200 mm Silicon Wafer Processing for Large Area Strip Detectors

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Abstract—We developed large silicon single-sided strip detectors made of 200 mm float-zone Si wafers. The single-sided silicon strip detectors have an effective active area of 156 cm² and 725 μm in thickness and were fully depleted. Basic performance was measured using Am-241 and Co-57 sources. The leakage current varied from strip to strip due to some contaminations during the processing.

I. INTRODUCTION

Silicon radiation detectors are currently fabricated on 100 mm (4”) and 150 mm (6”) silicon wafer. Detector fabrication has effectively been lagging ~ 10 years behind the regular semiconductor industry. One reason for this was a lack of high resistivity silicon wafers with diameter larger than 150 mm (6”) which can only be grown using the Float Zone (FZ) method. Most wafers for standard semiconductors are grown using the Czochralski (CZ) method which utilizes a crucible and allows up to 450 mm wafers [1].

FZ single crystal silicon is the common base material for thyristors and radiation sensors due to its superior properties. It is available with resistivity in the kΩcm range. Wacker Siltronic AG announced in 2003 that the company successfully pulled the first 200 mm FZ silicon wafers [2].

There are a number of applications where large detectors areas are required, and larger individual detectors would reduce the cost and complexity of such systems. For example, NASA’s Fermi mission (formerly known as GLAST) required 80 m² of silicon strip detectors [3]. Upcoming missions, like a large area Compton telescope, will require even more silicon [4].

An increase in wafer size is not trivial and has its own challenges:

(i) Basic detector development is normally done in a smaller format lab environment, with wafer sizes as small as 4” or 6” on lab type tools. Only a few micro-fabrication facilities can handle single 8” wafers. The processing of 8” wafers is normally done by semiconductor foundries and not in a R&D environment using small wafer quantities [5].

(ii) There were advances in processing between the era of 4” tools and 8” tools, so many processes do not actually translate directly. The process parameters need to be adjusted when transitioning to a larger wafer diameter. This is an engineering challenge for detector fabrication on 200 mm.

(ii) Most lithography steps on 200 mm are done with steppers. Large area detectors require contact lithography [6].

(iv) The larger wafer area can more easily lead to wafer bowing and can more easily lead to stresses in thin films, like passivation layers.

(v) In addition, larger wafers are more fragile at the same thickness than smaller ones [7].

II. DETECTOR DESIGN

The main detector was a single-sided strip detector of 125 x 125 mm area. It has 128 strips, each 0.97 mm wide and 125 mm in length, with a 50 μm gap between strip. (The 128 strips will allow easy integration with readout ASICs.) Figure 1 shows a photograph of the large area strip detector. The guard ring structure is comprised of 25 rings and is 2.2 mm wide. Figure 2 shows the layout of the strips on the large area detector with the guard ring structure. Beside the main detector smaller strip detectors and plain diodes populated the four sides of the main detector. The “baby” detectors were used to perform the IV and CV measurements, see Figure 3. The baby detectors were comprised of 8 strips. The strips dimensions were: 7.1 x 0.7 mm with a 100 μm gap between neighboring strips. In addition, small circular diodes with diameters of 300 and 750 μm were included.

Fig. 1. Photograph of fully processed 200 mm wafer.

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III. DETECTOR FABRICATION

This section describes the process sequence in detail. We performed our processing at the Nanoscience Institute (NSI) of the Naval Research Laboratory. The NSI is a state-of-the-art nano- and micro-fabrication facility with 200 mm processing capabilities. The main facility consists of a 5000 sq. ft. of Class 100 clean room. A few processes, like thermal oxidation, were done using a foundry service. A simplified process sequence is shown in Figure 4.

