PROCEEDINGS OF SCIENCE

Gamma irradiation of ITk silicon strip modules with early breakdown

Emily Duden,[a,*] **Jammel Brooks,**[b] **Aware Deshmukh,**[c] **Vitaliy Fadeyev,**[c] **Jim Kierstead,**[d] **David Lynn,**[d] **Meny Raviv Moshe,**[a] **Stefania Stucci,**[d] **Quinn Paddock**[c] **and Luise Poley**[e,f]

[a] *Brandeis University,*
415 South Street, Waltham, USA
[b] *Indiana University,*
107 S Indiana Ave, Bloomington, USA
[c] *Santa Cruz Institute for Particle Physics, University of California Santa Cruz,*
1156 High Street Santa Cruz, USA
[d] *Brookhaven National Laboratory,*
98 Rochester St, Upton, USA
[e] *TRIUMF,*
4004 Wesbrook Mall, Vancouver, Canada
[f] *Simon Fraser University,*
8888 University Dr W, Burnaby, Canada

E-mail: emily.rose.duden@cern.ch

In preparation for the forthcoming High-Luminosity phase of the Large Hadron Collider, the ATLAS experiment is working on major upgrades to its detector systems. A key component of these upgrades is the replacement of the current Inner Detector with the all-silicon Inner Tracker (ITk). The ITk consists of a Pixel Detector close to the beamline surrounded by a Strip Detector, which is made up of silicon strip modules. The silicon strip modules are operated at a bias voltage of up to 500V to ensure a 10:1 signal-to-noise ratio at the end of the ITk's lifetime. In such modules it is crucial to detect early breakdown, where current increases exponentially with increasing bias voltage below the 500V threshold. This contribution presents results from an irradiation campaign to investigate potentially beneficial effects of gamma irradiation on modules showing an early breakdown after gluing. Modules were exposed to an ionizing dose of 11 krad, corresponding to the dose accumulated after one week of operation in the HL-LHC. Preliminary findings suggest a discernible improvement in the breakdown voltage. These results mark a significant step towards establishing a reliable pattern of component recovery in the earliest stages of detector operations.

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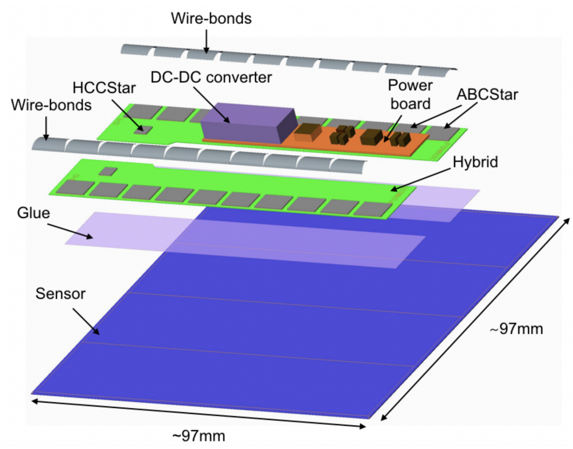


Figure 1: Expanded view of ITk short-strip barrel module [1].

1. Introduction

The High Luminosity LHC will produce an integrated luminosity an order of magnitude greater than that previously collected and thus provide sensitivity to sectors of physics currently beyond the reach of analyses. To achieve this luminosity, the LHC pileup will increase by more than a factor of three, presenting a challenging environment for the ATLAS detector. The associated radiation and track density increases will render the current ATLAS Inner Detector inoperable. As a result, it will be replaced with the new, all-silicon ATLAS Inner Tracker, or ITk[1]. The ITk is comprised of a pixel detector close to the beamline surrounded by a strip detector. Strip Detector modules consist of an approximately 100 cm^2 silicon sensor with necessary electronics glued directly on top. Front-end electronics are hosted by printed circuit boards called "hybrids" and powering and control functionality is provided by power boards. The ITk Strip module composition is shown in Figure 1.

