Advanced neutron and gamma detectors for plasma-wall interactions science on Alcator C-Mod
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Graphical overview of a proposed plasma-wall interactions diagnostic on Alcator C-Mod

Principles of in-situ ion beam analysis for plasma-facing components

1. Radiofrequency quadrupole linear accelerator injects 1 MeV deuterons (D+) into the C-Mod vacuum vessel through radial port
2. Toroidal and vertical tokamak magnetic fields (B) electromagnetically steer the charged D+ beam to the PFC surfaces of interest
3. D+ induce high-Q nuclear reactions with low-Z isotopes in the PFCs producing neutrons and gammas
4. In-vessel detection and spectroscopy of neutrons (n) and gammas (\(\gamma\)) provides PFC surface composition data

A LaBr\(_3\)(Ce) scintillation crystal + SiAPD performs high-resolution gamma spectroscopy in a compact form-factor

The AGNOSTIC LaBr\(_3\)+SiAPD detector and preamplifier, fabricated by Saint-Gobain Crystals\(^\text{®}\), is housed in a steel shielding box and is only 3 x 3 x 8 cm. The LaBr\(_3\) crystal is 0.9 x 0.9 x 3.5 cm in size.

LaBr\(_3\) \(^{137}\text{Cs}\) Energy Spectra

The energy resolution of the LaBr\(_3\)+SiAPD detector is ~2 times better than a conventional NaI+PMT at 661.7 keV and obtains similar photopeak counts despite the LaBr\(_3\) volume being almost 30 times less than NaI.

An EJ301 liquid organic scintillator + SiAPD is being fabricated in-house for neutron detection and pulse shape discrimination

The EJ301 liquid scintillator and SiAPD (a) are optically coupled, light-proofed with the ubiquitous black tape, and mounted to circuit board (b). The EJ301-SiAPD is then combined with a preamplifier and connectors (c) before being mounted inside a metal shielding box.

Recently obtained pulses (most likely cosmic events or background gamma rays) from the EJ301-SiAPD detector were digitized with the AGNOSTIC data acquisition system. Work is presently under way to implement pulse shape discrimination hardware and algorithms to separate neutron-induced events from gamma ray-induced events.

Alcator C-Mod presents an extremely hostile environment for traditional neutron and gamma detectors...

The demands for performing energy spectroscopy of the deuteron-induced neutron and gamma rays in the core of the Alcator C-Mod tokamak are severe, rendering conventional detectors useless:

- Strong magnetic fields (\(\leq 1\) tesla) - No PMTs, ferromagnetic material
- High temperature (\(\leq 100^\circ\) C) - No high purity germanium (HPGe) detectors
- Energetic neutron fluence (\(\leq 10^{12}\) m\(^{-2}\) per plasma shot)
- Strong mechanical shock (\(\leq 200\) g) - No PMTs, proportional counters
- Restrictive geometry (detector \(\leq 5\) cm) - No HPGe, proportional counters

...that can be addressed by coupling advanced silicon avalanche photodiodes to improved scintillation materials

Silicon Avalanche Photodiodes (SiAPD) are insensitive to magnetic fields, mechanically robust, radiation hard, low power, and very small.

Recently developed SiAPDs with large surface area (\(\geq 10\times 10\) mm\(^2\)) and high quantum efficiency (\(\geq 50\%\)) can be optically coupled directly to the scintillator for readout.

The SiAPDs convert optical photons to electrons via the photoelectric effect; the electrons are then multiplied by a factor of ~2000 by avalanche cascades induced by the high bias voltage across the photodiode.

Optical photons → Electrons → Voltage pulse → To data acquisition system

The emission spectra of LaBr\(_3\) and EJ301 scintillator are fairly well matched to the quantum efficiency of the SiAPD, achieving above 50% photon detection efficiency.