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SILICON PAD DETECTORS FOR LCCAL: CHARACTERISATION AND TEST BEAM RESULTS

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A prototype of an electromagnetic sampling calorimeter for future Linear Collider experiments has been commisioned by the LCCAL collaboration. In order to improve the reconstruction of the shower profile, three silicon pad detector planes have been inserted between lead and scintillator layers at 2, 6 and 12 X_0. The electrical parameters of the pad detectors have been determined by a static IV and CV characterisation; charge collection efficiency and tracking capability have been measured during beam tests. The results, including the design optimisation and the first images of electromagnetic showers, are presented in this paper.

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1. Introduction

Excellent jet energy reconstruction and shower separation are of utmost importance for experiments at future e^+e^- linear colliders. The energy flow algorithms, proven to be extremely effective at LEP, require a highly segmented calorimeter, both longitudinally and trasversely to the shower axis. The proposed technique is meant to fulfill those requirements. It consists of a sampling calorimeter made by absorber and scintillator layers with wavelength shifting fibers, complemented by three planes of Silicon pads to obtain very precise information on the transversal shower profile at different positions in the longitudinal development. This paper focuses on the full characterisation of the Silicon pad sensors; the description and the preliminary results of the complete prototype can be found in Ref. 2.

2. Prototype layout

Three silicon planes are positioned at 2, 6 and 12 radiation lengths inside the calorimeter prototype. They are made by pad sensors[a] built on n-type high resistivity silicon wafers and their main characteristic are shown in Table 1. The sensitive area is divided into 42 squared p-n junctions AC coupled to the front end electronics. The AC coupling has been implemented either building an integrated SiO_2 layer between the p-type region and the read-out metal or mounting an external capacitor on the adapter card. Since the pad sizes and pitches are 0.9 cm, the hybridisation of the sensor to the adapter card can be easily done using a conductive glue.

Table 1. Silicon sensor main characteristics.

Sensor Thickness	300 μ m
Silicon resistivity	4-6 kΩcm
Sensitive area	6×7 cm^2
Pad area	0.9×0.9 cm^2
Integrated SiO_2 thickness	265 nm
External SMD capacitor	470 pF

Each pad is connected to a channel of the VA-HDR9c analogue ASIC[b] characterized by a very high dynamic range and the possibility to select the gain value from a list of four (up to 100 MIPs[c] with a gain of 3.3 mV/fC and up to 300 MIPs with a gain of 1.2 mV/fC). Such feature is crucial in a setup like the calorimeter where a multiplicity up to 100 MIPs per pad is expected on the second layer.

[a] Processed by the Institute of Electron Techonology - Warsaw, Poland
[b] Produced by IdeAs - Høvik, Norway
[c] A **M**inimum **I**onising **P**article produces about 80 electron-hole pairs per micrometre in Silicon

Each layer corresponds to an array of 3×2 sensors mounted on a motherboard and addressed sequentially.

3. Prototype characterisation

The full production was accomplished in three batches with different technological characteristics; an optimisastion was made possible by a close interaction with the Silicon foundry. The most relevant figures of merit of the production are summarized in Table 2.

Table 2. Production yield for the three different batches.

	1^{st} batch	2^{nd} batch	3^{rd} batch
AC Coupling	Integrated	Integrated	External
Wafer rejected	1/11	2/9	0/9
Depletion voltage	32 V	27 V	28 V
Current at depletion per wafer	2.1 μA	0.8 μA	0.6 μA
Not depleted pads	0/420	8/249	0/378

3.1. *Soft and early breakdown*

Measurements of the I-V characteristics have shown an unexpected reverse current soft increase at full depletion as the backplane is approched. This phenomenon was interpreted as due to the presence of shallow impurities in the backplane region. Such impurities become active and start to produce charge carriers as soon as they are reached by the depletion causing the leakage current to increase. Nevertheless, even if the leakage current at depletion is not very low, the working condition is not dramatic, as shown Figure 3.1, and the leakage current equivalent noise charge contribution (See Eqs. 1) is still acceptable.

