

Liquid-borne nano particles impact on the random yield during critical processes in IC's production

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Abstract— Semiconductor industry faces a continuous challenge to decrease the transistor size as well as to increase the yield by eliminating defect sources. One of the sources of particle defects is ultra pure water used in different production tools at different stages of processing. In this paper, particle count data measured in ultra pure water is related to the yield of two large size products. An impact of nano-particle present in ultra pure water on yield of up to 4-6 % has been found in two different products.

Index Terms— Yield, Defect density, Particle contamination, Linear regression

I. INTRODUCTION

Yield of semiconductor industry can be defined as the fraction of Integrated circuit (IC) devices that are functional at the end of the fabrication process. The existence of any semiconductor industry is directly related to the cost of processing and to the number of the devices that can be produced without any defects. By determining the probability of defects located in the critical areas, it is possible to predict yield in the integrated circuits (IC). A number of yield models are used to predict yields including Poisson, Murphy, Seeds, and negative binomial models are well-known examples [1,2,3,4].

Generally, yield loss is divided into two components: systematic yield loss and random yield loss. Systematic yield loss is due to deviations in device and material parameters. Random defect yield loss is often associated with contamination problems and process induced particles. It was observed that a large part of the random defects is due to particle contamination coming on the wafer during different process steps and caused random yield loss.

For detection and monitoring of particulate defects in the process line dedicated inspection tools are used that are based on light scattering principles [4]. A laser beam is scanning the surface of the wafer and is scattered by the surface defects. The detection method is used in two types of monitor procedures.

In the offline monitoring, bare-wafers are processed in different tools and the added defects during the process on

these wafers is measured. In inline monitoring, production wafers are inspected after critical process steps.

The detrimental impact of particles is the main reason that IC manufacturing is done in the controlled environment of a clean room [5]. But still most of these contaminations have been generated or/and coming from the environment around the Fab. At the same time there is surprisingly little experimental evidence for the detrimental impact of particles.

We considered ultra pure water (UPW) as an important external source of particle contamination. UPW is used in many process steps like wet etch, cleaning steps as well as lithography.

This study is the continuity of our previous study in which we statistically investigate the possible relation between the particle concentration in UPW and defects measurements with offline monitoring [6]. In this paper, we focused to investigate the possible relation between the particle concentration in UPW and defectivity data of a mature product in the Fab.

II. METHODS

A. Methods to analyze ultra pure water

A water treatment plant provides UPW required for IC-production in the Fab. The amount of particle counts in UPW coming out of treatment plant is measured by using a particle-counting tool. In Fab Particle Measuring Systems “laser particle counter: ultra DI50” are installed. This tool is capable to detect particles down to 50 nm (Latex Sphere Equivalents). DI50 is calculated each 40 minutes during the time frame investigated.

The data has been separated into four different particle size classifications i.e. equal and bigger than 50 nm, 100 nm, 150 nm, and 200 nm. Table 1 shows the typical average value of particle counts and standard deviations for each size measured. The problem with measuring small size particles is interference of background noise by the tool. For this reason inline defects have only be correlated with particles > 200 nm. It should be noted that the reported size could deviate by a factor of two from the actual size. [7].

TABLE I. TYPICAL PARTICLE PERFORMANCE OF FAB, MEASURED WITH DIFFERENT TOOLS

Particle measuring tool	Sampling time	Typical readings* (Particles / L)			
		50 nm	100 nm	150 nm	200 nm
DI 50	40 min	300 (50)	150 (30)	100 (20)	50 (20)

Variations in the number of particles are shown in parentheses

B. Method to analyze yield

Mature products Y and X manufactured in the Fab with a die area of 35.5 mm² and 50.1 mm² (with minimum feature size 0.35 μm) respectively are selected. Defects due to particle contamination are monitored on the surface of the wafers using KLA SP1 Classic. A manufacturing database has been used to collect information about lot identification, duration and date the product was processed in each step, and yield of the lot.

Four process steps have been selected for this study. The pre-gate oxidation cleaning step (according to the specifications of International Technology Road-map of Semiconductor) is critically sensitive to particle deposition [8]. Additionally a photo poly gate step and a photo metal-1 step are also sensitive to particle deposition. Cleaning steps before anneal are considered to be a non-critical step for particle contamination and one was selected as well.

C. Statistical methods

Linear regression is considered to be the most appropriate way to determine possible relation between two different data sets. In this study, linear regression with confidence interval of 95% is used to determine a relation between the particle counts in UPW and defect density. Furthermore, the values of slope (unity 10³cm) and intercept (unity defects/cm²) are considered significantly different from zero only if the values are larger than two times the standard deviation. This means that the confidence level for a non zero value is larger than 97.7% [9].

III. RESULTS AND DISCUSSIONS

A. Yield variations due to particles present in UPW during pre-gate oxidation clean

In Fig. 1, particles present in UPW during a cleaning step are plotted against the defectivity data of all lots of product Y processed in half a year. Statistical analysis shows that during the cleaning step before gate oxidation UPW quality has a linear relation with the overall defectivity of the product. The slope (48(8)·10⁻⁵) is significantly larger than 0.

In Fig. 1, the intercept of the line represents the defectivity of

the process excluding the effect of particles in UPW during this process. The total possible yield without particles can be calculated using the Poisson equation [4].

$$D = -(\ln Y) / A \quad (1)$$

where Y is the yield, A is the area of the die and D is defect density.

