Back-thinning of CMOS Monolithic Active Pixel Sensors for the ILC at LBNL

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In this paper we present preliminary results concerning back-thinning of CMOS monolithic active pixel sensors which are under consideration for use in the Vertex Tracker at the International Linear Collider.

1. INTRODUCTION

The Vertex Tracker for the International Linear Collider (ILC) has requirements that largely surpass those of the detectors at LEP, SLC and LHC. Not only does the single point resolution need to be improved to just a few microns, but the material budget should not exceed 0.1% X_0 per layer. This is mainly motivated by the need to efficiently identify all of the secondary particles in hadronic jets initiated by a heavy quark in order to distinguish c from b jets and also to determine the vertex charge, which is important for searches for new physics at the high energy frontier. This translates to a requirement for Si pixel chips that do not exceed 50 μm in thickness. CMOS monolithic active pixel sensors are ionizing radiation detectors which feature a field-free, un-depleted sensitive volume. Because charge generation in these devices is confined primarily to a thin epitaxial layer of just 10-20 μm, it is possible to remove most of the bulk silicon using a back-thinning process without significantly affecting the signal charge collected. This makes CMOS detectors an appealing candidate for meeting the ILC physics requirements for material budget. While earlier studies have demonstrated successful back-thinning of wafers of CMOS pixel structures, in this study we back-thin individual diced chips and characterize the sensor performance before and after thinning to assess possible changes in signal charge collection. This paper presents the preliminary results of our study and is organized as follows. In Section 2 we review the specifications of the prototype chip used for testing as well as the experimental procedure. In Section 3 we discuss the characterization tools used to test each sensor. In Section 4 we discuss the details of the back-thinning process as well as procedures used to prepare and handle the chip before and after thinning. Our results are presented in Section 5 and a discussion of these results in Section 6. We conclude with Section 7 in which we discuss our plans for future work.

2. EXPERIMENTAL PROCEDURE

We have chosen to perform the back-thinning study on the Mimosa V chip [1, 2] developed at IPHC in Strasbourg, France. This chip is fabricated using the 0.6 μm AMS process and features a large active area of 1.9×1.7 cm^2 and more than 1 million pixels. The epitaxial layer is 14 μm thick and the pixel pitch is 17 μm. The detector is divided into four independent sectors. For testing purposes, the chip has been mounted on a mezzanine card which is installed on a readout board. Data acquisition and online analysis are performed using a LabView program and offline data analysis is performed using a dedicated C++ program.

The chip characterization procedure consists of three parts. The chip is mounted on the mezzanine card using a removable glue. First the gain of the detector is measured using a ^{55}Fe source, then charge generation at various depths is probed using collimated lasers of various wavelengths, and finally the response to minimum ionizing particles is studied using the 1.5 GeV electron beam at the Advanced Light Source (ALS) at LBNL. The chip is then removed from the mezzanine card by detaching the wire bonds and placing the chip and card into a heated solvent bath which dissolves the glue. The chip is next sent to Aptek Industries [3] for back-thinning, after which it is permanently attached to the mezzanine card with film adhesive and re-bonded. The same characterization procedure is repeated and the comparison of results allows us to determine the change in chip performance due to the back-thinning procedure.

3. CHARACTERIZATION PROCEDURE

We determine the detector gain using the X-rays emitted by a ^{55}Fe source. Charge generated by X-rays which convert in the shallow depletion region near the pixel diode is fully collected, resulting in a pulse height peak corresponding to the 5.9 keV emission line, or

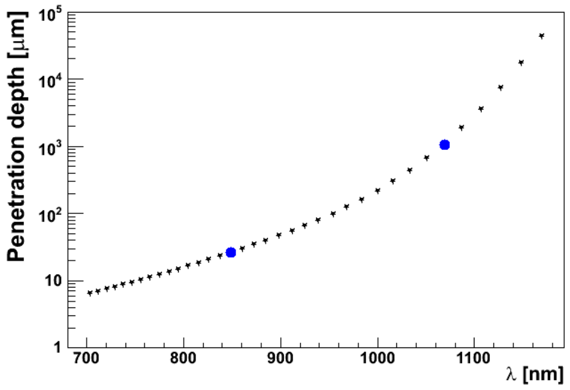

Figure 1: Penetration depth of photons in Silicon as a function of their wavelength.

