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METALLIC CONTAMINATION FROM WAFER HANDLING

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ABSTRACT: The surface photovoltage (SPV) method is used to characterize metallic contamination introduced by wafer handling. It is shown that particles from handling equipment introduce significant levels of metallic contamination. In most cases the correlation between particle contamination and metallic contamination is excellent. We also find that metallic contamination can be introduced during handling in areas where no particles are detected. However, in order to take manufacturing decisions based on surface photovoltage data, one must understand the strengths and limitations of the technique and avoid its pitfalls.

KEYWORDS: microcontamination, metallic contamination, iron contamination, particle contamination, surface photovoltage, wafer handling

Introduction

The investigation of different fabrication processes at Nortel identified that backside particle transfer was an important source of metallic contamination [1,2]. The diffusion of the metallic contamination from the backside to the front surface during any

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important thermal step can seriously harm devices. Metallic contamination in the bulk of silicon is known to affect the reliability and performance of devices by deteriorating the lifetime of minority carriers, increasing the leakage current at p-n junction, and lowering the gate oxide dielectric strength. In this paper, we will review the principles and limitations of the surface photovoltage technique and we will present SPV results obtained for furnace processing and photolithography. The introduction of particles and metallic contamination from wafer handling from monitoring and process equipment will also be presented. In this study, we used the SPV model SPV CMS 4000 from Semiconductor Diagnostics, Inc. Detailed information can be obtained from the SPV tools user's manual.

Surface photovoltage (SPV)

Principles

Minority carrier diffusion length and lifetime can be measured from the spectral dependence of the surface photovoltage [3, 4, 5]. Quantitative information on metallic contamination present in the bulk of silicon can be obtained since the minority carrier diffusion length is strongly affected by metal impurities. The iron concentration can also be measured with the surface photovoltage method. Iron forms Fe-B complexes with boron in p-type doped silicon, these complexes can be dissociated thermally, or by strong illumination at room temperature. A measurement of the diffusion lengths before and after dissociation yields the iron concentration since the interstitial iron (Fe_i) is ten times more effective to capture an electron than Fe-B complexes [6, 7]. The iron concentration can be obtained from

$$Fe \text{ (cm}^{-3}\text{)} = 1.1 \times 10^{16} (1/L_{\text{aft}}^2 - 1/L_{\text{bef}}^2) \quad (1)$$

where L_{bef} and L_{aft} refer to diffusion lengths before and after pair dissociation.

Since the optical Fe-B pairs dissociation used by our SPV system limits the measurement of the iron concentration to only 9 points on the wafer, a clean process that provides the necessary temperature-time factor to achieve thermal dissociation was needed. In the following experiments, we used the hot phosphorous acid bath to dissociate Fe-B complexes completely. The wafers pulled from the hot phosphorous acid are immediately given a cold DI water and HF rinse. This quenches the iron who takes up to eight hours to recombine. Comparisons with 9-point optical activation yield identical results in the common areas.

Prior to SPV measurements, the surface contamination is diffused into the bulk with an RTA drive-in step of 4 min at 1050 °C. The RTA robot handler introduces some iron contamination around the wafer center ($\sim 3 \times 10^{10} \text{ cm}^{-3}$).

Limitations

Other recombination centers such as oxygen precipitation and dislocation during boule pulling can reduce the diffusion length, and thus can be mistaken for metallic contamination. Oxygen precipitation can be easily recognized from high resolution diffusion length maps as a series of concentric rings of weak variation in the diffusion length slightly displaced from the center [1].

The measurement of iron concentration is affected by the presence of oxygen precipitation. We have shown that the iron concentration in different wafers after the same gate oxide growth process appears to increase with higher interstitial oxygen levels, because of the error associated with the measurement of small diffusion lengths [1].

Dislocations during boule pulling can also affect the iron concentration measurements since they result in the creation of a ring of low diffusion lengths. However, these dislocations can be removed easily by processing the wafer through rapid thermal annealing [1].

Results

Furnaces

Metallic contamination can diffuse into the bulk of silicon during any thermal step. The oxidation process introduces the most contamination in wafers because of the long times and temperatures involved. A diffusion length map obtained after an oxidation at 1125 °C in 10% O₂ to grow 160 nm SiO₂ is given in Figure 1. The measured iron concentrations are also superimposed on the diffusion length map of Figure 1. The low diffusion length regions in areas where the quartz boat touches the wafers in the furnace correspond to high iron concentration.

