Gamma-ray Large Area Space Telescope

(GLAST)

Large Area Telescope (LAT)

Results from the Testing of the GLAST LAT SSD Prototypes

(Copies of Transparencies from the GLAST LAT SSD Review Jan 30, 2001)
<table>
<thead>
<tr>
<th>Revision</th>
<th>Effective Date</th>
<th>Description of Changes</th>
</tr>
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<tbody>
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</table>
1. **PURPOSE**
The results from the test of 35 GLAST LAT SSD prototypes are presented. The tests were performed to qualify HPK as a GLAST SSD vendor.

2. **SCOPE**
The results of electrical and mechanical tests of the GLAST LAT SSD prototypes are presented. Both the GLAST LAT SSD and test structures were tested at SLAC/UCSC, Hiroshima U. and INFN-Pisa and compared to the tests performed at the manufacturer HPK.

3. **DEFINITIONS**

3.1 **Acronyms**
- **GLAST**: Gamma-ray Large Area Space Telescope
- **LAT**: Large Area Telescope
- **SSD**: Silicon Strip Detector
- **TBR**: To Be Resolved
- **TBB**: To Be Determined

3.2 **Definitions**
- **AC Coupling**: The Al metal electrode is covering almost the whole length of the p+ implant, separated from it by a dielectric material
- **AC Pad**: Pad to access the Al metal electrode on the strips
- **Active Area**: Area of the Volume from which charge is collected on the strips in \(<1\mu s\)
- **Buyer**: Institution procuring GLAST LAT SSD
- **C**: Capacitance
- **Contract**: Purchase agreement to procure GLAST LAT SSD’s
- **Coupling Capacitor**: Capacitor formed by Al metal electrode, dielectric and implant
- **Customer**: Institution involved in the procurement and testing of GLAST LAT SSD’s
- **C-V**: Measurement of body capacitance (C) as a function of voltage (V)
- **DC coupling**: Al metal electrode and implant in ohmic contact.
- **DC Pad**: Pad to access the strip implant
- **Bias Resistor**: Resistor connecting every implant to the bias ring
- **Bias Ring**: Implant surrounding the active area, connects to bias resistors
- **Fiducial**: Physical mark in the Al metal layers for alignment and metrology
- **Guard Ring**: Implant outside the bias ring without bias connection (“floating”)
- **HPK**: Hamamatsu Photonics
- **I-V**: Measurement of leakage current (I) as a function of voltage (V)
- **N-sub**: Substrate contact on the detector front
- **Pad**: Area of the Al metal layer accessible through the passivation
- **Pitch**: Distance between strip centers
- **Passivation**: Topmost layer covering of inert translucent material
- **Seller**: SSD Manufacturer, Vendor
- **Sensor**: Silicon Strip Detector (SSD)
- **um**: Micro meter (10^{-6} meter)
- **us**: Micro second (10^{-6} second)
- **V**: Voltage, Volt
4. REFERENCES
BTEM prototype detectors P. Allport et al, SLAC-Pub-8471, June 2000.
Flow-down of GLAST LAT SSD Spec’s H. Sadrozinski, SCIPP 00/33.
GLAST LAT SSD Specifications LAT-DS-00011-08
GLAST LAT SSD QA Provisions LAT-DS-00082-01
GLAST LAT SSD Testing Procedures LAT-DS-00085-01
Drawings SSD LAT-DS-00026
Test structures LAT-DS-00027

5. SSD TESTING RESULTS
Tests were performed as required in LAT-DS-00011-08 and described in LAT-DS-00085-01. A data base developed by INFN-Pisa was used to store the data (www.pi.infn.it/glast)
a. Overview: H. Sadrozinski (UC Santa Cruz)

Specifications of the GLAST Silicon Strip Detectors (SSD's)

Hartmut F.W. Sadrozinski
Univ. of California Santa Cruz

• GLAST Overview: Instrument -> Tracker (TKR) -> SSD
• Requirements
• Prototyping History
• Procurement History and Schedule
• Testing and QA
• Validation -> next talk (T. Ohsumi: electrical, A. Brez: mechanical, T. Handa: Irradiation)

Principle of Operation vs. Artist's View

charged particle anticoincidence shield conversion foil

Interface Requirements Document (IRD) defines the Space environment and the limited resources, including engineering margins (e.g. 5x for total dose).

