Further improvement of the Telescope Chip performances

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December 07, 2010

Abstract

The Telescope Chip (TC, alias MIMOSA-26) already equips the EUDET beam telescope since 2009. We have used the extra year to explore a new substrate which promises better performances especially in term of radiation tolerance. This study was done in two steps: a replication of the TC (UTC, Updated Telescope Chip) on this new substrate to observe the benefits and a new version of the IDC (Intermediate Digital Chip) to improve the pixel architecture.

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1 Investigations on a new substrate

On standard substrate, the depletion depth is a fraction of micron (figure 1 left). Therefore, charges are mainly collected through thermal diffusion. On a high resistivity substrate this depletion depth may reach several microns (figure 1 right) and speed up the charge collection. It has been shown [3] that high resistivity substrate can substantially increase the radiation tolerance. Even if radiation tolerance is not a main issue for the EUDET beam telescope, taking care of this constrain could enable this infrastructure to run for a longer time or in more hostile conditions. The UTC could be use for other applications too.

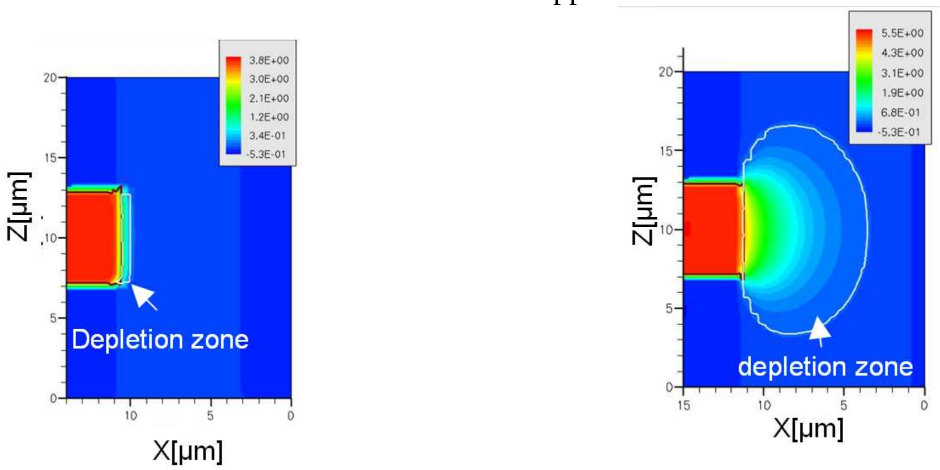

Figure 1: Results of ISE TCAD device simulations [3]: size of depletion zone with low resistivity substrate (left) is small while high resistivity substrate (right) is comparable to the P-epi thickness.

2 Performances of TC with a high resistivity epitaxial layer

The UTC (Updated Telescope Chip) has the exact layout of the TC and is back from foundry since January 2010. Like the former version of TC, the UTC is built in AMS 0.35 µm Opto process, with a pitch of 18.4 µm. This chip is composed of 1152 x 576 pixels which correspond to an active area of ~ 21.2 x 10.6 mm^2. A detailed description of the chip can be found in [2]. Contrary to the original version, this new TC (UTC) is built with a high resistivity epitaxial layer (400 Ω.cm resistivity). To investigate the improvement of this high resistivity substrate, sensors with epitaxial thickness of respectively 10, 15 and 20 µm have been built and studied. The results of UTC have been compared with ones of standard chips with 14 µm thick low resistivity epitaxial layer (~ 10 Ω.cm).

EPI layer	**Standard (~ 10 Ω.cm) 14 µm**			**High resistivity (~ 400 Ω.cm)**			
	seed	2x2	3x3	EPI	seed	2x2	3x3
Charge Collection (^{55}Fe source)	~ 21 %	~ 54 %	~ 71 %	10 µn	~ 36 %	~ 85 %	~ 95 %
				15 µm	~ 31 %	~ 78 %	~ 91 %
				20 µm	~ 22 %	~ 57 %	~ 76 %
S/N at seed pixel (^{106}Ru source)	~ 20 (230 e$^-$/11.6 e$^-$)			10 µn	~ 35		
				15 µm	~ 41		
				20 µm	~ 36		

Table 1: Laboratory results with X-ray (^{55}Fe) and β$^-$ (^{106}Ru) sources.

