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The Silicon Tracker for the GLAST Large Area Space Telescope *

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Abstract

GLAST is a Gamma Ray Large Area Space Telescope, which contains a large silicon vertex detector. The construction of the Beam Test Engineering model of GLAST is discussed, along with plans for the future construction of the final instrument. Special attention is placed on what was learned from the silicon tracker construction and the current status of the GLAST tracker.

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1 Introduction

The Gamma Ray Large Area Space Telescope (GLAST) mission is a silicon tracker, satellite based, gamma ray pair conversion telescope to be launched in 2005 [1]. The principal objectives of the GLAST mission involve the observation of energetic gamma rays, starting at 20 MeV and extending as high as TeV energies [1]. Observational data in this range are limited. In the past, gas chamber detectors were used to collect data. GLAST will employ 74 m^2 of silicon microstrip detectors to probe this energy regime. The GLAST Large Area Telescope (LAT) will provide overlap (50 GeV to 1 TeV) between past satellite observations and ground–based telescopes. It will offer tremendous opportunity for discovery in high–energy astrophysics by probing these systems with >50 times better sensitivity than previous missions.

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The GLAST telescope will be made up of 16 individual towers of silicon detectors. Each tracker will have a CsI calorimeter beneath it and the entire telescope will be covered with an Anti-Coincidence Detector (ACD). Figure 1 shows an artist's conception of the telescope.
The silicon tracker for the GLAST telescope will consist of more than one million readout channels. To verify the design, and construction techniques, a beam test engineering model (BTEM) was constructed and tested at a fixed target end station at the Stanford Linear Accelerator Center (SLAC). The BTEM corresponds structurally to 1/16 of the final instrument and about 4% of the total silicon. The BTEM tracker is a large, 2.7 m^2 silicon tracker, with 41600 readout strips and currently the largest inventory of good quality high yield detectors from 6 inch wafers. All the detectors, ladders and towers are interchangeable within the GLAST tracker. This is to keep a modular design. The only items not modular are the trays. Trays have different converter thickness reducing modularity (§ 5).

The BTEM consists of a CsI calorimeter to measure the deposited energy, an Anti-Coincidence Detector (ACD) for background rejection and the tracker for measuring particle direction. The BTEM was tested in a beam of positrons, hadrons, and photons in December 1999 and January 2000. The details of construction have been described in earlier papers [3]. The details of the tracker construction and plans for future construction are described here.

2 Construction of the Beam Test Engineering Model

Three or five detectors were edge-glued to each other (fig 2) to form a ladder. As a ladder the detectors were wirebonded together and then the wirebonds were encapsulated. The ladders were then placed onto the top and bottom of aluminum frames that supported the ladders and electronics. There is no structural support or electronics attached to the ladders until they are attached to the trays. The silicon tracker is a pair conversion telescope, the passive converter is lead (tungsten is being considered for the future). There are two thickness converters used, described in § 5. These trays are stacked one on top of the other until they form a single tower with seventeen trays and 16 X-Y layers of silicon (the topmost and bottommost trays only have silicon on the side towards the inside of the tracker). Trays are stacked such that there is only one plane of silicon after each converter. Each plane is made from two layers of silicon 3.2 mm apart, whose strips are oriented perpendicular to each other so that both an X and Y position can be measured after each conversion (fig 3).

The tracker also employs a self trigger mechanism that triggers an event when three consecutive planes are hit (six consecutive layers of silicon). Details of the front end electronics can be seen in [4].

Description	**4 inch**		**6 inch**		**Total**	
	Number	%	**Number**	%	**Number**	%
Good quality Detectors	280	94.6	251	98.8	531	**96.2**
Runaway or unstable leakage current	1	0.3	0	0.0	1	**0.2**
Unstable current after ladder assembly	13	4.4	3	1.2	16	**2.9**
Losses due to handling	2	0.7	0	0.0	2	**0.4**
Total	**296**	**100.0**	**254**	**100.0**	**550**	**100.0**

Table 1: Silicon yield during the GLAST beamtest construction.

3 Silicon Detectors

The silicon detectors used in the beamtest were all single sided 400 μm thick high resistivity n-type silicon with a pitch of 194 μm. A drawing of the detector layout is shown in fig 4. The silicon for the beamtest came from 6 inch and 4 inch wafers, with detectors sizes of 64.0×106.8 mm^2 and 64.0×64.0 mm^2 respectively. The detectors have 320 AC coupled strips with a 60 MΩ polysilicon bias resistor. The aluminum strip width is 52 μm. Detectors were patterned with bypass strips to allow bad channels to be bypassed. However, the number of bad channels was so small that no bypass strips were used, and they are removed in the final design.