Modules must receive a reverse bias voltage of up to -500V during detector operation to ensure appropriate end-of-lifetime signal to noise ratios. Thus, IV scans, in which various bias voltages are applied to the sensor and the resulting sensor leakage current is measured, are performed at each stage of module production. During assembly, a sensor occasionally exhibits early breakdown (Figure 2), in which the current increases exponentially below the required -500V bias voltage threshold. Several reasons for early breakdown have been identified, including

- Mechanical damage (chips, cracks, or scratches on the sensor)[2]
- Static charge build-up[3]
- Long-term application of bias voltage[4]
- Glue on the sensor guard ring[5]

Previous results show early breakdown in bare sensors due to presence of static charges was cured by 11krad of gamma irradiation with a ^{60}Co source [3], an equivalent dose to just one week in the HL-LHC. To determine whether modules with early breakdown might be similarly

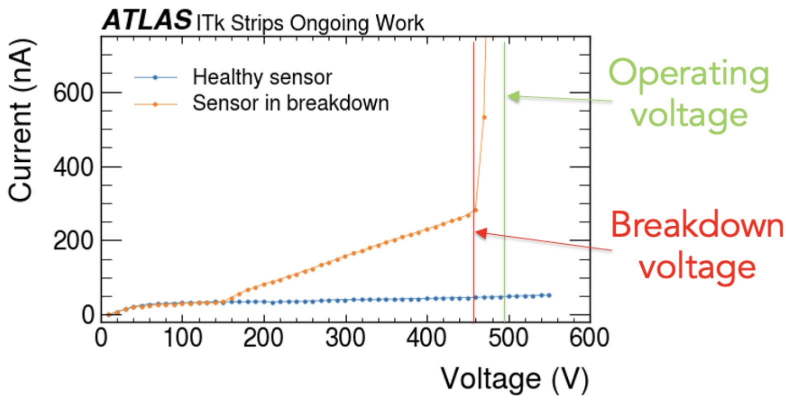


Figure 2: IV scans for a healthy sensor and a sensor in breakdown. The sensor in breakdown is characterized by exponentially increasing current before the -500V threshold voltage required for detector operation.

recovered, similar irradiation was performed on three modules. This paper presents the results of this irradiation campaign, with the aim of determining whether early breakdown can be reliably cured during detector operation.

2. Irradiation procedure

The three modules selected for irradiation, which exhibit early breakdown or close to early breakdown, are show in Table 1. The first two, BNL-PPB2-MLS-242 and BNL-PPB2-MLS-243, had breakdown voltages of approximately -520V and -450V respectively. These modules exhibited breakdown after hybrids were glued on the sensor but before power board gluing. They are considered "unbonded" as no front-end electronics have been wirebonded to the strips. The last module, BNL-PPB2-MLS-213, notably has visible glue on the guard ring, a known cause of early breakdown[5].

Irradiated module	Breakdown voltage	Assembly stage	Suspected breakdown cause
BNL-PPB2-MLS-242	~ 520V	unbonded	unknown
BNL-PPB2-MLS-243	~450V	unbonded	unknown
BNL-PPB2-MLS-213	~ 500V	completed module	glue on the guard ring

Table 1: Description of irradiated modules.

An IV scan was performed on all modules before irradiation. Modules were then placed in a moisture-proof bag with desiccant, flushed with dry air, and sealed. Irradiation was performed at the Brookhaven National Laboratory (BNL) Gamma Irradiation Facility, where modules received 11krad of ionizing radiation from a ^{60}Co source (Figure 3). Immediately after irradiation, IV scans were performed on all modules. Additional IV scans were taken in the following days and weeks. Module BNL-PPB2-MLS-213 was irradiated in 2krad increments, with IV scans performed after each step.