In order to simplify the process sequence, we fabricate a single-sided strip-detector on n-type silicon. The substrates were 725 μm thick ~ 9,000 Ωcm 200 mm n-type FZ wafers from Wacker Siltronic AG. The wafers were thermally oxidized at Rogue Valley. The oxide thickness was 600 nm. A standard contact lithography step using an AMB Inc. 200 mm aligner defined the strips and guard rings structures. The oxide mask was opened with BOE (buffered oxide etch). RCA I/II and Piranha cleaning steps were used to ensure cleanliness. The implants on the front- and back-side, Boron and Phosphorous, were done by Core Systems. The dose for Boron was $1.5 \times 10^{15} \text{ cm}^{-2}$ (25 keV energy, 7° tilt) and for Phosphorous $2 \times 10^{15} \text{ cm}^{-2}$ (40 keV energy, 7° tilt), respectively. The Boron implants on the front-side formed the strips. Since we used n-type silicon, no p-stops were used between the strips. The implants were activated during annealing in a Nitrogen environment at 950 °C after another full RCA clean. The metal contacts were e-beam evaporated using Aluminum in a lift-off process. The first generation device does not include any passivation layer.

IV. DEVICE TESTING

These measurements were performed on a probe station before the wafers were diced. Figure 5 shows an IV curve of a single strip (neighboring strip and guard rings were also biased). The detector shows an almost linear IV behavior up to 60 V.

We used the “baby strip detectors” for some initial testing. Figure 6 shows $1/C^2$ vs. voltage, where C is the capacitance, for a baby detector. The capacitance is constant from ~ 60 V which indicates that the detector is fully depleted.

Figure 7 shows a photon spectrum from a sealed Am-241 source taken at 70 V bias with a “baby strip” detector. The
energy resolution was 2.6 keV FWHM at 59 keV. This is evidence of good charge collection from the strips. Figure 8 shows a Co-57 spectrum taken at 70 V. The energy resolution was 6.5 keV FWHM at 122 keV.

Fig. 7. Am-241 spectrum taken with a single strip (“baby strip” detector).

Fig. 8. Co-57 spectrum taken with a single strip (“baby strip” detector).

V. YIELD

We find that the leakage current is inhomogenous over all strips. Figure 9 shows the leakage current at 60 V bias for different strips on the large area detector. The currents vary widely from $10^{-8}$ to $10^{-3}$ A. We tested two more wafers, which show a similar (but not identical) leakage current distribution. The processing needs to be improved to limit reverse bias current to less than $10^{-8}$ A per strip. These low currents are required for the whole detector to be useful as a spectroscopy gamma-ray detector.

The large change in leakage current is most likely caused by contamination. Metal contamination from various processes could cause this dramatic range of leakage currents. Water marks or similar contamination associated with the drying process could be another cause. Further studies are needed to determine the root cause of the problem.

Fig. 9. Leakage currents of different strips on the large area detector at 20 °C and 60 V bias.

VI. OUTLOOK

The next step is to increase the yield for the single-sided strip detectors. With the advance of 200 mm wafer processing and the expense of larger FZ wafers and new more expensive tools, the push for defect-free detector manufacturing is even more important. We plan to utilize a defect management system (DMS) [8]. A DMS is crucial to actually determining the root cause of a defect problem. The DMS stores all defect counts, x-y coordinates, defect images, and defect classifications – both by individual wafers and wafer lot. Defect images are linked to specific defects, and lot trend data is available. The inspection/detection tools and DMS allow for integrated yield management for rapid yield learning. Utilizing this methodology, the semiconductor industry has historically achieved the best yield increases [9].

For now, we have only fabricated single-sided detectors. In the near future, we will move to double sided silicon strip detectors. The sensors carry n- and p-type doped strips on opposite sites, orthogonally arranged. Double sided strip detectors allow two dimensional position measurements.

VII. CONCLUSIONS

To the best of our knowledge, we present for the first time a fully depleted detector fabricated on a 200 mm FZ wafer. The devices were tested under gamma-radiation obtaining an energy resolution of 2.6 keV FWHM at 59 keV. Larger radiation detectors will be beneficial for many future detector applications.

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