

COMPACT FULL-FIELD ION DETECTOR SYSTEM FOR SMALLSATS BEYOND LEO. J. Wrbanek¹, S. Wrbanek¹, G. Fralick¹, P. Clark², R. McNeil³; ¹NASA Glenn Research Center, 21000 Brookpark Rd MS 77-1, Cleveland, OH 44135 (John.D.Wrbanek@nasa.gov), ²Institute for Astrophysics and Computational Sciences, Catholic University of America, NASA GSFC, Greenbelt, MD 20771, ³College of Science and Technology, Morehead State University, Morehead, KY 40351.

Introduction: NASA Glenn Research Center (GRC) is applying its expertise and facilities in harsh environment instrumentation to develop a Compact Full-Field Ion Detector System (CFIDS) [1, 2]. The CFIDS is designed to be an extremely compact, low cost instrument, capable of being flown on a wide variety of deep space platforms, to provide multi-directional, comprehensive (composition, velocity, and direction) in-situ measurements of heavy ions in space plasma environments.

The CFIDS is comprised of a central spherical Cherenkov detector surrounded by detector stacks of Linear Energy Transfer (LET) detectors as well as Trigger and Veto (rejection) detectors for signal processing.

A design concept for this technology approach is illustrated in Figure 1. To enable this concept, advancements have been made in radiation detector technology using wide band gap (WBG) semiconductor devices.

Application: The manner and extent of the impact of high energy galactic cosmic radiation (GCR) ions on planetary magnetosphere, atmosphere, and surface (space weathering) processes are not systematically known, although such GCR ions are suspected to have a role in processes as diverse as space weathering [3, 4], cloud formation [5], and magnetospheric shaping [6].

On bodies lacking strong magnetospheres and true atmospheres, such as the Moon, energetic GCR interact directly with the surface, and play an important role in space weathering, redistribution of volatiles, and polymerization of organic materials, through radiation chemistry.

In order to provide a complete understanding of how energetic processes internal and external to the solar system shape magnetospheres, atmospheres, and surfaces, in situ particle observations should include measurements of GCR, along with solar wind and plasma. Missions to achieve these measurements would include flexible path orbiters, probes, landers or rovers beyond low Earth orbit (LEO).

SmallSats with mass less than 100 kg (such as CubeSats) are seen to be low-cost platforms ideal for conducting this range of observations either solo or in multiple locations as a swarm. However, current detector technology limits the measurement capability by restrictions of size, power and thermal stability of the SmallSat platform.



Figure 1 – Design concept illustration of CFIDS detector assembly (cables and signal conditioning hardware not shown for clarity).

Objective: To meet the challenges of low-power, low-noise, multidirectional robust detectors for a wide range of mass and energies, new ion detectors based on wide band gap (WBG) semiconductors are being developed for integration into the CFIDS instrument.

The new detector technologies being developed at GRC are in the specific areas of:

- Solid-state detectors to use with scintillator ribbon material for Trigger and Veto detector roles over large, irregular surfaces where photomultiplier placement is not feasible.
- Fast solid-state spherical Cherenkov detector that can detect radiation from all directions, amplifying the signal through use of integrating sphere properties designed into the detector.
- WBG solid-state devices as practical robust, thermally stable large area detectors for LET measurements in compact, stacked configurations.

Detector Development: Potential technologies for this detector system have been identified and demonstrated for lower power, more compact detector components.

Solid-State Trigger/Veto detector: Spacecraft-based trigger and veto detectors are comprised of scintillator blocks of plastic or iodide crystal mated to a photomultiplier tube (PMT) or a pixelated avalanche photo detector (APD), also referred to as a silicon photomultiplier (SiPM). The goal is to replace the role of PMTs and SiPMs in these types of detectors with WBG devices, saving on size, weight and required power.



Figure 2 – Miniature scintillation/diode ionizing radiation detector as demonstrated.

A miniature “paddle style” radiation detector was demonstrated using a gallium phosphide (GaP) photodiode mated to a polyvinyltoluene (PVT) scintillator block as shown in Figure 2. The preliminary results indicate that the improvement in required size and power with the use of the WBG material and, if used with acrylic ribbon scintillators, allows its use in the CFIDS concept.

Solid-State Cherenkov detector: At the heart of the detector system concept is a spherical Cherenkov detector. Typical Cherenkov detectors comprise of flat disks or blocks of sapphire or acrylic mounted on photomultiplier tubes. The goal is to replace the role of the relatively large photomultiplier tubes with solid-state devices that do not require temperature control or compensation.