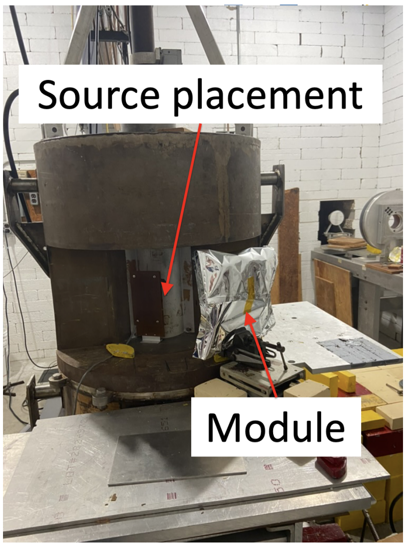


Figure 3: BNL Gamma Facility module irradiation setup. The module is sealed in a moisture-proof bag.

3. Results

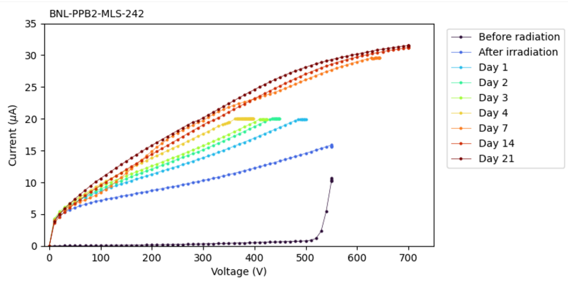
IV scans for modules BNL-PPB2-MLS-242 and BNL-PPB2-MLS-243 were conducted at reverse bias voltages up to -700V. Module BNL-PPB2-MLS-213 was biased only up to -550V to protect module electronics after bonding. IV scans before and after irradiation are shown in Figure 4.

After irradiation, leakage current increases by several orders of magnitude due to an expected increase in interface charge that is also observed in bare sensors[3] Additionally, sensors appear to self-anneal in the weeks following irradiation, resulting in increased current before stabilization. All three modules demonstrated an increase in breakdown voltage beyond measurable thresholds.

4. Conclusions and future work

Gamma irradiation was performed on three silicon strip modules to evaluate the effect on breakdown voltage. In all cases, breakdown voltage increased past a measurable voltage after the modules received an 11krad dose. Notably, early breakdown was cured in one module with visible glue on the guard ring, demonstrating that breakdowns caused by this phenomena can be mitigated with irradiation. However, with only one such module tested and the possibility of early breakdown due to glue on the guard ring self-healing over time, our statistics are too low to draw definitive conclusions.

Modules will experience an 11 krad dose of ionizing radiation within a week of operation in the HL-LHC. Thus, these results indicate that early breakdown can be cured at the start of detector operation. More data is needed to establish a reliable pattern of component recovery. As a result, BNL plans to irradiate modules with early breakdown discovered during assembly.



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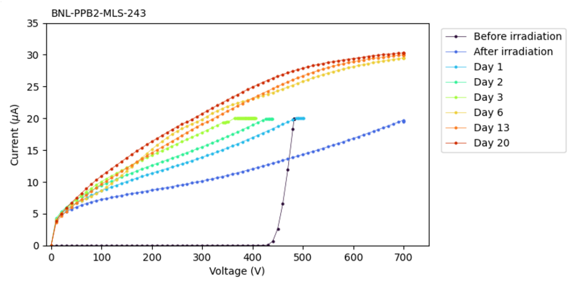

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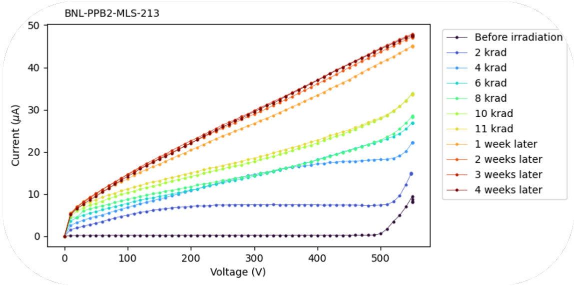

(c)

Figure 4: IV scans before and after irradiation for (a) module BNL-PPB2-MLS-242[6], (b) module BNL-PPB2-MLS-243[6], and (c) module BNL-PPB2-MLS-213.

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