1640 electrons, which provides the ADC count calibration in electrons. Typical values for the Mimosa V chip in our setup are in the range of 6 to 8 electrons per ADC count.

We use lasers to probe charge collection properties of the sensor. The penetration depth of photons in silicon is strongly dependent on wavelength as shown in Figure 1. We use an 850 nm laser to probe charge generation restricted to the epitaxial layer and a 1060 nm laser to probe charge generation throughout the full wafer thickness. The setup consists of a laser diode pig-tailed to 6 μm-core optical fiber. The fiber terminates on an aspheric lens doublet which provides a collimated beam with Gaussian profile. Data is analyzed by selecting a fixed 25×25 pixel matrix centered around the signal maximum and integrating the charge collected in this matrix over several hundred events.

The detector response to minimum ionizing particles is determined using the 1.5 GeV electron beam extracted from the booster ring of the ALS. The readout cycle consists of a reset followed by the readout of three subsequent frames of the 512×512 pixels corresponding to a sector of the chip. The readout sequence is synchronized with the 1 Hz booster extraction cycle so that the beam spill hits the detector just before the second frame. Correlated double sampling is performed online.

4. BACK-THINNING

Back-thinning is performed by Aptek Industries. Aptek uses a proprietary hot wax formula for mounting wafers and die to stainless steel grinding plates. The use of wax as an adhesive offers greater flexibility for handling thinner parts as well as eliminating the effects of ESD damage often seen on tape mounted systems. The back-thinning is performed by a wet grind process with a rust inhibitor for cooling the wafers and keeping the grind wheel free of debris which could damage the wafers when thinning below 100 μm. The process allows accurate thickness measurements in-situ. After the grinding a polishing process is performed which minimizes the stress from the backside of the device and allows us to achieve thicknesses down to 25 μm. Yields are dependent on various factors related to the quality of the silicon, including where in the ingot the wafers are taken from. Frontside processing factors such as oxides or polyamides as well as the doping of a wafer can cause stress in the silicon lattice and may result in failure in the silicon at ultra thin specifications.

Sector	**Noise**	^{55}**Fe**	**850 nm**	**1060 nm**	**1.5 GeV** e^-
1	-1	+1	-18	-22	-1
2	+6	-16	-6	-3	-10
3	-7	*	-23	-29	*
4	+12	*	-16	-10	*
Average	**+3 ± 7**	**-8 ± 8**	**-16 ± 6**	**-16 ± 10**	**-5 ± 5**

Table I Summary of characterization results for the four sectors of the Mimosa V chip. Results are given as percentage changes of signal pulse heights after back-thinning and the error quoted is the rms of the results for the four sectors.

5. RESULTS

Three chips have been characterized and back-thinned as part of this study. These sensors have been thinned from a thickness of 300 μm down to 50 μm, consisting of 10 μm oxide and metal layers, a 14 μm epitaxial layer and 25 μm Si bulk. The preliminary results reported in this paper are based on the analysis of the four sectors of the third of these chips.

Results are summarized in Table I in terms of the relative change of the response after the back-thinning. Values given for the ^{55}Fe data refer to the centroid of the 5.9 keV peak, those for the laser measurements refer to the mean value of the pulse height distribution, those for the 1.5 GeV e^- beam refer to the most probable value of a Landau function fitted to the cluster pulse height distribution. Typical distributions obtained before and after back-thinning are given in Figure 2 for ^{55}Fe data, in Figure 3 for the 850 nm laser and in Figure 4 for the 1.5 GeV e^- beam.