There were 550 detectors ordered from Hamamatsu Photonics: 296 from 4 inch wafers and 254 from 6 inch wafers. In addition we also received 5 detectors from Micron Semiconductor Ltd. from 6 inch wafers, similar in design to the Hamamatsu detectors.

3.1 Detector Yield

Table 1 shows the BTEM silicon yield. The numbers in this table only include the 550 detectors from Hamamatsu. Of the 5 Micron detectors, 3 had stable leakage currents and were used in the BTEM tracker. The overall yield for silicon detectors was 96.5% [2].

3.2 Bad Channels

Table 2 shows the progression of bad channels throughout the BTEM construction. When we received the detectors from the manufacturer the percentage of bad channels was 0.01%. After the ladders were constructed the bad channels were 0.05%. After the beamtest the number of bad channels increased to 0.10%, extremely low compared to typical silicon trackers.

Number of Bad Channels			
	Number	**Total channels**	**Percentage**
Before Assembly, individual detectors	25	176000	0.01%
After assembly into ladders	21	41600	0.05%
After Beamtest	42	41600	**0.10%**

Table 2: Bad channels during testbeam construction.

3.3 Leakage Current

All leakage currents throughout the testing process were measured at 100V. The average value was 3 nA/cm^2 and 2 nA/cm^2 for the 4 inch and 6 inch detectors respectively. Our initial specifications required the leakage current to be $<$ 50 nA/cm^2, but since the detectors we received were of such high quality, this requirement has been changed to $<$ 10 nA/cm^2 for the future.

4 Ladders

After receiving and testing the silicon detectors, they were assembled into ladders. All ladders in the BTEM tracker are the same length (32 cm), so ladders made from 6 inch detectors contain 3 detectors, and ladders made from 4 inch detectors contain 5 detectors.

4.1 Construction

The ladders were constructed using a device similar to the drawing in fig 2. The detectors were edge glued by referencing the edges of the detectors against Teflon pins. The glue was cured at 60°C for 2 hours. Some detector dicing cuts were inspected and the edges of the wafers were found to have chips on the order of 7 μm

The straightness of all the ladders was measured after the ladders were placed onto the trays. The straightness values from all ladders are shown in fig 5. This shows the average straightness of the ladders is 22 μm and most ladders fall within $10 - 30$ μm. This shows the edge referencing method works quite well. The tails in the distribution will be minimized by improving our gluing fixture. Details on construction can be found in [2].

Production Step	$\frac{I_{leak} \text{ after step}}{I_{leak} \text{ before}}$
Before Gluing	1
After Gluing	1.08 ± 0.28
After Wirebonding	1.61 ± 0.41
After Encapsulation	0.92 ± 0.29

Table 3: Tracking the leakage current for all ladders though the production steps. The leakage current did not significantly change after any step except for wirebonding, when the leakage current nearly doubled. This is consistent with other silicon trackers.

4.2 Leakage Current

During ladder production the leakage current was measured for

- Detectors: upon delivery (before edge gluing)
- Detectors: after edge gluing (before wire bonding)
- Ladders: after wire bonding
- Ladders: after encapsulation of wirebonds.

Table 3 shows how the ratio of leakage current per ladder changed before and after steps in production. There was no significant change except after wirebonding when the leakage current nearly doubled. There was also negligible change during the beam test. More details are found in [3].

4.3 Ladder Yield

Table 4 shows the breakdown of the ladder yield. The overall ladder yield was 97.7%. Details of the repairs can be found in [3].

5 Trays

The structural support modules of the GLAST tracker are the trays. An exploded view of the trays can be seen in fig 6. The trays are made of an aluminum closeout frame with an aluminum hexcel core. Carbon fiber sheets are glued to the top and bottom of the aluminum core to give the tray rigidity. On the top of the tray there is a kapton printed circuit glued to the carbon and the silicon ladders are glued on top of this circuit. On the bottom of the tray, there is a lead converter placed between the carbon sheet and the kapton circuit. Two different converter thickness are used, 3.5% X_0 towards the top of the tracker, 28% X_0 towards the bottom and the bottommost two trays containing no lead

Ladder Production Summary		
Good ladders	**130**	**93.5%**
rejected: high current	2	1.4%
rejected: large misalignment	1	0.7%
repaired: leaky detector	1	0.7%
repaired: handling errors	3	2.2%
repaired: glue failure	1	0.7%
repaired: other	1	0.7%
Total:	139	100.0%

Table 4: Ladder yield during beamtest construction. Overall yield was 98%

converters. The electronics are mounted on the sides of the tray to minimize dead area in the tracker.

The ladders were glued into the trays using shims for alignment. The positions of the ladders were measured after construction. The results showed that the ladders are systematically rotated within the tray an average of 0.007° with a random rotation of 0.01°. The ladders were 32 cm long, so an angle of 0.01° corresponds to a change of 55 μm over the length of the ladder. Preliminary alignment results from the beam test tracks show the alignment to be on the order of 60 μm. Better ladder placement methods are being developed for the future.
After tray construction the trays are stacked one on top of each other to make up the entire tracker (fig 7).