The IRD requires trades in:
- **Power**
  - number of channels (SSD pitch),
  - ASIC power consumption
  - SSD strip capacitance (ladder length ~36cm, strip geometry),
  - SSD biasing power <4W for 1k SSD
- **Radiation**
  - Expected 5Y total dose 1kRad (half in low energy protons), design for 5kRad
- **Heat management**
  - operate SSD at 25°C max
- **Launch weight, vibrations**
  - Footprint of SSD
  - Strength of SSD wafers (<100>)
  - Strength of glue joints

Predictability of Performance

- Poly-silicon biasing
- Oxide-Nitride combination for coupling dielectric
- Low leakage current
- Low depletion voltage
- Silicon dioxide passivation
- Large Aluminum overhang
- Balance strip width effects: capacitance vs. field
- Accurate mask alignment
- No voltage across saw-cut

Ease of Testing

- AC coupling
- Large, redundant bonding/probing pads
- N-sub contact on top

Ease of Assembly

- Separate fiducials for alignment, bonding and metrology
- Accurate control of saw-cut

- Numbers: GLAST is modular:
  - 16 flight (+2 calibration towers) with 18 x-y SSD planes each
  - 4 x SSD per plane (4 ladders with 4 SSD each)
  - Number of SSD needed:
    - 10368 (+ 5% spares + 5% wastage) = 11,500
  - Total SSD Area: 83m², ~1M channels, ~5M wire bonds
  - Simple mechanical assembly method:
    - Butt-join and wire-bond 4 SSD to “ladders”
    - Glue 4 Ladders onto both sides of 3cm thick panels (“trays”)
    - Attach MCM on the side of the panel via 90° interconnect
    - Stack trays into towers
  - QA:
    - Tight specification increase reliability of SSD
    - Charge manufacturer with all detailed testing
    - Test important parameters before further integration step

Science Requirements Document (SRD)

- Derives the GLAST LAT instrument performance requirements from the GLAST science objectives.
- Sets requirements and goals for several instrument parameters, e.g.:
  - Effective Area = (Active area * conversion probability * reconstruction efficiency)
  - Cosmic Ray rejection
- The science requirements flow down into the TKR and SSD specifications.

GLAST LAT Committees on TKR issues:

- SSD Configuration: April/May 2000 (“GLSSDGW”) LAT-TD-00470
- Converter Optimization: June/Nov 2000 (“GTCC”) LAT-TD-00239-01

These Committees specified the footprint of the instrument,
the size of the trays, and the layout and size of the SSD, taking into account the SRD and the IRD (see next)

The following issues were addressed in the SSD design (“GLSSDGW”) and are reflected in the specification

<table>
<thead>
<tr>
<th>Issue</th>
<th>Action</th>
<th>Reason</th>
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<tbody>
<tr>
<td>Leakage Current</td>
<td>Minimize</td>
<td>Power, Noise, μ-Discharge</td>
</tr>
<tr>
<td>Depletion Voltage</td>
<td>Minimize</td>
<td>Power, Safety, Efficiency</td>
</tr>
<tr>
<td>Detector Thickness</td>
<td>Optimize</td>
<td>Signal vs. Depletion Voltage</td>
</tr>
<tr>
<td>Saw-cut dimensions</td>
<td>Control</td>
<td>Mechanical assembly</td>
</tr>
<tr>
<td>Number of bad strips</td>
<td>Minimize</td>
<td>Efficiency, C.R. rejection</td>
</tr>
<tr>
<td>Strip geometry</td>
<td>Optimize</td>
<td>Capacitance vs. μ-Discharge</td>
</tr>
<tr>
<td>Mask Alignment</td>
<td>Control</td>
<td>μ-Discharge, Testing</td>
</tr>
<tr>
<td>Dielectric of Caps</td>
<td>Oxide-Nitride</td>
<td>Poroholes, Bondability</td>
</tr>
<tr>
<td>Radiation Effects</td>
<td>Measure</td>
<td>Leakage current, Capacitance, Strip isolation, Bias resistor</td>
</tr>
<tr>
<td>Guard ring/Edge design</td>
<td>Narrow</td>
<td>Leakage current, active area</td>
</tr>
<tr>
<td>Bonding/probe pads</td>
<td>Redundant</td>
<td>Repairs, Automatic Test</td>
</tr>
<tr>
<td>Fiducials</td>
<td>Dedicated</td>
<td>Ease &amp; QC of assembly</td>
</tr>
</tbody>
</table>