For this comparison, the sensors have been extensively characterized in laboratory, especially with ^{55}Fe and ^{106}Ru sources at 20 MHz and 20°C. The Charge Collection Efficiency (CCE) is extracted from the reconstruction of clusters generated by the 5.9 keV X-Ray of the ^{55}Fe source (table 1 –first part). The results clearly indicate an increase of the CCE with HR (High Resistivity) substrate, especially for 10 or 15 µm-thick epitaxial layers. It could be understood as a better depleted volume. Noise measured with different epitaxial layers is similar.
Then, another important information is the signal to noise ratio (S/N) of the sensor obtained by using ^{106}Ru source: the 3.5 MeV β^- of the source could be considered as MIP (Minimum Ionising Particle). Like shown in table 1, S/N obtained for HR substrate is almost twice more than one observed with standard substrate. Maximum S/N is obtained with the 15 µm thick HR-sensor.

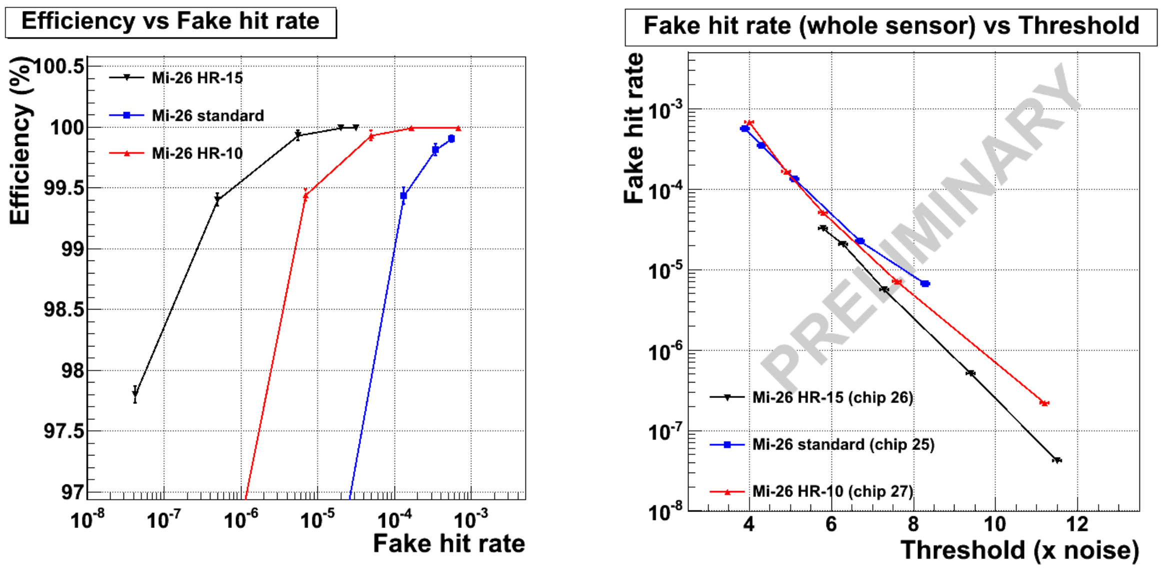

Figure 2: Preliminary test beam results for not irradiated sensors with various epitaxial layer : efficiency versus fake hit rate (left) and average fake hit rate versus discriminator threshold (right).