We have also observed that contaminated reclaim wafers can introduce significant levels of bulk contamination in adjacent wafers during long oxidations [1].

Photolithography

The photo-engraving (PE) process is repeated 20 to 30 times during fabrication. The introduction of metallic contamination at every photo-engraving process step can thus lead to the accumulation of large contamination in the bulk if diffused during any thermal process. In order to investigate the PE process, several wafers were submitted to different

steps such as the photoresist deposition, the etch process and the O₂ and CF₄ ash process in various combinations. After processing, the wafers were cleaned as usual and then RTA'd at 1050 °C for 4 minutes. High levels of metallic contamination were introduced during the etch process. The iron concentration map of a wafer submitted to photoresist deposition, the etch process and the CF₄ ash process is shown in Figure 2. The high iron concentration regions in a triangular pattern (peak values of 1.4x10¹³ cm⁻³) correlate with the wafer support of the etcher. In this case, the wet clean has proven ineffective at removing the metallic contamination.

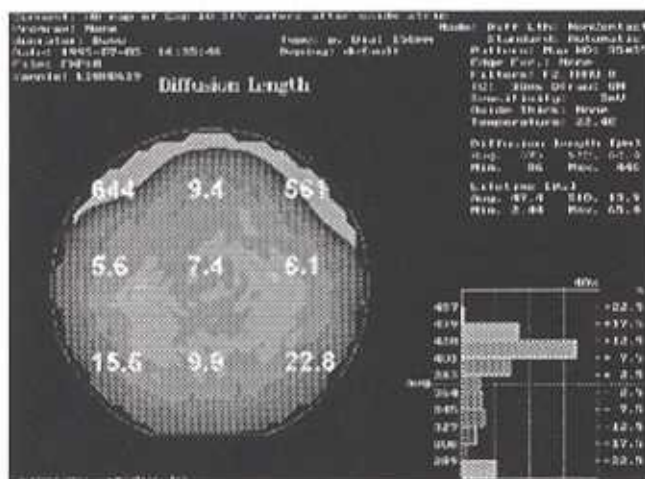


Figure 1. Diffusion length map and iron concentration values (in units of 10¹⁰ at/cm³) of a wafer after furnace processing.

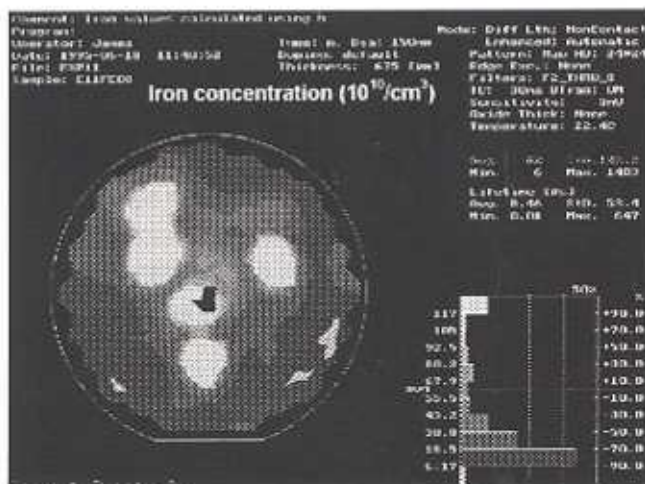


Figure 2. Iron concentration map of a wafer submitted to a standard photo-engraving step, including clean.

Backside contamination from wafer handling

We have shown that wafer handling during normal processing can introduce significant levels of metallic contamination into the bulk of silicon. In order to characterize the transfer of backside contamination during handling, wafers were placed on the chucks of several monitoring and processing equipment (no processing was done). The metallic contamination transferred to the wafer surface was then diffused into the bulk by RTA. Particle monitoring wafers and control wafers were also included. The particle map and the iron concentration map for a Rainbow etcher are shown in Figure 3. We can see that the particles transferred from the chuck of the etcher to the wafer surface introduce significant levels of iron contamination (peak values of $9.5 \times 10^{12} \text{ cm}^{-3}$).