Leakage Current: (av)<240nA, max<800nA

- The low detector leakage current is an indication of a mature manufacturing process.
- A low detector leakage current specification allows us to eliminate the time consuming leakage current measurement on every strip and measure instead the entire current on the detector only.
- The leakage current has to be kept low to reduce shot noise (35cm long strip)
- Single detector strips with ~20nA has increased noise level
- One of the major limitations for the GLAST LAT is the available power. The power assigned to the detector biasing is 4W at end of mission, mainly due to radiation damage.
- At 150V, this is 2.6W/SSD, and the initial detector current should be a small fraction of this number.
- Because we observe a factor 2 increase of the leakage current from production test to finished ladders, our specs mean an initial current of about 500nA/SSD, about 20% of the end of mission limit.
Detector Thickness: 400um

- The 7.6K requires sufficient S/N as specified. The signal is proportional to the path length. For normal incidence, it’s the thickness (400um), for large angles it’s the pitch (226um). So if S/N is a problem, the pitch has to be increased as well, which hurts the science.
- The depletion voltage has to be kept low to reduce power and noise. We set an upper limit of 150V, but would like to operate at 100V (like in the BTEM).
- The depletion voltage depends on the square of the detector thickness and the inverse of the resistivity. Thus changing the thickness from 400um to 500um requires an increase in resistivity of 36%, from 4KΩ-cm to more than 5KΩ-cm. We are told the wafer manufacturers can’t guarantee a stable supply of 6" wafers with resistivity higher than 4KΩ-cm on our time scale.
- We see now depletion voltages at 120V, which would increase to 185V with 500um thickness at the same resistivity. This is too high.
- Our principle supplier prefers 400um detectors and fabrics (exclusively?) in that thickness. Mixing different thickness sounds like an assembly nightmare.

Prototypes of GLAST SSD with Hamamatsu Photonics (HPK)

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<td>180</td>
<td>100</td>
<td>180</td>
<td>100</td>
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<tr>
<td>Pitch (um)</td>
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<td>100</td>
<td>150</td>
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<td>100</td>
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<tr>
<td>Thickness (um)</td>
<td>180</td>
<td>100</td>
<td>180</td>
<td>100</td>
<td>100</td>
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<tr>
<td>Bounding</td>
<td>180</td>
<td>100</td>
<td>180</td>
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<td>100</td>
</tr>
<tr>
<td>Bounding   Pt</td>
<td>180</td>
<td>100</td>
<td>180</td>
<td>100</td>
<td>100</td>
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<tr>
<td>Copper (um)</td>
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<td>100</td>
<td>150</td>
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<td>150</td>
<td>100</td>
<td>150</td>
<td>100</td>
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<tr>
<td>L/S</td>
<td>150</td>
<td>100</td>
<td>150</td>
<td>100</td>
<td>100</td>
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<tr>
<td>L/S</td>
<td>180</td>
<td>100</td>
<td>150</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>L/S</td>
<td>180</td>
<td>100</td>
<td>150</td>
<td>100</td>
<td>100</td>
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Additional Prototypes:
- Micron (UK), STM (Italy), CSEM (Switzerland) (7)

Testing is a large part of the SSD / tray manufacturing process

4 Step Procurement Process

1998: Market survey (RFP), contract 12 manufacturers
- >6" wafers
- > Identify cost-drivers in fabrication and testing
1998-2000: Prototyping with 3 manufacturers, involve them in writing specs
1998-1999: Purchase large number (>500) of SSD, build BTEM, 2 month beam test at SLAC

Fabrication and Test Plan of Flight Sensors:
- prototyping (Jun 2000 – Dec 2000),
evaluation (Dec 2000 – Jan 2001),
ramp-up (Feb 2001 – Aug 2001),

Tray Production is embedded in the GLAST LAT Schedule

Promoted SSD (500 SSD/month)
- 2001: 500 SSD/month
- 2002: 1000 SSD/month

Each wafer has a GLAST2000 SSD and a GLAST cut-off.
We are now establishing the correlation between SSD and test structure performance.

