Lost alpha diagnostic based on an imaging bolometer and a multi-foil thermal detector

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The diagnosis of lost alpha particles is important for the operational safety and evaluation of an experimental fusion reactor. A radiation-hard diagnostic device has been proposed based on an imaging bolometer and a multi-foil thermal detector. In this paper we discuss ongoing work with testing prototype imaging bolometers on JT-60U and the testing of a prototype multi-foil thermal detector on an ion accelerator.

1. Introduction

The confinement of alpha particles is an important topic for the operation of a fusion reactor as they should transfer their energy to the fuel plasma and then be exhausted safely through the divertor. If their confinement is poor the 3.5 MeV helium nuclei could escape through the last closed flux surface and scrape-off layer in a spatially localized manner that could do serious damage to the first wall of the reactor. Therefore the diagnosis of lost alpha particles is important for the operational safety and evaluation of an experimental fusion reactor. A lost alpha detector has been identified as one of the key diagnostics for the ITER experiment which will soon enter the construction phase. The diagnostic requirements specified by the ITPA diagnostics group are given in a Table 1 [1].

In spite of this importance, a suitable diagnostic solution has yet to be found for the ITER device. Two options have been deployed on magnetic plasma confinement devices to study the loss of energetic ions. The first is the scintilator probe that has been used successfully on various plasma confinement devices to diagnose the energy

PARAMETER	CONDITION	RANGE	RESOLUTION			
			Temporal	Spatial	Energy	Accuracy
First wall flux	Default	2 MW/m2 + (with FI -?)	100 ms	*a*/10 -poloidal direction*	250 keV (desired)	10%
	Transients	20 MW/m2 (with FI - ?)	10 ms	TBD	-	30%

Table 1 Measurement requirements for lost alphas on ITER [1].

distribution and pitch angle of escaping energetic ionized particles [2]. The second are Faraday cup detectors, which provide information on the energy distribution of lost ions [3]. However, both of these concepts are subject to questions regarding their applicability in a neutron-rich fusion reactor environment. For the former, a suitable scintilator material should be found that can operate at high temperature and withstand the high neutron fluxes. For the later, problems with detecting the expected nanoampere level electrical currents in the presence of radiation induced electromotive forces are anticipated. These problems call for a new technique which is durable and reliable in a fusion reactor environment and can provide the necessary information on the escaping alpha particle energy distribution and pitch angle.

A new concept for measuring energetic ions escaping from a fusion reactor has been proposed based on the combination of a multifoil thermal discriminator and an imaging bolometer [4] and is known as the InfraRed MultiFoil Thermal Detector (IRMFTD) The imaging bolometer is a radiation-hard energy detector which uses a thin metal foil to absorb the energetic radiation or particles from its front side facing the plasma and is imaged on the back side by an infrared camera through a periscope infrared optical path [5]. The infrared camera measures the change in temperature of the thin foil and then this information is used in the solution of the two-dimensional heat diffusion equation for the power deposition distribution in the foil. A stack of multiple thin foils is placed in front of the imaging bolometer to discriminate the energy distribution of the absorbed particles as shown in Figure 1. By layering the discriminating foils in a stair-step fashion, one dimension can be used for energy discrimination and by proper orientation of the detector with respect to a slit and the magnetic field the other dimension can be used for pitch angle discrimination as shown in the conceptual design in Figure 2.

In this paper we report on ongoing research into the development of this diagnostic.

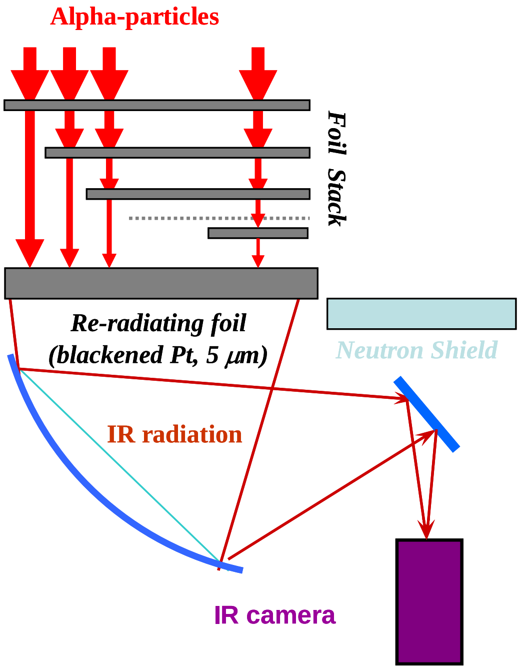

Figure 1 Conceptual design of IR multi-foil thermal detector.