Then the sensors have been qualified in test beam with 120 GeV π^- at the CERN-SPS. The set-up consisted of a telescope made of 4 planes, each with one standard TC and in the middle two TC as DUT (Device Under Tests).
At first, not irradiated sensors with respectively standard and HR-10 µm and HR-15 µm epitaxial layer have been studied, especially detection efficiency and average fake hit rate (Figure 2). The fake hit rate is the probability for one pixel in one event to pass accidentally the discriminator threshold, while there is no MIP crossing the pixel in this event. We average this probability over all the pixels of a given sensor to obtain an average fake hit rate which depends on the discriminator threshold, as observed on the figure 2 right. The similitude of the rate of the three epitaxial layer types is in agreement with the noise independence from the substrate.
Then, sensors irradiated up to 1.10^{13} n_{eq}/cm^2 fluency have been studied. For efficiency versus fake hit rate, the plateau is larger for HR-15 then HR-10 and standard chips. It means that the operating point is different and there is a bigger margin with HR-15 chip. It is what we can see on figure 3: with HR-15, there is still a plateau while with HR-10 this plateau is much reduced after a 1.10^{13} n_{eq} /cm^2 fluency at 0°C.

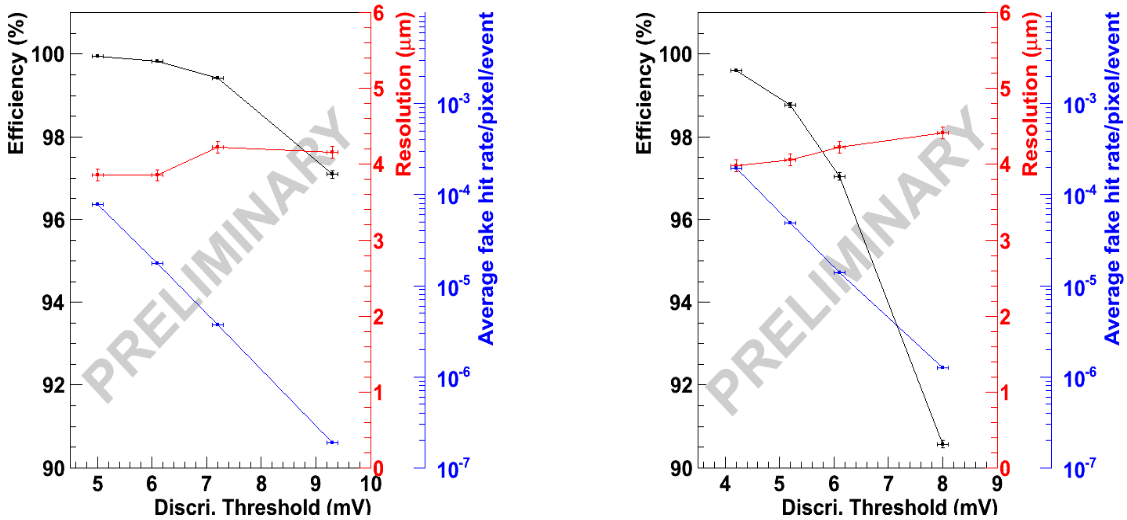

Figure 3: Preliminary test beam results for sensors irradiated at 1.10^{13} n_{eq}/cm^2 fluency with respectively HR-10 µm (right) and HR-15(left) µm epitaxial layer: detection efficiency, spatial resolution and average fake hit rate versus threshold.

A new version of the EUDET beam telescope will be available with 50 µm thinned UTC with HR-10µm epitaxial layer.

3 A new IDC to complete this study

A new IDC (Intermediate Digital Chip) is back from foundry since June 2010. Like the former versions, this new IDC (IDC-HR) is built in AMS 0.35 µm Opto process. This IDC-HR was built on different substrates: 14 µm standard low resistivity (~ 10 Ω.cm), 10, 15, 20 µm high resistivity (~ 400 Ω.cm) epitaxial layer. Its design has two main objectives: optimize the pixel and explore new pixel possibilities. This chip especially allowed studying for two different amplification schemes: Common Source (CS), like in TC and CASCODE (CAS) with different optimisations for this substrate with 2 pixel pitch: 18.4 and 20.7 µm. IDC-HR is built to explore voltage bias for collection diode improvement as well as elongated pixels. Here we are just focusing on the results of the pixel optimisation with 15 µm high resistivity epitaxial layer. A detailed description of the IDC can be found in [4].

