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Design and simulation using FIDAsim of a diamond detector neutral particle analyzer (DNPA) on HL-2A tokamak

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In magnetic confinement fusion devices, a comprehensive understanding of the energetic particle (EP) behaviors in the presence of magnetohydrodynamic (MHD) fluctuations is significant for the research of fast ion (FI) confinement and transport mechanism (Fasoli et al. 2007; Chen and Wang 2020). As a diagnostic for the direct measurement of the FI, the neutral particle analyzer (NPA) (Summers et al. 1978) has been well developed to measure the energy spectrum of the FI. Diamond detectors (Artemev et al. 2019) are promising for their advantageous properties. To study the feasibility of the installation and explain the results of NPA spectrum, a simulation code, FIDAsim (Geiger et al. 2020), is used about the forward modelling.

A CVD diamond NPA (DNPA) has been designed and installed for the measurements of energy spectrum of the fast neutralized particles fleeing from the CX reaction with fast ions inside the plasma. By applying the new customized detector (CIVEDEC-12, 4.5mm × 4.5mm × 500 μm), we developed this DNPA system on HL-2A, as shown in Fig. 1. The DNPA system is located at the end of a guiding tube which is connected to a port tilted upwards of HL-2A O sector, the angle between the LOS and midplane is about 40 . The vertical distance between detector sensor and midplane is 84 cm. The intersection length between DNPA viewing cone and beam centerline is 8.3 cm. The LOS of DNPA intersects almost perpendicularly with 4 sources of NBI #2 (tangential injection) near plasma core (R_{tan}=1.54 m and R_0=1.65 m), which manifests this DNPA has an active view.

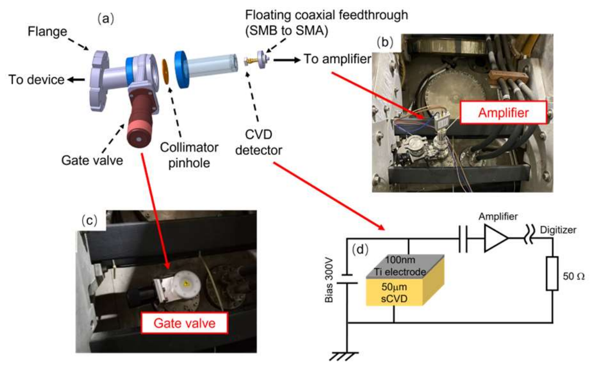

Fig. 1. System schematic and photographs of the DNPA system configurations. (a) CF 35 gate valve; (b) Cx-L amplifier; (c) CATIA model of assembly.

The line of sight (LOS) of the DNPA intersects with neutral beam and the tangency radius is 154.8 cm. The pitch angle is about -0.22 which means this DNPA mainly collect information about trapped ions. With the fast ion distribution calculated from TRANSP/NUBEAM module, the velocity-space measurement range of this active DNPA overlaps with the fast ion distribution over the most energies with the pitch angle defined by the LOS of the detector. FIDAsim simulation results show that, in discharge #36982, the flux peaks at approximately 3.5 × 10^9 (neutrals [s^{-1} keV^{-1}]) at 11.5 keV which nears the third beam energy (12.9keV). At low energies (< 2 keV), passive component which comes from reactions with cold neutrals is dominant due to a high density of cold neutrals near the edge. At relatively high energies (> 8 keV), active components prevail the spectrum, especially at the energies near third beam energy. The capability of discriminating active and passive allows this DNPA to determine the background neutral density profile, thereby facilitating plasma transport studies. Furthermore, the flux contribution coming from halo neutrals (thermal CX emission) are also considerable. Comparisons of differential 16.5 keV charge-exchange efflux with halo and without halo along DNPA sightline clearly illustrate that halo neutrals significantly increase the efflux. As expected, most charge exchange events occur near the edge and contribute most to the neutral flux. In our future work, this DNPA will be tested with respect to the pulse shape discrimination and this system will participate the next experimental campaign to validate the simulation. Meanwhile, a new DNPA is under development on HL-2M tokamak, and the design will emphasize the neutron shielding with respect to high neutron flux plasma.

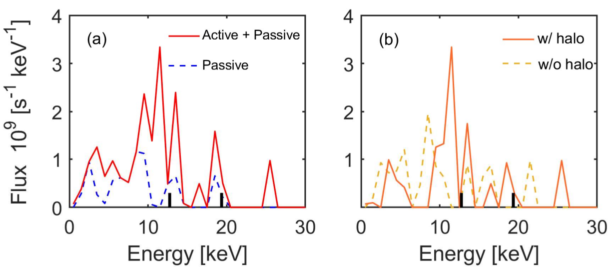

Fig. 2. (a) Active and passive signal and (b) the contribution of halo neutrals to DNPA. The black lines indicate the half and third beam energy.

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