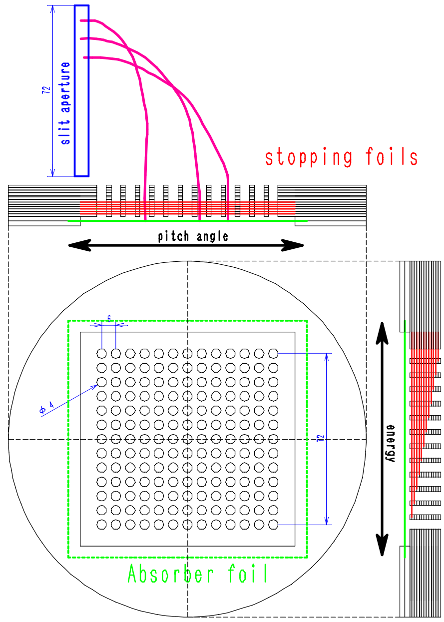

Figure 2 Conceptual design of discriminator stack and re-radiating foil for IR multi-foil thermal detector.

This R&D can be separated into two areas: development of imaging bolometers; designing, fabricating and testing prototype multi-foil thermal detectors on ion beam facilities. In the following we report on the current status and future plan for each of these areas.

2. Imaging bolometer testing on JT-60U

An integral part of the IRMFTD is the imaging bolometer. Imaging bolometers have been operated recently on the helical devices LHD and CHS [6,7]. However this is not a sufficient test of the viability of an imaging bolometer for a tokamak device because of the lack of disruptions in a helical device. There for we embarked on a project to test an imaging bolometer on the JT-60U tokamak. The bolometer foil, pinhole camera and vacuum IR window were installed in JT-60U in August of 2003 [8]. The IR camera was installed in 2004 and initial data were taken during the 2004-2005 campaign as shown in Figure 3 [9]. Loss of IR camera signal during the high powered NBI indicated that the neutron and magnetic shielding of the IR camera were not adequate. Therefore the shielding was increased for the 2005-2006 campaign. Soft iron magnetic shielding was increased from 6 mm to 20 mm, a 15 mm lead shield was added for gamma rays, and the boron-doped polyethylene was increased from 3 cm to 9 cm.

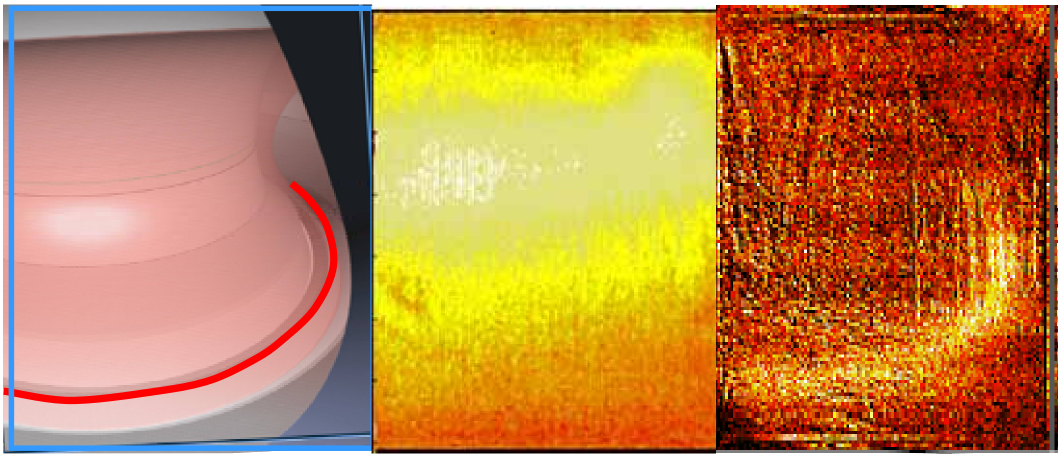

Figure 3 CAD image of field of view of imaging bolometer in JT-60U with divertor shown in red (left), IR camera images of core radiation at disruption (middle), and divertor radiation during Hydrogen discharges (right).

