Photon Back-Scatter Analysis of SOI Wafers

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Silicon-on-insulator (SOI) provides novel challenges in metrology and prevention of subsurface micro-defects. This article shows the potential of a unique analysis tool to pinpoint and eliminate sources of such damage, which can severely degrade minority carrier lifetimes and therefore bipolar device gain. Cross-sectional analysis of an IC manufacturing process has been done for the first time, indicating curing by annealing and generation of new defects by different process steps.

Introduction

Photon back-scatter (PBS®) analysis is a very sensitive tool to detect (subsurface) lattice defects and possibly strain typically introduced by the sawing-polishing sequence in the wafer preparation process [1]. We have used this tool for the first time to both analyze SOI wafers from different manufacturers and to study the evolution during processing. Such strain and defects are known to serve as recombination centers and thereby affect minority carrier lifetime in silicon, potentially increasing uncontrollably parameter spread in finished circuits.

PBS® Technique

Photon back-scatter (PBS®) uses a circularly polarized He-Ne laser probe beam at the 632.8nm wavelength with a 300µm diameter on the wafer surface, see Fig.1. An incidence angle of 55° off-normal is chosen to increase absorption of P-polarized (electric vector is parallel to the plane of incidence) light. Separate P-polarized and S-polarized (electric vector is perpendicular to the plane of incidence) detectors are set up 25° off normal in the same quarter-plane of incidence as the laser source (the backscatter direction). The signal intensity at this angle is normalized to the surface reflectance and probe beam power. For the PBS® measurement, only the P-polarized component of the scattered light is used.

The measurement is done in two steps. First, some 21 adjacent spots, in the center of the wafer, are analyzed by measuring the scatter versus azimuth angle for each location. The results are used to determine an orientation in the subsurface damage indicated by a maximum scatter direction. The plane of incidence is fixed in this direction and the whole wafer is X-Y scanned under these optimum conditions. The final maps cover 116mm on a 125mm wafer with 0.25mm x- and y resolution (pixel size).

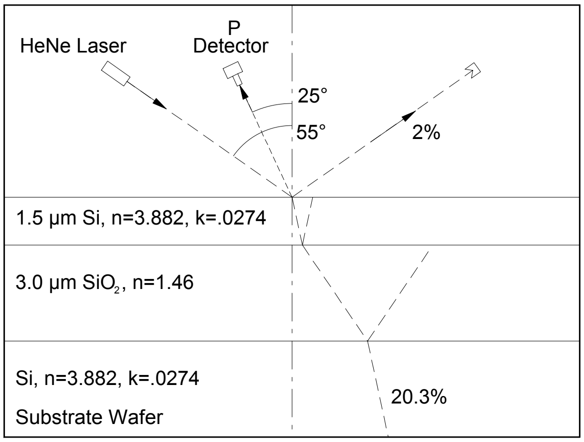


Figure 1: Schematic representation of PBS® in SOI with indication of probe beam direction and intensity.

Fig. 1 shows that the calculated reflectance (calculated for a two-layer film from Heavens [2] using the complex index of refraction values from Palik [3]) is only 2% for the P-polarized light. This number can vary considerably even with a very small shift in the thickness of the layers. The actual measured reflectance was about 0.7%. The calculated intensity transmitted into the substrate wafer was 20.3%. Only a very small percentage of this light is scattered back through the surface to be detected.

Given the incomplete attenuation in this "thick" SOI film and the generated multiple reflections it is a-priori not clear if this technique can be applied to SOI films. Indeed, it will be shown that interference from material interfaces can completely overpower the weak scatter-signals from material defects. Additionally, no quantitative information is available on how much of the back-scatter signal stems from each layer or interface. We report here initial results and expect that analysis of defects will rapidly improve with growing experience.

Sample preparation

Several 125mm SOI wafers from different suppliers with 1 and 3µm buried oxide and 1.5µm SOI film were laser-marked, PBS® analyzed, and processed to different stages in a thin-film SOI high-voltage BCD (bipolar-CMOS-DMOS) process [4]. Such processes typically involve extended high-temperature steps (up to several hours at 1200°C) and it is not evident to what extent defects will be annealed out or freshly introduced. Most wafers used in this study were left unpatterned to eliminate effects from topography, but “masked” and “unmasked” wafers were used to identify the effect of such local process steps. A few wafers were patterned with a single mask each, such as localized oxidation of silicon (LOCOS) and removal of the oxide, resulting in a patterned SOI film thickness.