3.2. *Leaky pads*

During the tests, a problem connected to the integrated AC coupling was traced. A quite high percentage of pads was actually behaving as being DC coupled. Careful checks on test structures excluded the obvius hypothesis of pin-holes due to a low quality of the thin oxide and identified the reason for the leaky pads in polysilicon residuals in the region between the read-out metal and the aluminum bridge across the polysilicon resistor and the p-type side of the junction. The presence of such residuals is possibly connected to the different etching speed of polysilicon from the very wide metal region and from the narrow p-type region. Since no reliable

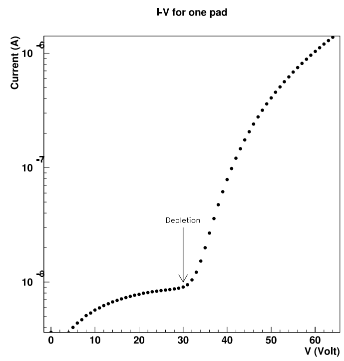


Figure 1. I(V) curve for one pad where the *soft* breakdown problem is shown. Since the current at depletion (arrow) is of the microampere order, the working condition is acceptable.

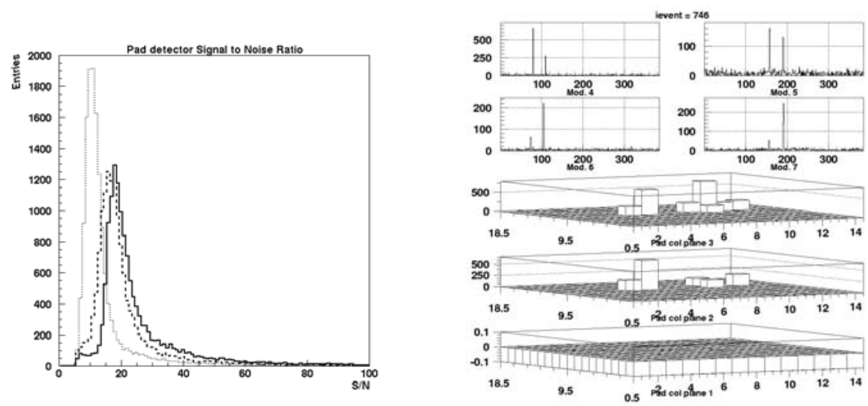
technology improvement was defined, it was finally decided to simplify the sensor and rely on external SMD bias resistors and coupling capacitors at least till the technological processes will be sufficiently fine tuned.

4. Preliminary beam test results

In order to make a full dynamic characterisation of the prototype two beam tests have been performed: the first one using the beam test facility at Laboratori Nazionali di Frascati (LNF) and the second at CERN using the SPS H line. The signal to noise ratio (SNR) for one single MIP crossing the detector has been measured for wafers of different production batches and is shown in Fig. 2(a). From Eqs. 1, the theoretical value of the SNR has benn estimated to be 22:1, taking into account the contribution to the ENC of the front end electronics, the leakage current and the bias resistor. This value has to be compared with the measured one for the last batch (18:1) demostrating that the detectors behave correctly.

$$ENC_{FE} = A + \frac{B}{pF} \approx 1000e^{-} \tag{1}$$
$$ENC_{I_l} = \frac{e}{q}\sqrt{\frac{qI_lT_p}{4}} \approx 30e^{-}$$
$$ENC_{R_b} = \frac{e}{q}\sqrt{\frac{T_pk_BT}{2R_b}} \approx 230e^{-}$$

I_l leakage current at depletion voltage. T_p peaking time. R_b bias resistance.



(a) (b)

Figure 2. (a) SNR for silicon sensors belonging to the three different production batches (first one - dotted line, second one - dashed line, third one - solid line) and obtained using one single MIP. (b) Event display of the three silicon pad layers at 2, 6 and 12 X_0 respectivly (the last three plots), for two 750 MeV electrons hitting the prototype tracked by two pairs of silicon chambers (the four top plots).

The LNF beam line is characterised by the possibility to tune the number of electrons impinging on the device under test. Exploiting this feature the shower to shower separation capability (Fig. 2(b)) of the calorimeter is under investigation as well as the possibility to track the shower transversal development. Moreover the energy linearity of the behaviour of the silicon sensors has been studied using electron beams with energy in the 2 to 6 GeV range.

5. Conclusion

A prototype of an electromagnetic calorimeter for the future linear collider experiments using silicon pad detectors for the shower reconstruction and separation has been implemented and tested. The prototype perfomance resulting from the first beam tests is in good agreement with the design rules and the proposed technique for the jet energy reconstruction fits the requirements for a linear collider detector.

References

1. TESLA Technical Design Report DESY 2001-011 ECFA 2001-209, Part IV
2. P. Checchia *Proceedings of the 8th International Conference on Advanced Technology and Particle Physics*, Como, 6-10 October 2003