Technological Experience in the Construction of Silicon Trackers Detectors for Space Experiments

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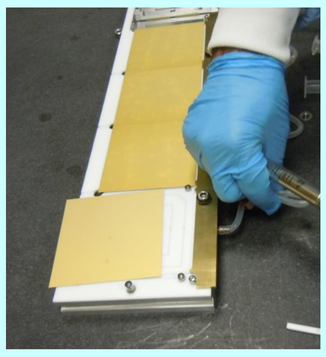
ABSTRACT: Silicon trackers technology, developed in the last century for accelerator based experiments is currently used in several space-borne astroparticle experiments. The challenge is not only in the design and construction of the detector itself, but also in fulfilling the additional requirements imposed by the launch process and the hostile running environment in orbit. In particular, the silicon trackers for DAMPE and LIMADOU experiments designed, assembled and tested under INFN Perugia leadership have been successfully launched in space: DAMPE in December 2015 and LIMADOU in February 2018 and they are currently taking data. In this contribution, we report on the design of both trackers, the chosen assembly techniques and the results from the construction. We will also briefly report on the space qualification test performed on the flight hardware.

Technological approach for Silicon Detectors in space

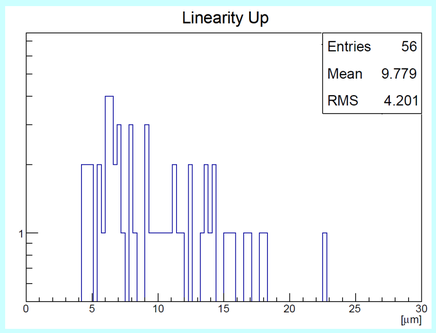
The silicon trackers for DAMPE[1] and LIMADOU/CSES[2] experiments have been designed and built following the very stringent requirements typically to the space experiments such as: resistance to the mechanical stress during launch (vibrations and mechanical shocks), thermo-mechanical stability in a large temperature range, low power consumption and low weight, traceability of the quality of the components through documentations on design, test, assembly, and integration, reliability under space conditions.
For each experiment the Thermo-Mechanical Model, Engineering Qualification Model and Flight Model have been built, and completely tested in conformity with the requests from the space agencies. To fulfill those requirements particular attention was given in the choice of each detector part component: light and robust supports and reinforcements, low power consumption front-end electronics chip, space qualified glues. The assembly procedures follows stringent Quality Assurance issues and space qualification tests were done on each component, singles modules and whole integrated tracker in terms of vibrations, shock, thermal and thermo-vacuum cycles.

DAMPE silicon single-sided microstrip detectors production flow and quality of assembly

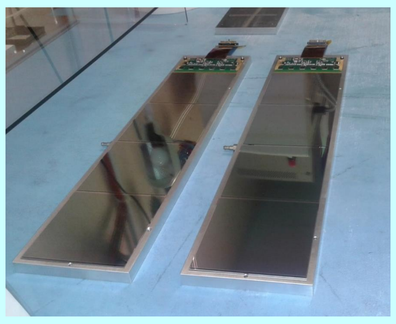
The DAMPE STK (Silicon-Tungsten Tracker) with an area of 7m^2 contains 192 modules glued on seven light-but-rigid trays made of aluminum honeycomb and carbon fiber reinforced polymer. Five trays are equipped with silicon modules on both sides, while the top and the bottom ones are equipped on only one side. Inside of three trays are inserted tungsten converter plates with thickness of 1mm. A silicon module is made of four single-sided silicon microstrip sensors with the strips running parallel to the module length. The Tracker Front-End electronics which collect and amplify the signals from the strips sustain mechanically the four sensors on flex extensions with 380μm of thickness. Space qualified resins were used in the assembly.

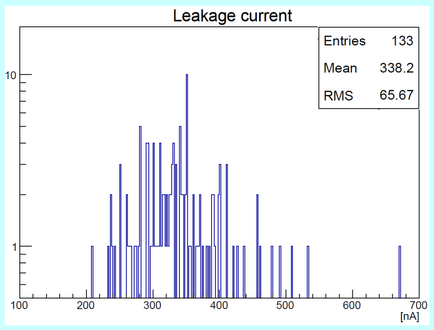


768 single side silicon sensors with overall dimensions of 9.5cmx9.5cm and 192 Front-end Electronics Hybrids were used for the DAMPE STK. Six VA140 chips on each Hybrid.
The sensors are aligned manually to pins on assembly jigs manufactured with precision better than 10μm. The front end hybrids were glued over the silicon sensors. FM modules production was done in parallel for a total assembly time of three months. Production yield was of 96%.



Metrology measurements of the sensors position are done before FE electronics gluing and, respectively at the end of the assembly. The alignment precision of sensors in modules measured after assembly was better of 10μm (design request 40μm); the average of inter-cross distance measured on sensors was of 992.53μm (design 920μm)





Electrical test on all silicon sensors was done by producer before assembly showing an average of total leakage current of 116nA@150V. The measured leakage current of assembled modules @INFN Perugia is **338.2nA@80V.** Over 73728 readout channels, DAMPE STK has only **0.2%** of noisy channels

The EQM DAMPE Silicon Tracker during vibration test @SERMS, Terni in 2014

Some Quality Assurance Issues for the Module Assembly

- Each component (sensors, electronics, reinforcements and other component parts) are to be visual inspected, mechanically and electrically tested before assembly. Acceptance criteria applied. A precision of 5 to 10μm is requested for instance for the cutting line of sensors and less than 2% of noisy strips
- burn-in test in large range of temperatures, typically from -35°C to +75°C for a high number of hours on all front-end electronic boards
- Long term electrical measurements on samples of sensors
- module metrology check during each assembly step and electrical measurements step by step when needed
- Final mechanical alignment check and electrical test
- Functional test with radioactive sources or cosmic rays on completed modules
- Single modules and whole tracker tests with particle beams
- Writing assembly and test procedures, keeping data sheets and report of the non conformance activity if the case

