

Performance of the CREAM Silicon Charge Detector during its First Flight

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The Cosmic Ray Energetics And Mass (CREAM) experiment was launched as a long duration balloon payload from McMurdo Station, Antarctica on 16 December 2004. For the charge measurement of incident cosmic-ray particles entering its calorimeter module, CREAM has a Silicon Charge Detector (SCD) comprised of 182 silicon sensors in an active area of 779mm×795mm. The sensors are DC-coupled PIN diodes fabricated from 380μm thick, n-type wafers. This presentation describes the construction of the detector and the performance of the SCD during its first flight.

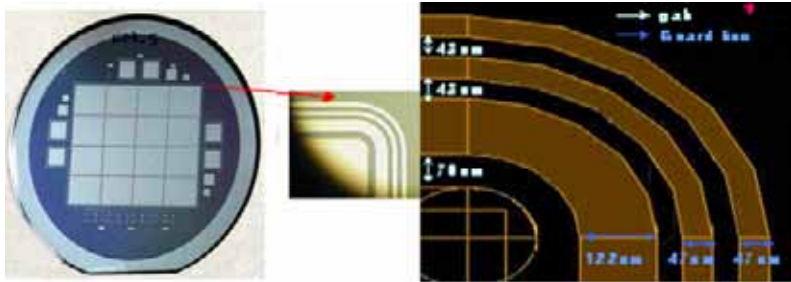
1. Introduction

CREAM [1] is a balloon-borne experiment to measure the composition and energy spectra of cosmic rays at energies up to 1000TeV ($=10^{15}$ eV) with a series of long duration balloon flights. The charge measurement of primary cosmic rays is a critical parameter measured by CREAM. The SCD was designed and constructed for this purpose. The SCD is an array of two dimensional PIN diode silicon sensors that are segmented in the optimum size to allow the measurement of the primary cosmic ray in the presence of back-scattered particles from showers in the targets and calorimeter below the SCD. The SCD was successfully tested using high energy heavy ion beams at CERN. In the following, we describe the construction of the SCD, the result of CERN beam test and the performance of the SCD during the flight.

2. Silicon Charge Detector

The base material of the PIN diode silicon detector is a 380μm thick, N-type wafer with high resistivity (5kΩ·cm). Three guard rings were implemented around active cells in the sensor design in order to reduce the electric field on the side of the junction edge. The effect was confirmed in a reduced leakage current and

improved junction breakdown voltage. Figure 1 shows the design of guard rings. The fabrication procedure has been optimized for high yield of good quality sensors. A common contact is made on one side by phosphorous diffusion while the individual detector pixels are created on the other side by boron ion implantation.



The electrical characteristics like capacitance and reverse current at the various bias voltages were checked for all sensors. For most of the sensors the full depletion voltage was measured to be $80 \pm 15\text{V}$ and the leakage current was measured to be $5 \pm 3\text{nA/cm}^2$ at 100V , 25°C .

Figure 1. Guard ring design in the silicon sensor.

The SCD consists of 26 ladders, each holding seven silicon sensor modules with associated analog readout electronics [2]. One ladder is composed of one printed circuit board and seven sensors. 26 assembled ladders are mounted on an aluminum frame for the mechanical support. The sensors partially overlap to be dead region free in the x- and y-directions. Each silicon sensor is comprised of 16 silicon pixels in a 4×4 array, with each pixel capable of measuring the signal from cosmic rays with atomic numbers from 1 to 28. The total size is $818.39\text{mm} \times 818.39\text{mm} \times 8\text{mm}$ and the active area of the SCD is $779\text{mm} \times 795\text{mm}$. The total detector height is 35.2mm including the detector cover. Figure 2 shows the SCD during integration. In order to keep the detector temperature in the operational range the installation of thermal straps was carefully designed to conduct out the heat from the front-end electronics, which is seen in Figure 3.

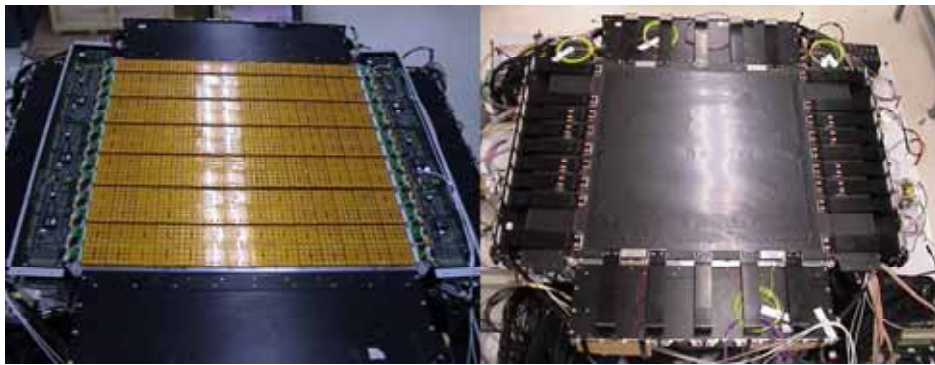


Figure 2. Assembled SCD without cover.

Figure 3. SCD after installation of the covers and thermal straps.

3. Beam Test

The SCD was tested using a heavy ion beam line at CERN with fragments of 158GeV/nucleon indium beams in November 2003. Figure 4 shows excellent charge resolution of $0.2e$ for the charge (Z) range from $Z=1$ up to $Z=33$. The linearity of the detector response in the wide charge range is seen in Figure 5. The beam test results of the SCD are reported in more detail in [2].

