Design and Construction of the Silicon Charge Detector for the CREAM Mission

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Abstract

A Silicon Charge Detector (SCD) is designed and constructed for the Cosmic Ray Energetics And Mass (CREAM) experiment to provide precision measurements of charge of incident cosmic ray particles with resolution of 0.2 charge unit. The aim of the CREAM experiment is to understand the source and acceleration mechanisms of ultra high energy cosmic ray particles. The payload is planned for launch in December 2004 from McMurdo Antarctica as an Ultra Long Duration Balloon mission. The SCD consists of 26 ladders each holding 7 silicon sensor modules and associated analog readout electronics. The silicon sensors are DC coupled PIN diode made from 380 μm thick, n-type wafers. Each sensor is pixellated with 16 cells, 2.12 cm^2 in area, to distinguish the incident particle charge in the presence of backscattered particles resulting from interactions in the lower parts of the instrument (Carbon target and Calorimeter). We present the status of the SCD, including readout electronics and mechanical support structure.

1. Introduction

One of the puzzles in the astrophysics is high energy cosmic rays and its origin. The cosmic ray flux [1] decreases rapidly as energy increases and energy spectrum follows a power law in energy characteristic of shock wave acceleration. However, energy spectrum extends more than 5 orders of magnitude beyond the highest energies, Z (atomic number)$\times 10^{14}$ eV, thought possible for supernova

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shocks. The existence of high energy cosmic rays beyond the supernova acceleration limit is still a mystery. There are also spectral features [2, 3] known as "knee" and "ankle" which might imply changes in sources, propagation, and acceleration. Cosmic rays at these high energies of 10^{14}-10^{20} have been detected in ground-based observations of air showers in the atmosphere. The weakness of this type of indirect measurements is that the primary particle that initiated the air showers can not be identified. By flying particle detectors on spacecraft or high altitude balloons, cosmic rays can be measured directly.
The Cosmic Ray Energetics And Mass (CREAM)[4] experiment will investigate high energy cosmic rays over the elemental range from protons to iron utilizing a series of Ultra Long Duration Balloon (ULDB) flights. The "knee" is the transition region where the cosmic-ray energy spectrum steepens from $dN/dE \sim E^{-2.7}$ below 10^{14} eV to $E^{-3.0}$ above 10^{16} eV. The goal of the experiment is to observe energy spectral features from 10^{12} to 10^{15} eV and abundance charges that might be related to the supernova acceleration limit. The high energy composition measurements are difficult because of the very low particle fluxes and detector must be large enough to collect adequate statistics, yet stay within the weight limit for space flight. The CREAM instrument consists of a Timing Charge Detector (TCD) to measure charge and velocity of incoming particle, a Transition Radiation Detector (TRD) to measure the Lorentz factor γ of particles of $Z > 3$, a pixellated Silicon Charge Detector (SCD) for identifying particles of $Z < 28$ and a sampling tungsten/scintillator calorimeter for energy measurement of all nuclei. The SCD is being built for the CREAM mission and its main purpose is to identify the charge of incident cosmic ray particle by measuring the rate of ionization loss of a particle in the silicon.

2. Silicon Sensor Design and Fabrication

The key design factor for the SCD is to minimize the effects of backscattered particles generated by the interaction in the carbon target and the showers produced in the calorimeter. This is accomplished by a finely segmented silicon pad of the SCD. With this segmentation, backscatter is expected to cause charge mis-identification of about 2%-3% of low-Z particles near 10^{15} eV incident energy, and significantly lower for lower energies and higher charge. The active area of the silicon pad is optimized to be 15.5 mm by 13.7 mm. The silicon sensor is built from 4x4 silicon pads. The SCD consists of 26 ladders each holding 7 silicon sensor modules and associated analog readout electronics. The SCD consists of 182 individual silicon sensors, each capable of measuring the signal from cosmic rays with atomic numbers from 1 to 26. The silicon sensors are fabricated in SENS Technology and are made on 5-inch single-sided polished wafers. The wafers are 380μm thick with a rms variation of 15μm. The thickness variation within wafers is $<3.5\mu$m. The silicon is phosphorus-doped with a resistivity of $> 5000\Omega$cm.