6. DISCUSSION OF RESULTS

The results of tests of the four sectors of a Mimosa V chip show no significant degradation in the performance after back-thinning to 50 μm. The ^{55}Fe

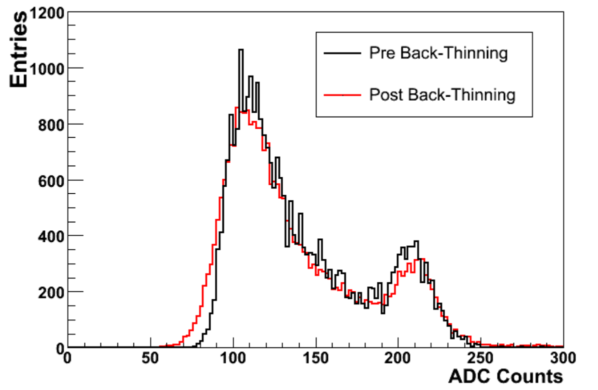

Figure 2: Cluster pulse height spectra for the ^{55}Fe source before (black) and after (red or grey) back-thinning.

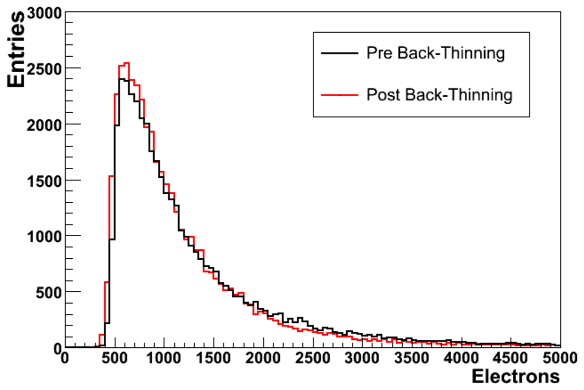

Figure 4: Cluster pulse height spectra for 1.5 GeV e^- before (black) and after (red or grey) back-thinning.

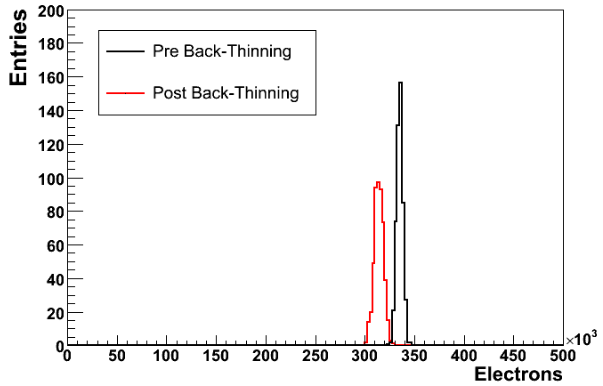

Figure 3: Cluster pulse height spectra for the 850 nm laser beam before (black) and after (red or grey) back-thinning.

data indicate that after the back-thinning process the gain is only slightly affected. It is of interest to consider the change in width of the 5.9 keV emission line peak. For sector 1 this value does not change significantly while for sector 2 it shows an increase of 40%. This effect is under investigation.

Data collected with laser sources indicate that the measured collected charge has decreased by an amount varying between 3% and 29% for all sectors and with both lasers. While this may indicate that the back-thinning has slightly affected the charge collection properties of the sensor, the change is consistent with the repeatibility of the measurement. This is supported by the ALS data obtained for sectors 1 and 2 which indicate a mean decrease of just 5% in the most probable value of the collected charge.

7. CONCLUSION

We have characterized, successfully back-thinned to 50 μm and re-characterized a Mimosa V CMOS monolithic active pixel sensor. Preliminary results indicate that the back-thinning procedure has not significantly affected the gain and charge collection properties of the sensor. These results will be extended by more data to be obtained by characterizing additional sensors, possibly back-thinned down to 35 μm.

Acknowledgments

We thank Marc Winter for discussion and Howard Matis for help with the data acquisition system. This work was supported by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. We are indebted to the staff of the ALS for their help and the excellent performance of the machine.

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