The detector was thermal-vacuum tested before the flight, at NASA-GSFC in early September 2004. The tests were conducted in a temperature range of -10°C to 40°C at a 4 torr vacuum, and the SCD operation remained stable throughout.

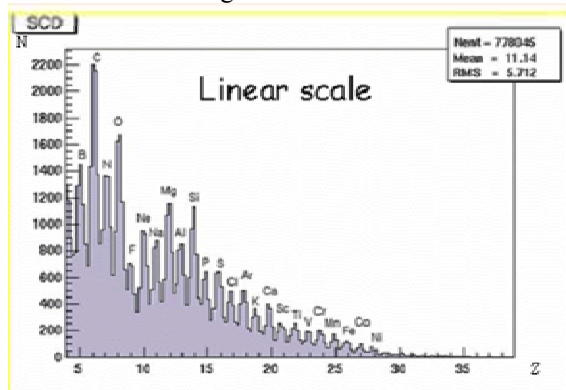


Figure 4. The charge identification of a silicon sensor

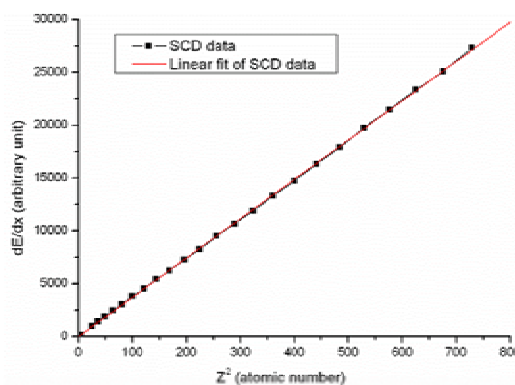


Figure 5. Linearity of the SCD data

4. SCD Performance during the Flight

The quality of data as well as the detector operation condition were monitored during the entire period of the flight. Figure 6 shows the variation in the CREAM altitude (top), the temperature of a front-end readout board (second), the average readout pedestal (third), and the number of noisy channels (bottom). The SCD temperature was maintained in the range $25\text{-}33^{\circ}\text{C}$. The temperature was found to rise by about 2°C for a change of 1.5km in the payload altitude. The fluctuation in the readout pedestal is correlated with the change in the temperature and the dependence was estimated to be about $20\text{ ADC counts}/^{\circ}\text{C}$. Measurements of readout pedestal were made every 5 minutes for all channels for future correction. The number of noisy channels also varied with the temperature, which is seen in the bottom plot of Figure 6. The short time period with unusually high number of noisy channels on January 20th coincides with a large solar flare [3]. Readout electronics were periodically calibrated during the flight by injecting a calibration charge into the readout analog chip. The result is shown in Figure 7 for a channel. The electronics gain remained stable during the operation period.

5. Conclusions

The SCD is a detector designed to measure the charge of primary cosmic rays in the CREAM experiment. It was successfully operated during its long balloon flight in Antarctica from 16 December 2004. The SCD was maintained within the operational temperature range throughout. The condition of the readout electronics and the quality of data were monitored and the variation of pedestal is found to be correlated with changes in the detector temperature. However, the gain in the readout electronics remained stable.

6. Acknowledgements

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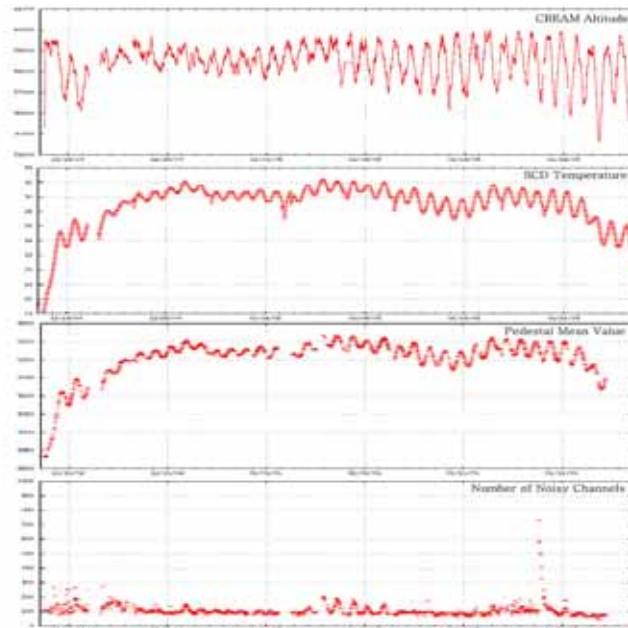


Figure 6. Changes in SCD conditions during the flight. From top, CREAM altitude, temperature of a front-end readout board, average readout pedestal, and number of noisy channels.

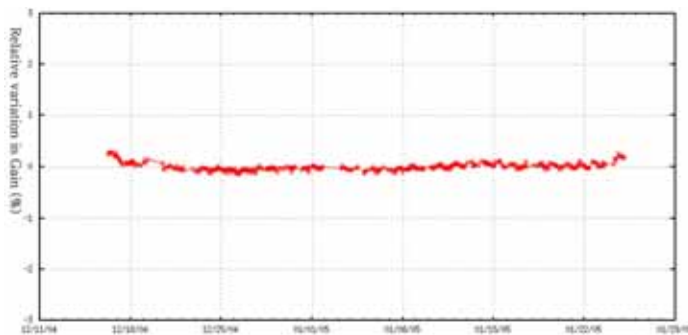


Figure 7. Result of electronics calibration runs taken periodically during the flight.

References

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