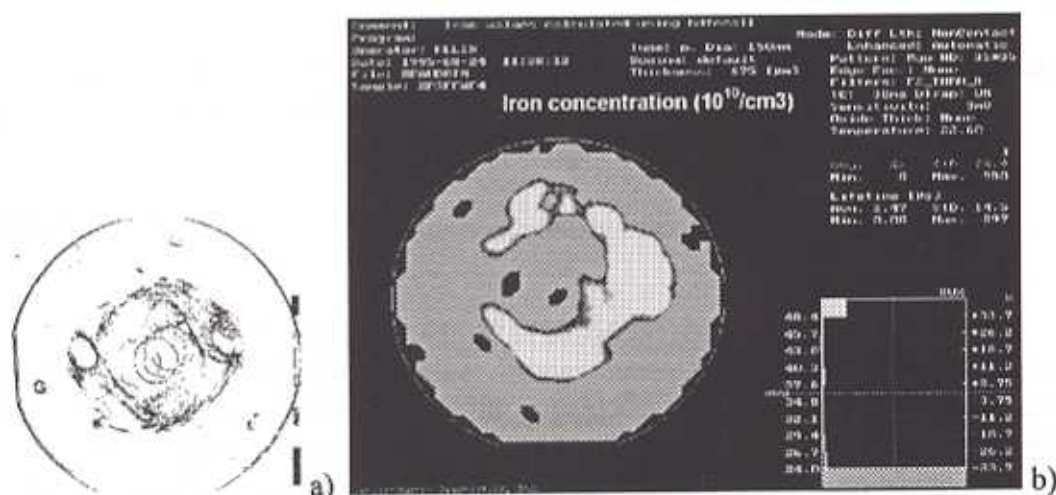


Figure 3. a) Particle map from a wafer placed on a Rainbow etcher. b) Iron concentration map of a wafer put on a Rainbow etcher and processed by RTA.

In general, particle maps correlate with diffusion length maps and iron concentration maps. In some cases, areas of low diffusion lengths do not correlate with high iron concentration [2]. Low diffusion lengths can also be attributed to other fast-diffusing metal impurities such as chromium.

A similar experiment was conducted for the handlers of a resist strip equipment. The particle map and the iron concentration map are shown in Figure 4. In this case, there is no correlation between high iron concentration and particles. The iron concentration peak values introduced by this equipment are approximately $2 \times 10^{12} \text{ cm}^{-3}$. Metallic impurities can thus be introduced during handling where no particles are detected. The traditional method of monitoring handling equipment through particle maps is not sufficient to characterize the cleanliness of the wafer or of the instrument.

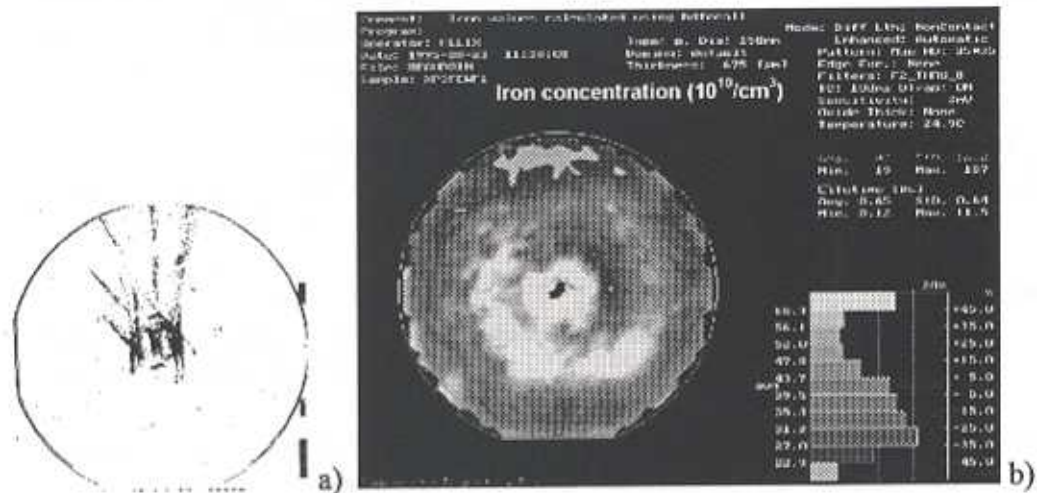


Figure 4. a) Particle map from a wafer placed on a resist stripper. b) Iron concentration map of a wafer put on a resist stripper and processed by RTA.

Conclusion

Wafer handling during processing can introduce significant levels of metallic contamination in wafers through contact. In some cases, there is a lack of correlation between particle contamination and metallic contamination. Particle monitoring is not enough to assess completely contamination issues. The surface photovoltage is shown to be a powerful method to detect metallic contamination introduced from wafer handling. However, other recombination centers such as oxygen precipitation and dislocation must be accounted for in order to avoid false iron concentration measurements.

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