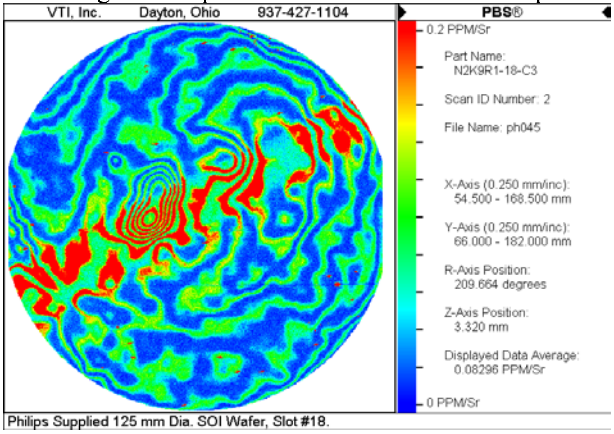
Experimental results

Surprisingly, the results were very informative despite the many potential problems in SOI. This experiment showed also that some minimum requirements must be met by the SOI material for this method to be useful, i.e. the thickness control of SOI film and buried oxide must be excellent. Fig. 2 shows a sample where SOI thickness varied between 1.3 and 1.7µm. Sufficient scattered light comes from the top and bottom SOI interface to generate Newton fringes. The band of high scatter signal from 2 to 8 o’clock across all fringes of the wafer is typical of curved polishing damage that is very close to the surface. This feature disappeared in processing.

Several SOI wafers showed ghost images of the bonding and polishing tools (Fig. 3). Also frequently seen were structures looking a bit like water stains with high contrast (low and high PBS® scatter values with essentially no transition region), as shown in Fig. 4.

Comparing a wafer as received and after an extended anneal cycle (Figs. 5 and 6) reveals that some features are preserved (encircled). It is not clear if the others have been annealed out or if the process-induced signal (“flame-like” feature extending from the flat at right towards the left) just overpowered it (notice the big difference in intensity scale). It is also interesting to note that Fig. 6 shows clear “imprint” of a wafer-cassette on both sides, the wafer having been inserted with flat down.

Despite the Newton interference pattern with varying SOI thickness it was also possible to obtain useful signals on patterned wafers. As an example the effects of a certain contact etch was studied (Fig. 7). Clearly, the back-scatter signal varies from circuit to circuit (repeating pattern in picture), “empty” fields are taken up by process-control monitors (PCM). The differences within die and also from die to die might be an indication of local and global differences in plasma-density of this tool at the chosen setting. A limitation in this analysis mode is not only the incident spot size but also the internal reflectance, giving rise to a somewhat wide probe area.



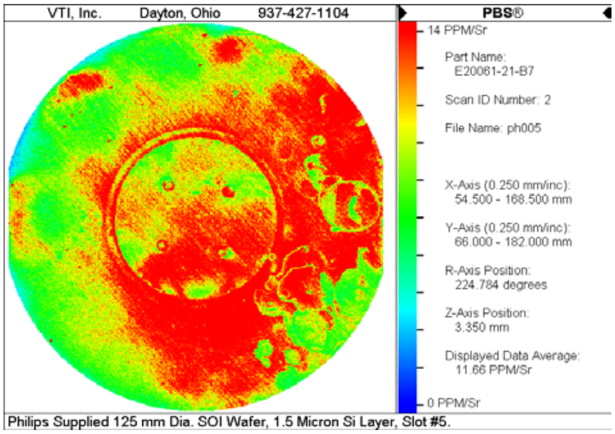
Part Name: N2K9R1-18-C3
Scan ID Number: 2
File Name: ph045
X-Axis (0.250 mm/inc): 54.500 - 168.500 mm
Y-Axis (0.250 mm/inc): 66.000 - 182.000 mm
R-Axis Position: 209.664 degrees
Z-Axis Position: 3.320 mm
Displayed Data Average: 0.08296 PPM/Sr
Philips Supplied 125 mm Dia. SOI Wafer, Slot #18.