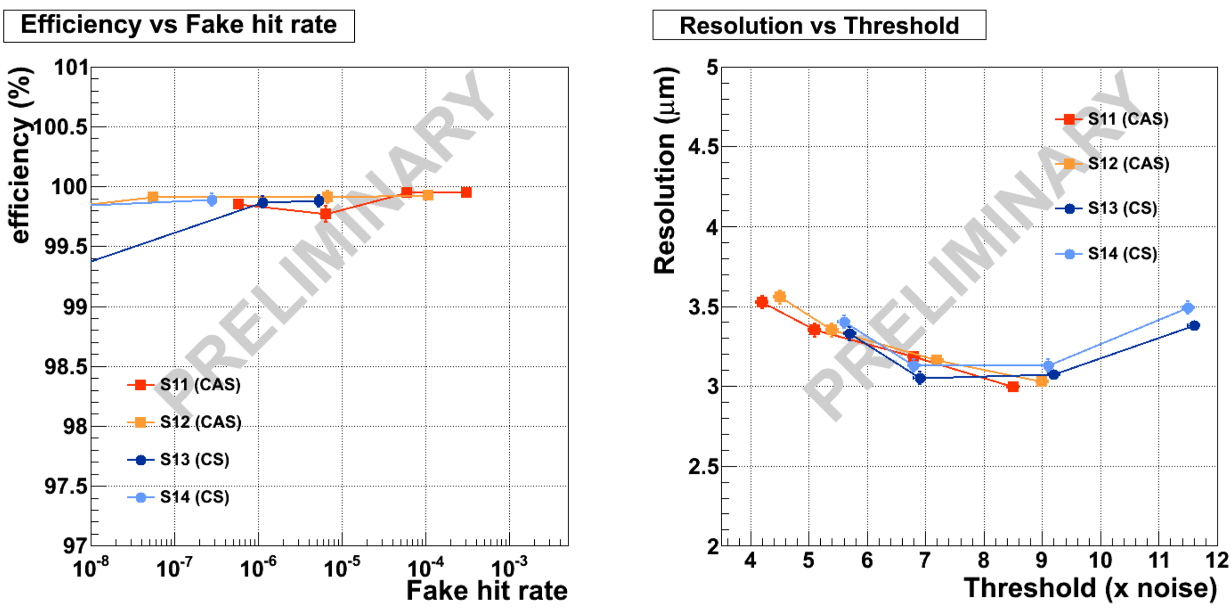

Figure 4: On the left, efficiency versus fake hit rate; on the right, resolution versus threshold.

This sensor has been characterized in laboratory and with a 120 GeV π beam at CERN-SPS. Figure 4 shows the test beam results of the binary outputs before irradiation at 20°C. For all the sub-arrays shown, detection efficiency is still ~ 99.8 % for a fake being less than 10^{-7} which is better than the UTC performances. The single point resolution is ~ 3.5 µm and can decrease to 3 µm when the threshold is optimal: the cluster contains only the useful pixels. This improvement of the single point resolution would mean a better telescope resolution: 1.5 µm. The low fake hit rate observed is also interesting for a large area sensor. The analysis for the other pixels is still ongoing.

4 Conclusion

UTC results are fully satisfactory for the EUDET beam telescope. A version of the telescope with 50µm-thick UTC will be soon available. The improvements explored with IDC with high resistivity substrate will be useful in the next European Project AIDA [5].

Acknowledgement

This work is supported by the Commission of the European Communities under the 6th Framework Programme "Structuring the European Research Area", contract number RII3-026126.

References

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