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Fast neutron spectroscopy with very high energy and time resolution for diagnosing fusion DT burning plasmas

Neutron spectroscopy is a key diagnostics of high power fusion plasmas [1]. In particular, it can determine the plasma ion temperature, the so called thermal to non-thermal fusion power ration and the fuel ion ratio (nD/nT) of the concentration of deuterium and tritium isotopes in a DT burning plasma. The latter is a crucial parameter to be measured in order to control the produced fusion power. The determination of the fuel ion ratio requires to measure with very high energy resolution and sensitivity minor components in the expected 14 MeV neutron energy spectrum In particular, one must be able to distinguish from the main 14 MeV neutron thermal emission a fraction of about 1% of suprathermal neutrons, the latter emitted by reactions between neutral beams and thermal ions and emitting neutrons up to about 18 MeV [2].
In recent times, diamond-based detectors (CVD- chemical vapour deposition diamonds [3]) have shown an interesting potential as high resolution neutron spectrometers for fusion and other applications [4]. Diamond features 1) insensitivity to magnetic fields; 2) high radiation resistance; 3) low dark current; 4) good energy resolution (˜1% FWHM@14MeV), at present limited by the fast preamplification electronics; 5) very high counting rate capability (>1 MHz). A neutron spectrometer based on a 12-pixel CVD diamond matrix has been built and installed at the JET fusion tokamak in United Kingdom. This technology has already been identified of interest by ESA [5] also for application others than nuclear fusion.
The sensitivity of present diamond neutron spectrometers to weak components in the neutron spectrum is today limited at about 1% in "normal"(i. e. natural isotopic carbon concentration with about 99% of 12C and 1% of 13C) diamond detectors. There are two competitive reactions of neutrons in the MeV energy range, namely 12C(n,alpha)9Be and 13C(n,alpha)10Be, the latter featuring a Q value of about 2 MeV lower than the first reaction. The resulting detector response function is thus such that sets the sensitivity to weak components in the high energy tail of the 14 MeV neutron spectrum to about the 1% level.
Target goals of this proposal is the realization of a prototype diamond based neutron spectrometer which features an energy resolution<0.5% at 14 MeV, counting rate capability of 5 MHz and a signal to background >10ˆ4 in the neutron energy range 12-20 MeV. This will be realized first, by the development of a custom low noise fast spectroscopy preamplifier. Second, it is proposed the development of 13C-free CVD diamond. The CVD technique allows to grow enriched 12C crystal by the use of 13C-free methane as a starting gas. 13C-free methane can be obtained by the use of gas centrifuges, a standard technology already used not only for the isotopic separation of uranium but also for other atoms like zinc or lithium [6]. Aim of this proposal is to grow high purity single crystal CVD diamonds enriched at least at 99.99% of 12C, build the detector and characterize in the laboratory and at fast neutron sources, including 14 MeV monoenergetic sources. The measured performances will be benchmarked to standard natural carbon composition diamond spectrometers. If the development will be proven to be successful, the first application will be the installation at JET fusion laboratoris in UK for the next DT campaign and tested for determination of the fuel ion ratio. the Other possible applications can be spectroscopic analysis of charged particles, such as protons or alpha particles or radiation therapy dosimetry, the latter being favored by the tissue-equivalent behavior (atomic number of the detector is very close to the mean of human tissue).

References

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Summary

Future DT burning plasma experiments such as ITER will require dedicated nuclear diagnostic for monitoring the plasma performance and evolution. Spectroscopy of 14 MeV neutrons is a key diagnostics of high power fusion plasmas since it allows the measurement of the plasma ion temperature, of the so called thermal to non-thermal fusion power ratio and of the fuel ion ratio of the concentration of deuterium and tritium isotope. In this proposal we propose to develop a new compact neutron spectrometer which, for the first time, features i) very high energy resolution (<0.4%@14MeV); ii) enhanced sensitivity to weak components in the neutron spectrum; iii) time resolution on the 10-100 ms scale thanks to a counting rate capability up to 5 MHz. The spectrometer will be based on CVD diamond detectors. A successful demonstration of such compact diamond neutron spectrometer prototype will open up the possibility to perform time resolved measurement of the ion temperature and of the fuel ion ratio, and to achieve spatial resolutions by performing multiple line of view observation in a camera configuration.

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