Silicon Sensors Characteristics

	DAMPE	LIMADOU
Type of sensors	single sided	double sided
Overal dimensions	95mm x 95mm	109.63mm x 77.58mm
Active area	93.196mm x 92.807mm	106.63mm x 71.58mm
Thickness	320μm	300μm
P side nr of strips	768	768
P side strip pitch	121μm	91μm
P side readout pitch	242μm	182μm
P side nr of readout strips	384	384
N side nr of strips	-	576
N side strip pitch	-	91μm
N side readout pitch	-	182μm
N side nr of readout strips	-	384
Production	Hamamatsu Japan	FBK Italy

Example of Requested Space Qualification tests

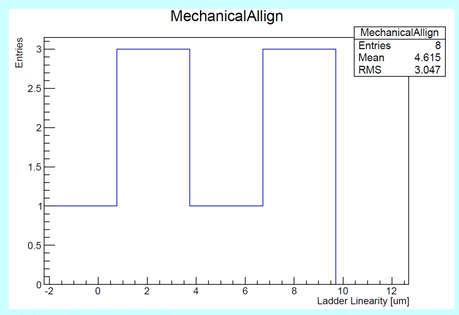
-Resonances search on all directions with a sine wave with a variable frequency (ex 5 to 100Hz), low amplitudes and low g
-Sinusoidal vibration test on all directions with frequencies up to thousands of Hz and acceleration up to 16g
-Random vibration test with frequencies up to 2000Hz and average accelerations up to 12g
-Pyro-shock on X, Y and, Z axis with frequency up to 4000Hz and acceleration up to 200g
-Thermal cycles and thermo-vacuum cycles in ranges from -45°C to +50°C

LIMADOU Silicon Double-Sided Microstrip Detectors production flow and assembly quality results

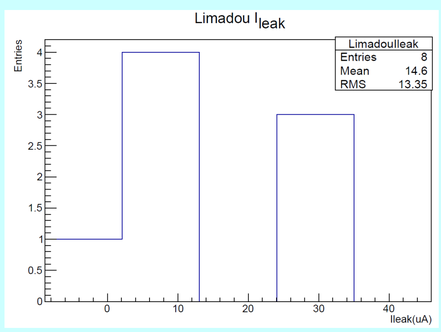
The HEPD (High Energy Particle Detector) Silicon Tracker for the CSES/LIMADOU experiment consists of two double-sided silicon planes (21.3cm x 21.3cm) which allow to measure two coordinates with a single detector, reducing thus the material budget. Each plane is covered with three modules (21.32cm x 7.16cm). Each module is composed of two silicon microstrip sensors with the active area of 10.66cm x 7.15cm

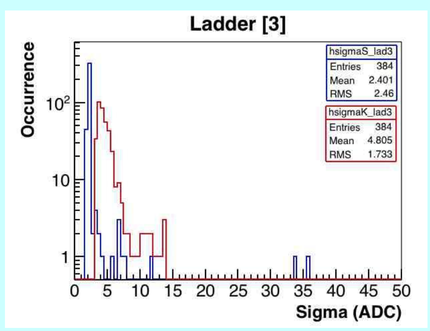
HEPD Silicon Tracker numbers:
6 double sided silicon modules
12 Front-End Electronics Hybrid are glued on p and n side of the module. Each hybrid contains six VA140 chips (64 channel low noise, low power, high dynamic range charge sensitive preamplifier circuit)
6 long kapton router for the *n* side multiply strip reading
6 short kapton pitch adapter for the *p* side
12 mechanical supports glued on each side of the module

The sensors are manually aligned with n-side up using precise pins and jigs. Metrology measurements of the sensors position are done before kapton gluing procedure.
A kapton foil 50um thick is glued on the sensors and on the Front-End electronics hybrids. A mechanical support is glued on top of the module. After curing time the module is turned with p-side up and the p-side electronics, kapton and reinforcement are glued. Wire bonding, electrical/mechanical test, functional test with radioactive source and cosmic rays complete the assembly.

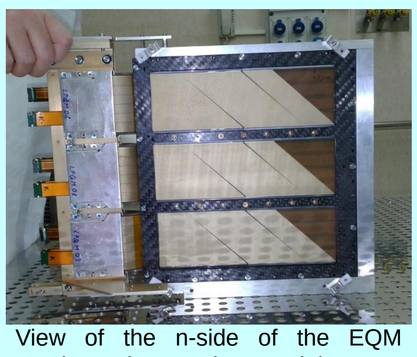


Mechanical alignment precision of sensors in modules better than 5μm





Average leakage current on seven Flight Model modules after assembly is 14.6μA@80V due to two modules with high leakage current sensors. The calibration of a high current ladder show a low noisy behavior



View of the n-side of the EQM Tracker plane. The modules are mounted in the light Carbon Fiber structure

References

[1] *The Dark Matter Particle Explorer mission*, Astroparticle Physics 95 (2017) 6-24, J. Chang, G. Ambrosi et al.
[2] *The HEPD particle detector of the CSES satellite mission for investigating seismo-associated perturbations of the Van Allen*, Science China, Technological Sciences (2018), https://doi.org/10.1007/s11431-018-9234-9, Ambrosi Giovanni, Bartocci Simona et al.

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