6 Future Plans

The final GLAST instrument will contain 16 towers each about the size of the BTEM and 74 m^2 of silicon microstrip detectors. The entire GLAST instrument is 3000 kg and uses 650W of power.

6.1 Detector changes

The detector design used in the final detector will be similar to the 6 inch wafer detectors used in the BTEM. The differences include: increasing the pitch to 228 μm for power consumption concerns; removing the bypass strips; detector dimensions are 8.95×8.95 cm^2; there will be 320 readout strips per detector. GLAST will contain 9216 detectors in 2304 ladders each with 4 detectors. The silicon to silicon glue also had to be changed to EPO-TEK 2216, a 24 hour room temp cure, to meet space qualifications.

Other changes to the instrument include: optimizing converter thickness, changing converter material (Possibly use tungsten instead of lead), and changing the way the electronics are mounted onto the trays. Thicker converters collect more photons, but at the price of reducing angular resolution. The converter material must be chosen to minimize thermal expansion mismatch with the silicon and have a small X_0 to convert photons. The way the electronics were mounted to the BTEM required bending the kapton circuit around a corner, making repairs difficult. The new design has the kapton attached to a curved piece that can be replaced, allowing for removal of the electronics.

6.2 Timeline

The timeline for GLAST: we have just finished the second beam test, and verified the construction and technology choices. In the summer of 2001 we will launch the BTEM instrument on a balloon to test it further. We will begin construction of the final flight instrument in 2001 and have it delivered in 2004. Two main production centers, one in the USA and the other in Italy, will handle tracker production.

7 Conclusion

The most important lesson for the silicon community that GLAST has taught us: single sided 6 inch wafer technology from Hamamatsu is very viable. The detectors from these wafers have an average of 2 nA/cm^2 leakage current at 100V and $< 0.1\%$ bad channels. During the GLAST BTEM high yields were achieved, 96.5% for detectors and 97.7% for ladders. This is attributed to simple robust designs that minimize handling and chances for errors. Having a modular design is very important in maintaining a high yield. Almost all of the components of the GLAST tracker are interchangeable, the exception coming from the different thickness converters.

For the GLAST design, there are still final developments to be made: ladder placement onto trays, converter silicon thermal expansion mismatch and the mounting of the electronics onto the trays. However, the beam test has demonstrated the construction methods are sound, especially the results of 22 μm straightness over 32 cm from referencing the diced edges of silicon wafers. This makes ladder construction much simpler and faster. GLAST is now ready to move into the balloon flight test and then into production of the final instrument.

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References

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[3] P. Allport *et al.*, *The Assembly of the Silicon Tracker for the GLAST Beam Test Engineering Model*, SLAC-PUB-8471. Proceedings of 4th International Symposium on Development and Application of Semiconductor Tracking Detectors, Hiroshima, Japan, 20-25 Mar 2000.

[4] V. Chen *et al.*, *The Readout Electronics for the GLAST Silicon-Strip Pair-Conversion Tracker*, Proceedings of 4th International Symposium on Development and Applications of Semiconductor Tracking Detectors, Hiroshima, Japan, 20-25 Mar 2000.

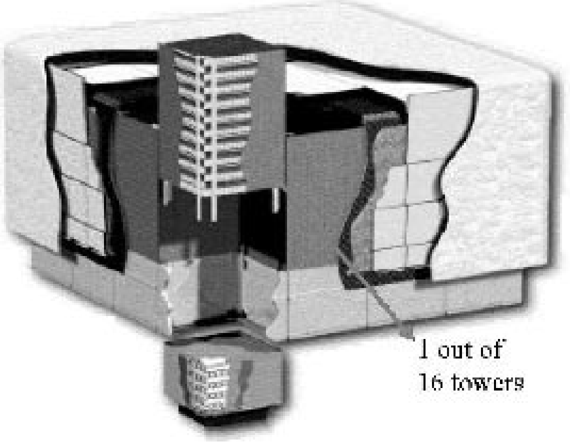

Figure 1: Artist's conception of GLAST telescope

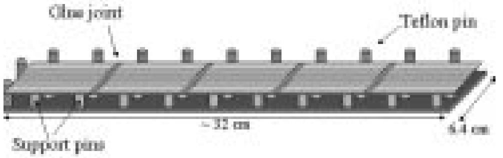

Figure 2: Jig used for gluing detectors into 32 cm long ladders. In the future the detectors will be pushed against the pins by springs and held in place by vacuum.

