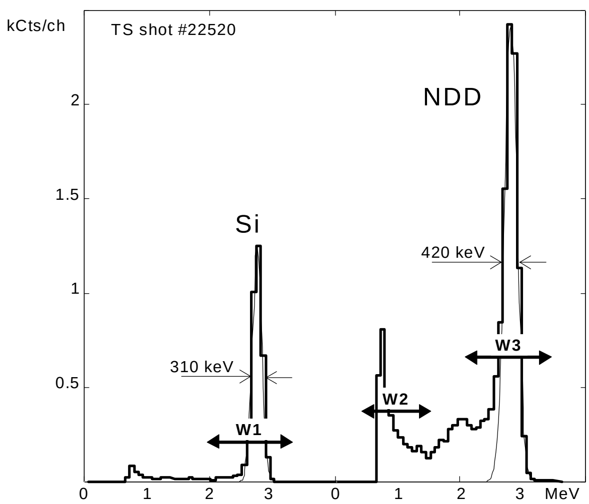

Fig. 2. Proton spectra measured with Si and NDD.

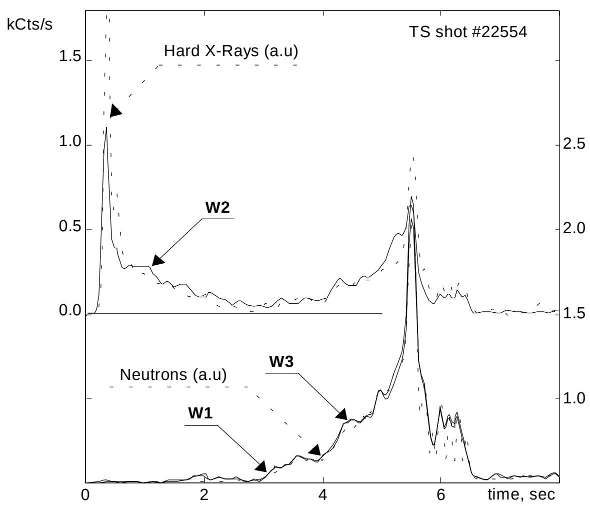

Fig. 3. Time evolution of proton count rates, hard X-rays and neutron fluxes.

In Figure 3, the time evolution of the count rate in the three energy windows, defined in Figure 2, is shown together with neutron and hard X-ray monitor signals. Low-energy count rates follow the hard X-ray radiation intensity, while the 2.7 MeV signal is correlated with the neutron rate on both the silicon and diamond detectors.

Evaluation of NDD/nouvistor-preamplifier hybrid assembly performance at elevated temperatures and magnetic fields has been made in the laboratory (up to 200^{o}C) and the TORE SUPRA sampling port (t = 150^{o}C, B = 2.5 T) with the use of an ^{241}Am α-source. No notable deviations and/or long-term instabilities of spectral the curve were observed during the heating/cooling cycles and the magnetic field ramp up/down during 2 weeks of operation.

Finally, testing of NDD performance with a 2 m long cable connection to the preamplifier, located at the vessel vacuum flange, had been carried out. No proton peak could be distinguished in the external noises before the installation of isolation units. However a dramatic improvement was seen after installation of the isolation units and no extra filtering was required to clearly monitor protons at the preamplifier output during plasma shots.

5. Conclusions

The following conclusions can be drawn from this work:

- NDD applicability to escaping DD fusion proton detection and spectral measurements with an energy resolution of 300 keV had been verified at TORE SUPRA.
- NDD applicability to hostile ambient conditions (T = 150-200^{o}C, B = 3T) with high reliability and long-term stability were demonstrated without need for any active cooling.
- A hybrid assembly of NDD plus a small vacuum triode preamplifier was successfully tested at elevated temperatures (up to 200^{o}C) and magnetic fields (up to 3T). Enhanced immunity to harsh tokamak environments and EMI noise had been obtained.
- Total front-end isolation electronics with proper shielding and loopless grounding was tested for enhanced EMI noise suppression. This solution proved to be most suitable, allowing the closest location of the detector to the plasma edge inside the vacuum vessel.

References

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