Figure 2: Newton fringes on a SOI wafer with poor film thickness uniformity.

In order to gain additional insight into the depth of the defect structures seen on the maps, one of the test wafers was mapped in the ultraviolet (325nm) as well as the red (632.8nm) before any processing was done. At this short wavelength the probe beam does not penetrate through the silicon layer. The defect detection depth in silicon at 325nm is estimated to be about 10nm. The standard results are shown in Fig. 8 and the UV results are shown in Fig. 9. The two maps are almost identical except for scale. The similarity of the two maps indicates that the damage patterns in this wafer come right up to the surface and are not confined to the interface between the layers as might be expected. Note that the UV measurements were made on a different instrument with a different coordinate system and the map only covers a 100mm diameter area on the wafer.

Conclusions

This paper has shown the potential of photon back-scatter analysis of SOI wafers. Both bonding-related and process-induced patterns have been detected and discussed. Due to the observed variability between starting wafers, process-induced effects can only be studied by analyzing a wafer before and after such a step. Nevertheless this method has been used to control and improve the annealing of implantation-induced defects. It appears that even die-to-die comparisons are possible and meaningful with this tool, allowing the monitoring of LOCOS oxidation and certain resist-masked plasma-processing steps.



Part Name: E20061-21-B7
Scan ID Number: 2
File Name: ph005
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Y-Axis (0.250 mm/inc): 66.000 - 182.000 mm
R-Axis Position: 224.784 degrees
Z-Axis Position: 3.350 mm
Displayed Data Average: 11.66 PPM/Sr
Philips Supplied 125 mm Dia. SOI Wafer, 1.5 Micron Si Layer, Slot #5.

Figure 3: Ghost image of bonding/polishing tool on SOI wafer.

References

[1] F. Orazio et al, “Using optical technology to detect subsurface wafer damage and its effect on epitaxial layers”, Micro pp73-92, 3-2002.

[2] O. S. Heavens, “Optical Properties of Thin Solid Films”, pp62-63, Dover Publications, Inc., New York, 1965.

[3] E. D. Palik (Editor), “Handbook of Optical Constants of Solids”, pp565, 760, Academic Press, 1985.

[4] S. Merchant et al, “Realization of high BV > 700V in thin SOI devices”, ISPSD’91, pp31-35, 1991.

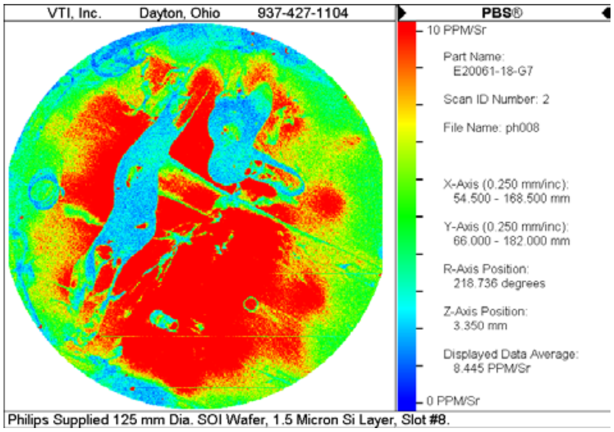

Figure 4: SOI wafer with “water-stains” of low scatter signal.

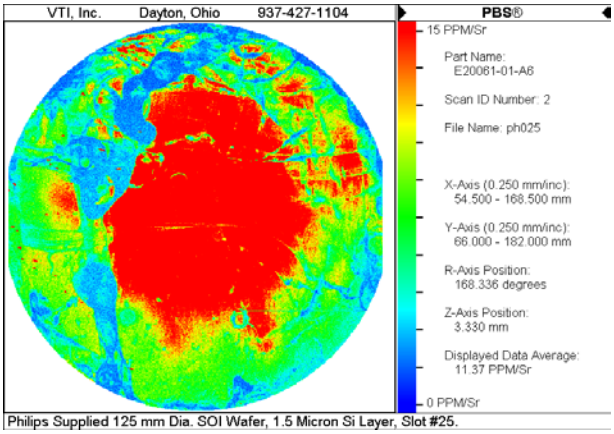

Figure 5: As received SOI wafer prior to extended heat treatment.