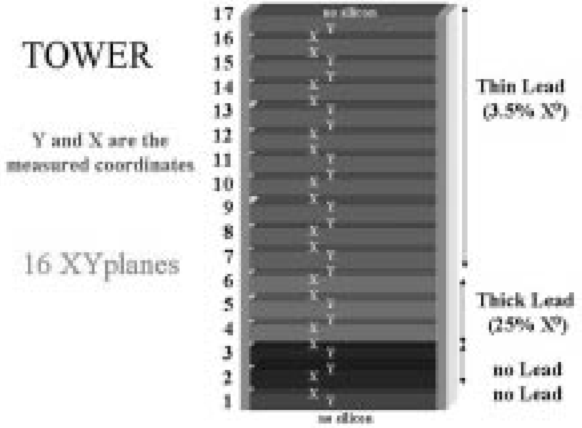

Figure 3: Arrangement of the silicon layers in the BTEM tracker design.

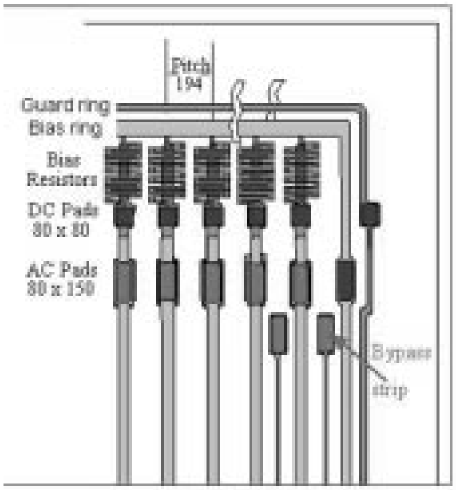

Figure 4: Drawing showing details of silicon detectors used in the GLAST beamtest.

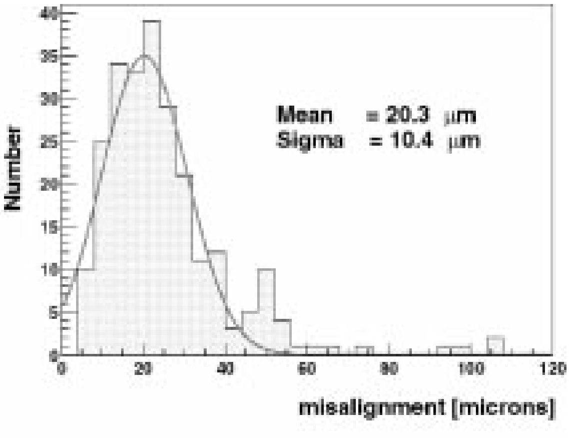

Figure 5: The distribution of the straightness of all the ladders used in the BTEM tracker. Most ladders have two entries; this is from measurements on both sides of the ladder.

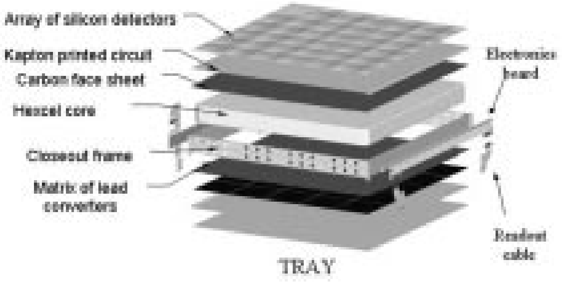

Figure 6: Drawing showing the construction of the trays.

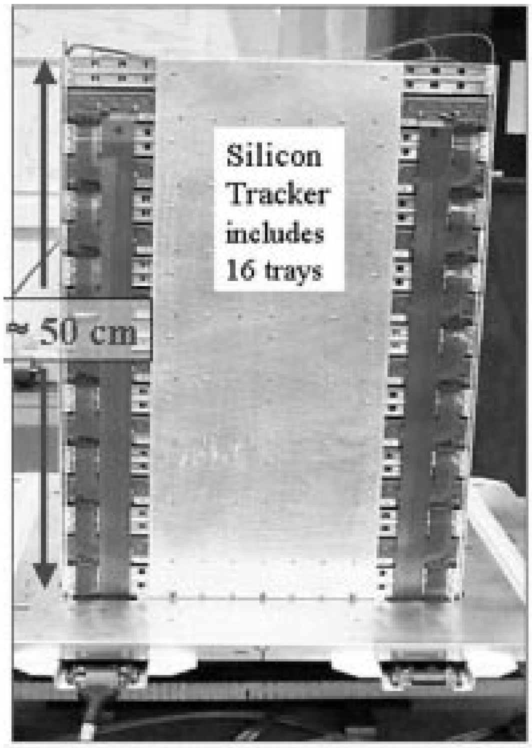

Figure 7: This is a picture of the BTEM tracker, plates have been removed to clearly show the seventeen trays stacked on top of each other. The overall tracker size is 50 cm × 32 cm × 32 cm.