Procedures for the characterization of diamond detectors as neutron spectrometers

Detectors made of synthetic single-crystal diamonds are suited as high-resolution neutron spectrometers for use in extreme neutron fluxes like the ones present in fusion facilities. In a measuring campaign at PTB’s ion accelerator facility, a procedure was tested which allows the response functions of the detector to be determined in the energy range relevant for fusion diagnostics, i.e. from 6 MeV to approx. 16 MeV.

Single-crystal synthetic diamond detectors, when used as neutron spectrometers, provide an energy resolution that cannot be achieved by any other spectrometer operating in extreme neutron fluxes like the ones at the fusion experiment ITER, which is currently under construction in Cadarache (France). These detectors work according to the same principle as silicon semiconductor detectors. The neutrons incident on the detector generate charged particles by nuclear reactions with the carbon nuclei of the diamond crystal; these particles are then stopped and release their energy inside the semiconducting crystal. When used in neutron fields, diamond has the advantage of being extremely resistant to radiation-induced damage of the crystal.

When using diamond detectors as neutron spectrometers in fusion facilities, the detector response functions to monoenergetic neutrons must be known for the energy range from approx. 6 MeV to approx. 16 MeV. Within the scope of a project funded by EFDA (European Fusion Development Agreement), a measurement procedure was developed at PTB which allows the response functions of the detector to be determined in this energy range.

At PTB’s ion accelerator facility, the detector response functions of a commercially available diamond detector were investigated for 9 neutron energies. In the procedure used, a monoenergetic deuteron beam from PTB’s cyclotron incident on a gas target generates high-energy neutrons. The energy of the deuteron beam – and thus the neutron energy – can be varied quasi-continuously. Results of this measurement are represented in Fig. 1.
Fig. 1: Pulse height spectra of the diamond detector for irradiation with 2 different neutron energies: a, top) 16 MeV; b, bottom) 14 MeV. Depending on the incident neutron energy, different nuclear reactions are induced which result in different responses of the detector. The newly developed procedure allows the neutron energy to be varied quasi continuously from 6 MeV to approx. 16 MeV and, thus, the detector to be fully characterized in a neutron energy range which is relevant for the diagnostics of neutrons in fusion experiments.

In the pulse height spectra, different reaction channels which open at increasing neutron energy are clearly visible. Signals which do not originate from the neutrons in the monoenergetic peak of the spectrum are separated using the time-of-flight method. This is shown in Fig. 2. The highlighted area in Fig. 2 corresponds to the monoenergetic neutron peak.

Fig. 2: Signals registered in the diamond detector for irradiation with neutrons at an energy of 16 MeV. Signals which do not originate from monoenergetic neutrons can be separated from the remaining neutrons (left of the highlighted area) and gamma signals (right of the highlighted area) using the pulsed beam structure and the time-of-flight method.
In principle, the total energy range can be covered using this method, but this is not possible in practice due to the long measurement time. Thus, Monte Carlo calculations are necessary to complement the measurements to obtain a complete response function of the detector. To achieve this, existing computing codes still need modification. Then, with the aid of unfolding methods established at PTB, it will be possible to determine the spectral neutron energy distribution for a wide neutron energy range on the basis of measured pulse height spectra.

Contact
A. Zimbal, Department 6.5, Working Group 6.53, e-mail: andreas.zimbal@ptb.de