A THIN-FOIL FARADAY COLLECTOR AS A RADIATION-HARD, HIGH FLUENCE CHARGED PARTICLE SPECTROMETER

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We have developed a radiation-hard, charged particle spectrometer, consisting of thin parallel conducting foils as current collectors. Prototype detectors have been tested in accelerator bombardments and at the fusion plasma facilities TFTR and JET. In the case of the accelerator bombardments, a detector consisting of 6 Al foils, each of thickness about 6 μm, demonstrated an energy resolution of about 7% for 7 MeV alpha particles. The prototype tested immediately outside TFTR demonstrated the expected insensitivity to moderately high levels of fast neutrons and hard gamma rays. The prototype tested inside JET similarly indicated operational capability at elevated temperatures as a lost alpha particle detector for d-t tokamak fusion plasmas.

Conventional charged particle detectors, such as surface barrier Silicon detectors or thin scintillation detectors suffer from the inability to operate effectively at high temperatures and high background radiation fields. An alternative detector concept not suffering from these limitations is that of a stack of parallel thin metallic foils, electrically insulated from one another and connected to separate ammeters.

The ability of such a stack of foils to operate as a spectrometer derives from the fact that the range of the charged particles is an increasing function of energy and consequently the energy of the particle can be inferred from the deepest foil in the stack which registers current. The minimum fluence will be limited by the sensitivity of the ammeters chosen to register the currents. A complication arises from the fact that as the energetic particles pass through or stop in a given foil, secondary electrons will be emitted. The suppression of these secondary electrons is essential if the optimal spectrometric capability of the detector is to be realized. The expected insensitivity to background neutron and gamma radiation has been described in some of our earlier works devoted to this concept.[1 and references therein] Specifically for d-t tokamak experiments such as JET or ITER, the proposed detectors should be able to measure the first wall flux of lost alpha particles at the μA/cm² levels in the presence of intense fast neutron and hard gamma ray backgrounds with an expected signal to noise ratio of at least two orders of magnitude. This has been successfully tested to date with the placement of a prototype detector immediately outside TFTR during d-t plasmas with total neutron source strengths exceeding 10¹⁸n/s. [1] The ability to operate inside a tokamak during d-d plasma operation has likewise been demonstrated on JET[1].
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The response in general and the energy resolution in particular of such a detector can best be evaluated by exposing the detector to a well collimated, monoenergetic ion beam from an accelerator. We have recently carried out a series of such measurements for several detector designs. The bombardments were carried out at the Tandem Van-de-Graff facility at Sandia National Laboratory with He\(^+\) and He\(^{++}\) ion beams with energies from 1 to 7.5 MeV. The detectors, differing in their foil materials and in the manners in which the adjacent foils are electrically insulated from one another, are described in the following Table 1. The first detector in this table is identical to the detectors presently installed in the JET tokamak as first wall detectors of lost alpha particles. Except for the Al/polyethylene detector, all are capable of operating at temperatures up to about 1500° K.

**Table 1. Description of detector designs investigated**

<table>
<thead>
<tr>
<th>Detector design</th>
<th>Insulation</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>4 x 2.5 μm Ni foils</td>
<td>2 mm thick ceramic rings</td>
<td>no active insulation between foils</td>
</tr>
<tr>
<td>6 x 6 μm Al foils</td>
<td>1 μm polyethylene sheet</td>
<td>low temperatures (≤600° K)</td>
</tr>
<tr>
<td>3 x 2.5 μm Ni foils</td>
<td>0.05 μm Alumina deposition</td>
<td>fabrication by deposition facility</td>
</tr>
<tr>
<td>2.5 μm Ni + 2 x 5μm Ni</td>
<td>2.5 μm mica sheets</td>
<td>easily assembled</td>
</tr>
</tbody>
</table>

In the case of each detector we observed that currents were only measured from foils at depths from the front face of the detector less than or equal to the range of the particles in the foil material.[2] Thus, for example, no current was measured in the third foil of the first detector in Table 1 for alpha particles with energies less than about 2 MeV. The response from each of the six foils in the Al foil/polyethylene insulator sandwich detector are shown in Figure 1 below. The spectrometric capabilities of this detector are obvious from this figure. We are clearly able to distinguish between, for example, 6.5, 7.0 and 7.5 MeV He\(^{++}\) with this detector indicating an energy resolution better than about 7%. The current in the first foil arises, we believe, from secondary electrons being ejected from the front face of the first foil. This belief is supported by our measurements with He\(^+\) beams in which the net current fraction in the first foil is about zero as the positive electric current due to the ejection of secondary electrons is canceled by the negative electric current from the single atomic valence electron on the He\(^+\) ion which is immediately stripped off of the ion as it enters the first foil. The active insulating layers between the foils in the last three detectors given in Table 1 appear to suppress the secondary electrons produced by the passage of the energetic ions through the foils. Specifically, for the first detector given in the table, with no active insulators between the foils, significant negative currents were measured in the third foil during the bombardment of the detector with 3.5 MeV He\(^{++}\) ions, indicating that electrons from the second foil struck the third foil where the ions stopped, producing a net negative current. This negative current was, however, suppressed, leaving the positive current from the stopping alpha particles in the third foil when the detector was placed in a 0.2 T magnetic field parallel to the planes of the foils indicating that the secondary electrons were prevented from leaving the foils. This suppression of the secondary electrons from the second foil will thus allow these detectors to serve as lost alpha particle detectors in large tokamaks such as JET or ITER since the strength of the toroidal fields in these machines is several Tesla, significantly greater than the 0.2 T used in the present experiment.
Figure 1. Fraction of total current in each foil of Al/Polyethylene sandwich detector during bombardment with He\textsuperscript{+} beams of energy 6.5 MeV (top), 7.0 MeV (middle) and 7.5 MeV (bottom).

The robustness and moderately good energy resolution of these detectors should permit the application to tasks such as the first wall measurement of lost alpha particles from tokamak fusion plasmas, the real time measurement of light ion fission fragments from fission reactor experiments and the in-beam measurement of accelerator beam energies as a control diagnostic. We are continuing the development and testing of these detectors in an effort to optimize energy resolution, sustainable heat load, economy and the suppression of the secondary electrons. This work is supported by the U.S. Department of Energy Office of Magnetic Fusion Science under contract #DE-FG03-95ER54303.

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References
2. The ranges were calculated with the code SRIM, J.F. Ziegler and J. Biersack (1996).