A fast, large area solid-state UV detector based on the WBG semiconductor zinc oxide (ZnO) has been recently developed at GRC. The proof-of-concept detector was fabricated on commercially available bulk single-crystal undoped ZnO. Inter-digitated finger electrodes and contact pads were patterned via photolithography and formed by sputtered silver, as shown in Figure 3. The device tested had an active area of 1 mm by 2 mm (2 mm²), designed to have a 1 ns response time with 10 V applied bias voltage which in a bridge circuit can detect small, fast pulses of UV light like those required for Cherenkov detectors.

The ZnO-based detector was demonstrated to be sensitive to UV light at 254 nm, slightly less so at 370 nm, and not sensitive to room lighting (about 430-630 nm). Compared to commercial SiC and GaP detectors tested in parallel, this detector also demonstrated improved sensitivity to UV than the existing devices.

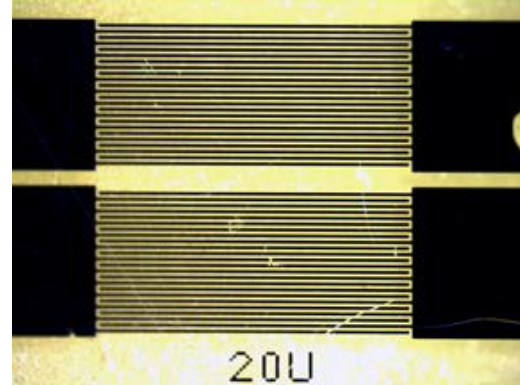


Figure 3 – Proof of concept ZnO-based UV detectors with 20 μ m electrode spacing. The sizes of the inter-digitated finger areas are 1 mm by 2 mm.

WBG LET detector stacks: The application of silicon carbide (SiC) as LET detectors is based on the material’s wide band gap and high displacement energy. These properties give several advantages over silicon-based detectors. Sensors and electronic devices made from SiC have much better resistance to radiation damage from energetic charged particles that can form defects in the semiconductor [7]. The wide band gap nature of SiC also makes measurements by the detectors unaffected by thermal drift due to sun/shade transitions.

Micro-electro-mechanical-system (MEMS) based devices fabricated from silicon carbide (SiC) to conduct low-noise neutron and alpha particle spectrometry have been reported in the context of reactor core monitoring [8]. A low power, low mass space radiation detector prototype system (as shown in Figure 4) using a SiC Schottky power diode was developed at GRC for dosimetry use during future lunar missions [9]. Recently a large area (70 mm²) SiC radiation detector based on High Purity Semi-Insulating SiC was fabricated demonstrating the feasibility in achieving the large LET detectors needed for the CFIDS concept, as shown in Figure 5.

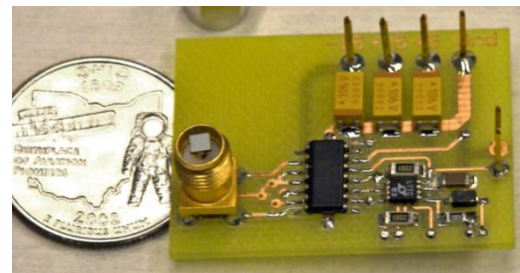


Figure 4 – SiC Dosimeter prototype developed for the NASA Exploration Technology Development and Demonstration Project.

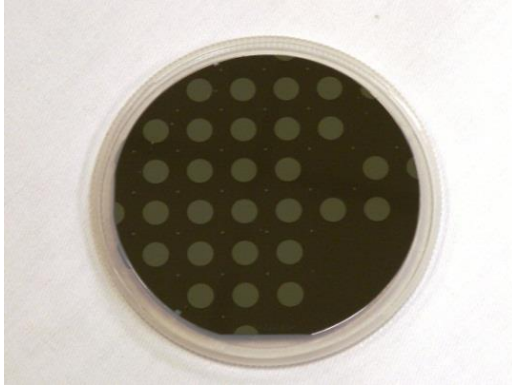


Figure 5 – Large area (70 mm²) SiC radiation detectors fabricated in an array for dicing.

The current design of the spherical space radiation detector requires four LET detectors per stack with low-Z PTFE absorbers between the detectors. Modelling of the stacked system with SRIM and GEANT Monte Carol simulations has shown that a 4-fold coincidence of SiC detectors providing LET information, low energy protons can be distinguished from high energy electrons and the stack has the capability to measure the ion energy.

Benefit: The CFIDS instrument with next generation detector technologies will require lower power and less mass than traditional instruments. The signal conditioning electronics for all the detectors in this concept is expected to require no more than 15 W, and should fit in a 10 by 10 by 10 cm³ space separate from the detectors. With less physical and electrical demands on science platforms, the instrument can be flown on CubeSat and other small satellite platforms beyond LEO.

References:

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