Calculated yield with the intercept value using (1) is 92.3 %. The actual average yield for these 159 lots is 91.1 %. The 1.2 % yield difference between the calculated yield and actual average yield is the yield loss caused by the particle contamination in the UPW only in this process step during the whole period.

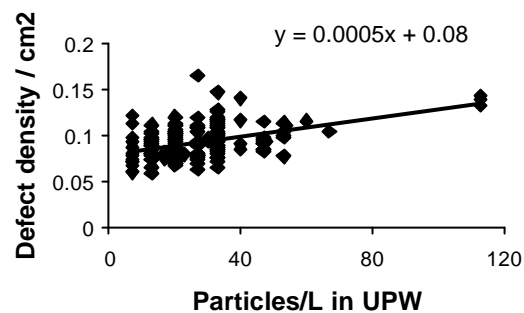


Figure 1. UPW particle monitored data and defect density of pre-gate cleaning process with p = 0.001.

Fig. 2 shows the defectivity data of the 54 lots of product X that were processed during half a year.

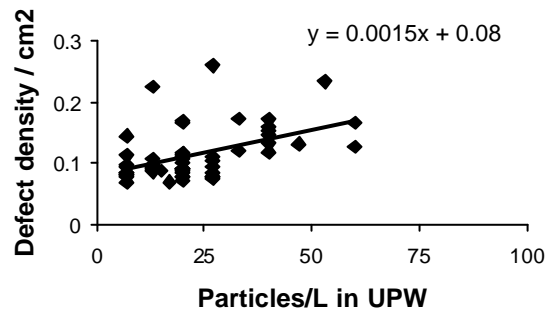


Figure 2. UPW particle monitored data and defect density of pre-gate cleaning process with p = 0.001.

The slope (15(3)·10⁻⁴) is larger than 0, which again suggests a relation between defect density of the lots and particle counts in UPW. The impact of these particles on yield is calculated by using the intercept value of equation shown in Fig. 2. The yield loss caused by particles in UPW during this step is 3.1%.

B. Yield variations due to particles present in UPW during photo poly process

During the Poly-gate patterning, development of the photo poly is one of the steps in which UPW is used inside the litho tools. Table 2 shows that during the photo poly step UPW quality has an influence on the overall defectivity of both products (X and Y) with slopes significantly larger than 0. In this case, the yield loss (due to the particle counts in UPW) calculated in product X using the intercept is 1.4 % and yield loss for product Y is 1.1%.

C. Yield variations due to particles present in UPW during the photo metal-1

Photo metal-1 is also considered a critically sensitive to particle deposition. Particle data of UPW was compared with the defectivity data of the products during metal-1 step and results are shown in Table 2. The slope values indicate a significant relation between both data. The intercept gave a yield loss of 1.5 % in product X and 1.4 % in product Y due to the particles in UPW during this step.

D. Yield variations due to particles present in UPW during the cleaning step before anneal

An anneal step is considered a non-critical step for particle contamination. To verify this statement, the particles data of UPW supplied during cleaning before the anneal step was compared with yield. The slope values show in Table 2 for both products are not significant different from 0. This indicates that UPW quality has no influence on the overall defectivity of the product during this non-critical step.

TABLE II. RANDOM YIELD LOSS INDIFFERENT PROCESS STEPS DUE TO PARTICLE CONTAMINATION IN UPW.

Steps	Product	Slope* (10 ³ cm)	Intercept* (Defects / cm ²)	Yield loss due to particles* (%)
Photo poly	X	7(1)·10 ⁻⁴	0.074 (0.003)	1.4 (0.3)
	Y	5(1)·10 ⁻⁴	0.08 (0.003)	1.1 (0.3)
Photo metal-1	X	8(1)·10 ⁻⁴	0.078 (0.003)	1.5 (0.3)
	Y	7(1)·10 ⁻⁴	0.08 (0.002)	1.4 (0.2)
Pre-cleaning of anneal	X	-7(4)·10 ⁻⁴	0.13 (0.01)	Not significant
	Y	-8(5)·10 ⁻⁵	0.10 (0.06)	Not significant

*Variations in the number of particles are shown in parentheses

IV. DISCUSSION

The impact of particle contamination due to UPW is not well known. This makes it difficult to define the specification limits on the quality of UPW. The presented statistical analysis indicates that specific particle contamination entering in Fab with UPW causes a random yield loss in two different products. The total yield loss due to particle contamination in product X is 6 % in three critical process steps and in product Y, yield loss is 3.7 %. The product with larger active areas has more probability for particle deposition compared with the product with smaller area. The difference of yield loss in two different products can be explained by the product size.

V. CONCLUSIONS

A statistical approach identifying the defectivity of two products caused by particle counts in UPW has been described. For the first time a direct impact of particle contamination in ultra pure water on random yield loss is found. It has been shown that nano particle contamination in UPW in three critical steps causes a mega impact on the yield loss up to 6%.

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The topic of PhD is “Impact of nano particles on integrated circuits yield”. This means to understand the deposit ion and the removal mechanism of nano particle contamination. To determine the source of these contaminations and evaluate the loss of random yield caused due to these contaminations. The field requires a good knowledge of colloidal chemistry, statistical methods and Nano technology.