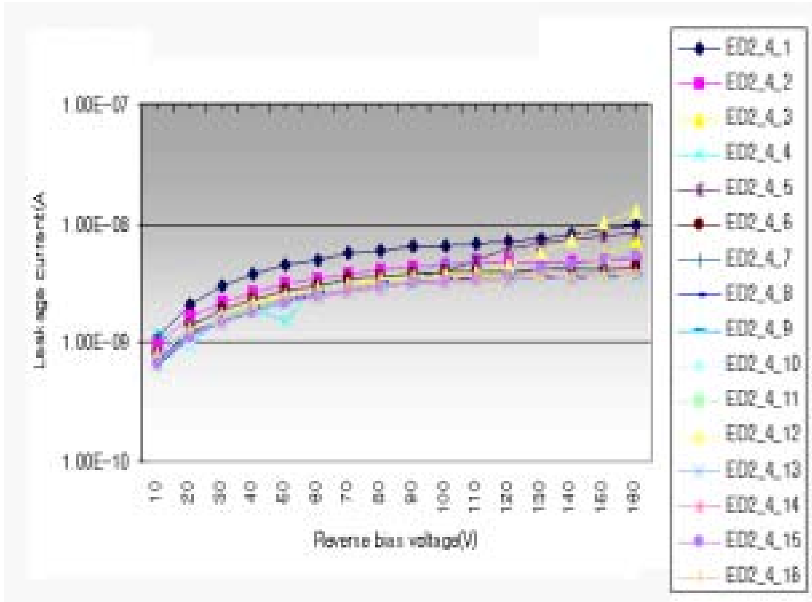

Fig. 1. Leakage current measurements as a function of the reverse bias voltages for 16 pixel arrays

The detectors are PIN diode. A common blocking contact is created on one side by phosphorous diffusion while the individual detector pads are created on the other by etching apertures into a silicon dioxide layer. Rectifying contacts are created in these apertures by boron ion implantation. After aluminum contacts are deposited, the whole surface is passivated with silicon dioxide.

3. Sensor Test

The finished sensors are tested on the wafer with probe stations for full depletion and leakage current. The capacitance and leakage current are measured for the sensor test. Capacitance measurement shows that all the sensors fully depleted at a bias 87$\pm$ 8 volts. Selected sensor is required that a leakage current per pad is $<$20 nA at 100 volts and is measured 7$\pm$2 nA. Also the leakage current should not increase at a rate $>$3% per volt at 100 volts. The Fig. 1 shows typical leakage current measurements for a 4 by 4 pixel arrays. The sensors are checked with ^{90}Sr β source normally incident on the detector. The S/N ratio of about 30 is obtained at 100 volts. When each sensor is connected to a preamp, shaper and pulse height analyzer, sensors with the S/N ratio $>$3 are selected for use in the experiment. About 80% of the fabricated sensors are passed our leakage current, capacitance and S/N ratio requirements. The SCD will be launched from Antarctica where the 24 hr daylight and the high albedo from the ice will increase SCD temperature. The SCD may also spend considerable time at near equatorial latitude where an eclipse of 11 hr will make the SCD cold. The SCD must also be able to survive a wide range of thermal and pressure environments. Thermal and vacuum testing is required to verify the SCD can survive such environment extremes. The leakage currents of the sensor are measured at SaTRec in the KAIST by varying pressure from 10^{-5} to 740 Torr. The measured leakage currents are stable for pressure changes. Temperature is also changed from -15° to 50° at 10^{-5} Torr for the leakage current measurement. The results show the leakage currents are increased as a function of the temperature as expected.

4. Mechanical Structure

For the particles incident outside the TCD acceptance, the SCD is located between the TRD and the carbon target covering the area of target top. The active area of the SCD is 79 cm by 79 cm and the SCD has two types of ladders with 13 ladders on each. A total detector thickness is 7 mm and a height of a electromagnetic shielding box with a thickness of 2.5 mm is 14.5 mm.

There are 7 silicon sensors in a ladder and the sensors are partially overlapped to be dead region free in x- and y-directions.

5. Conclusion

Composition measurements of cosmic ray provide a means of distinguishing among models of cosmic ray origin and propagation. The CREAM balloon experiment is designed to measure cosmic ray elemental spectra from 10^{12} to 10^{15}. The SCD is being built to identify the charge of incident cosmic ray particles and to to minimize the effects of backscattered particles generated by the interaction in the carbon target and the showers produced in the calorimeter. Currently, most of the silicon sensors are constructed and associated electronics are being finalized. The SCD will be completed for an instrument integration in the mid of August. The instrument will be delivered to NANA/WFF for an integration at the end of December to complete the balloon craft end-to-end hang test by early February 2004.

6. References

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