Acceptance QC: flight sensors
- Order high quality SSD > testing of detectors is done by vendor:
  - i-V, C-V, bad Channels, Process Parameters, NO single channel current!
  - Measurement of parameters crucial for assembly by GLAST assembly institution:
    - i-V (and possibly of dimensions)

Process Control: test structures
- Thorough test on test structures, one out of every lot (48) by Hiroshima U. & INFN:
  - Measures at detector parameters specified in specifications
  - Test wire bonding on test structures

Assembly QA: flight sensors / ladders
- Testing after bonding and encapsulation by GLAST assembly institution:
  - Vital parameters (i-V of ladders and coupling caps on every strip)
  - Test before tray assembly:
    - i-V on ladders

This program is based on our experience with the >500 HPK SSD in the Beam Test Engineering Module (BTEM, SLAC-8471).
b. Mechanical Tests: A. Brez (INFN-Pisa)

**GLAST SSD mechanical measurements**

- **Instruments and methods:**
  - 15cm x 30cm micrometric computer assisted table with 5µm resolution over the whole range
  - Microscope with a computerized CCD camera with 768 x 576 pixels
  - pixel size = 0.64µm
  - view area = 500 µm x 370 µm
- **Dimensional check:** distance from strip 1 to strip 384:
  - Nominal distance = 87324 µm
  - Measured distance = 87329 ± 5 µm
  - Measured pitch = 228.01 ± 0.01 µm

**DICING MEASUREMENTS**

- **Statistics of the Dicing Errors**
  - Front cut orthogonal to the strips
  - Side cut parallel to the strips

- **Wafer Thickness**
  - (10µm sensitivity measurement)
  - A moderate bending (~10µm) has been measured on a wafer

**Relevant measurements for the device's assembly:**
- marker_edge dist. ~ 300µm
- marker_edge dist. = 200µm
- requirement: 0µm ± 2x, 2y = 20µm
- correction parameters:
  - $D_{x} = f_{x} + f_{y}/2$
  - $D_{y} = f_{y}$
c. Electrical Tests: T. Ohsugi (Hiroshima U.)

Depletion Voltage agrees well among different measurements.
Capacitances at depletion indicate good thickness uniformity.

Don’t expect variation of inter-strip capacitance wafer-to-wafer.
Expect variation of body capacitance wafer-to-wafer only due to thickness variations.

Strip capacitance
Backplane (Body) Capacitance: 1860pF/384Strips/8.75cm = 0.55pF/cm
Inter-strip Capacitance: 5.5pF/0.82/8.75 = 0.77pF/cm
Total strip capacitance = 1.3pF/cm (Spec <1.5pF)

Coupling capacitance varies with thickness of dielectric
- Measure between 550 and 650pF, (Spec >500pF).

The 35 HPK GLAST2000 SSD exceed the specifications.
The measurements at HPK and GLAST correlate very well.

- The bad channel count continues to be 10x lower than specified
- The leakage current is very low, below the specifications. We plan to rely on the HPK measurements.
- No e-discharge observed up to 200V bias
- Depletion voltages are low (~60V) except for a batch of 5 SSD.
- Radiation damage is well in hand and understood.
- Based on the measurements, we see no obvious need to change the parameter values at which we reject SSD’s.
- Measurements of the correlation between full SSD and test structures are being finished to allow the QA plan to be finalized.

- Leakage Current depends on Temperature, Humidity, Time
- Use HPK measurement, below specs.

Bad strips are shorted coupling capacitors, open connections or strips shorted together.
- A total of 4 bad strips were found by HPK: 0.03% (Spec <0.2%)
- Hiroshima found the shorted capacitor,
- Hiroshima had 3 disconnected Bias resistors
- SLAC checked 2 SSD and found no bad strips
- INFN Pisa measured ALL capacitors on 10 detectors and found NO bad channels.