In addition other improvements were made to enable triggering of the IR camera and 14 bit data acquisition.

3. Foil testing on an ion beam facility

Tests have been carried out on an ion beam facility using a simple prototype IRMFTD shown schematically in Figure 4 [10]. Three types of stopping foils were tested; nickel

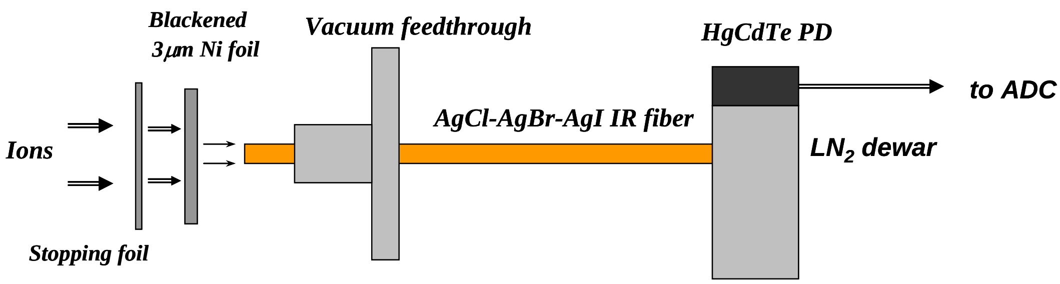

Figure 4 Schematic of prototype IRMFTD [10].

(1 μm), diamond-like carbon film (150 nm), CVD damond membrane (155 nm). The results of the transmitted power fraction versus beam energy are shown in Figure 5. The discrepancy at low energies is attributed to scattering.

4. Conclusion

Preliminary work has been done on the development of an infrared multifoil thermal detector for measuring energetic charged particles in fusion devices. This work has basically demonstrated the proof of principle of using foils to discriminate ion energy and the durability and operability of an imaging bolometer in a tokamak environment. However, much work remains to demonstrate the viability of the diagnostic for ITER. Work on JT-60U will continue to demonstrate the applicability of an imaging bolomter in a tokamak reactor environmentwith high neutron fluxes. Experiments with a prototype IRMFTD will be extend to investigate a prototype IRMFTD using multiple foil layers and an IR camera and its application to an existing fusion device. In addition consideration of integration issues for ITER and detector locations have begun.

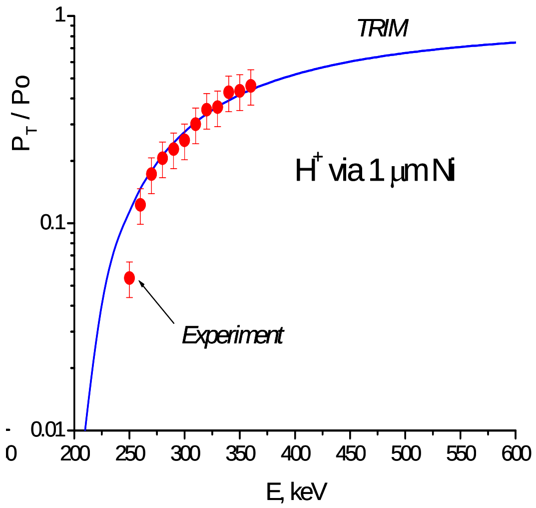

Figure 5 Transmitted power fraction versus H^+ beam energy for .a one micron Ni foil compared with the prediction of the Monte Carlo calculation, TRIM (in blue) [10].

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