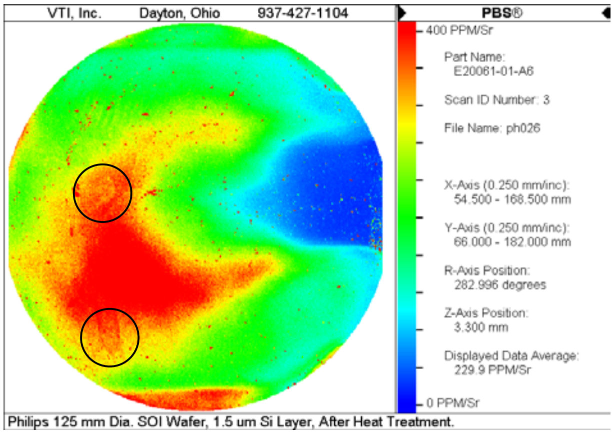

Figure 6: Same SOI wafer after of several hours of anneal at 1200°C. Encircled features were visible prior to processing.

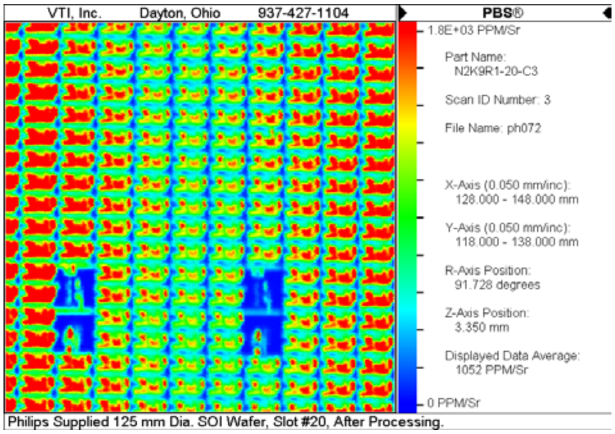

Figure 7: Patterned SOI wafer showing macroscopic variation of back-scatter signal overlaid with repeating circuit pattern.

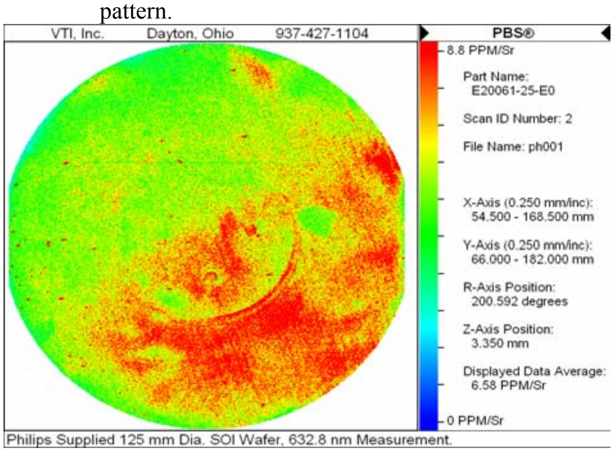

Figure 8. Standard measurement of a test SOI wafer showing tool marks and other damage.

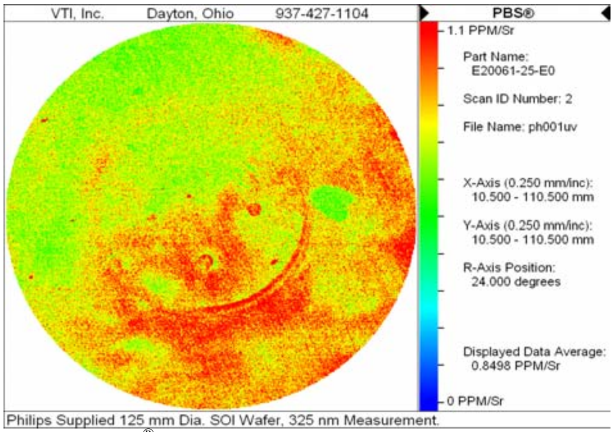

Figure 9. PBS® measurement made at 325nm of the wafer in Fig. 8. Note that this map only covers a 100mm diameter area on the wafer.