The bad channel rate is 10x better than specified.
The measurements at HPK are confirmed by GLAST

- Bias Resistance
  Spec: Polysilicon, 20MΩ <R <80MΩ, wafer uniform to 10MΩ
  Observed ~35-40MΩ, very uniform, agrees with HPK

- Al Trace Resistance
  Spec: R < 50Ω
  Observed R=25-30Ω, very uniform, agrees with HPK

- Interstrip Isolation
  Spec: >1GΩ, Observed >1TΩ
d. Irradiation Tests: T. Handa (SLAC)

Validation of the GLAST Pre-production SSD  
-- Radiation Damage --

Takanobu Handa  
SLAC  
Jan. 30, 2001

Review of the GLAST SSD Specifications

- Radiation dose expected : 1 krad / 5 years
- x5 engineering margin : 5 krad
- Our tests (x2 over requirement) : 10 krad
- $^{60}$Co gamma-ray irradiation at UCSC : 10 krad
- $^{60}$Co gamma-ray irradiation at Hiroshima : 8 krad

**Specs**

<table>
<thead>
<tr>
<th>irradiation level</th>
<th>leakage current at 150V bias (corrected to 25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 krad</td>
<td>Live(76.7 cm$^2$) 3.0 nA/cm$^2$</td>
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<tr>
<td></td>
<td>Baby(4.62 cm$^2$) 5.9 nA/cm$^2$</td>
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<tr>
<td></td>
<td>Skinny(1.60 cm$^2$) 12.4 nA/cm$^2$</td>
</tr>
<tr>
<td>10 krad</td>
<td>Live(76.7 cm$^2$) 44 nA/cm$^2$</td>
</tr>
<tr>
<td></td>
<td>Baby(4.62 cm$^2$) 53 nA/cm$^2$</td>
</tr>
<tr>
<td></td>
<td>Skinny(1.60 cm$^2$) 64 nA/cm$^2$</td>
</tr>
</tbody>
</table>

* 150V bias voltage  
* Temperature correction to 25°C

**Results**

<table>
<thead>
<tr>
<th>irradiation level</th>
<th>leakage current at 150V bias (corrected to 25°C)</th>
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</thead>
<tbody>
<tr>
<td>0 krad</td>
<td>average ~ 230 nA, max = 251 nA</td>
</tr>
<tr>
<td>10 krad</td>
<td>3360 nA</td>
</tr>
</tbody>
</table>

**Smaller total strip capacitance (C_total) is favorable for lower readout noise**

$C_{total} = C_{inter-strip(all neighbor)} + C_{back-plane}$

$C_{inter-strip(all neighboring pair)} = C_{inter-strip(one neighboring pair)} / 0.83$

$C_{back-plane} = 0.53 \text{ pF/cm}$

We measured $C_{inter-strip(one neighboring pair)}$

**Strip isolation**

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<thead>
<tr>
<th>irradiation level</th>
<th>leakage current at 150V bias (corrected to 25°C)</th>
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</thead>
<tbody>
<tr>
<td>0 krad</td>
<td>&lt; 1.5 pF/cm</td>
</tr>
<tr>
<td>10 krad</td>
<td>&lt; 1.6 pF/cm</td>
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</table>

**Specs**

<table>
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<th>leakage current at 150V bias (corrected to 25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 krad</td>
<td>&gt; 1 GΩ</td>
</tr>
<tr>
<td>10 krad</td>
<td>&gt; 1 GΩ</td>
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</table>

**Results**

<table>
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<tr>
<th>irradiation level</th>
<th>leakage current at 150V bias (corrected to 25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 krad</td>
<td>~ 1000 GΩ</td>
</tr>
<tr>
<td>10 krad</td>
<td>~ 1000 GΩ</td>
</tr>
</tbody>
</table>
Bigger $C_{coupling}$ is better not to lose the signal charge

**Specs**

<table>
<thead>
<tr>
<th>0krad</th>
<th>$&gt;500$ pF</th>
</tr>
</thead>
<tbody>
<tr>
<td>10krad</td>
<td>$&gt;500$ pF</td>
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</tbody>
</table>

**Results**

<table>
<thead>
<tr>
<th>0krad</th>
<th>$\sim560$ pF</th>
</tr>
</thead>
<tbody>
<tr>
<td>10krad</td>
<td>$\sim565$ pF</td>
</tr>
</tbody>
</table>

GLAST HPK pre-production detectors meet our specifications after 10krad gamma-ray irradiation on these parameters:

- Leakage current
- Inter-strip capacitance
- Inter-strip resistance
- Coupling capacitance