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Impact of particles in ultra pure water on random yield loss in IC production

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ABSTRACT

The influence of environmental particle contamination on offline measured defects and manufacturing yield in integrated circuits is discussed. One of the sources of particle contamination is ultra pure water used in different production tools at different stages of processing. Particle count data measured in ultra pure water is compared with the offline defects caused by process tools and the relation has been statistically confirmed. Particle count data is also compared with the defect density of large size products. An impact of particle contamination on yield of 4–6% has been found. In this study, fundamentals are provided to define the meaningful specifications of ultra pure water for wafer fabrication.

1. Introduction

The semiconductor industry is trying to increase the yield by controlling the contamination in the environment. Yield is defined as the average ratio of the number of usable devices that pass different tests to the number of maximum potentially usable devices at process start. By determining the probability of defects located in the critical areas, it is possible to predict yield in the integrated circuits (IC) [1,2].

Yield is divided into two components: systematic yield and random yield. Systematic yield represents the deviations in device and material parameters. Random defect yield is often associated with contamination problem. 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 [3].

As a result of the shrinkage of technological features into nanoscales, it is becoming more necessary to control the nano particle contamination [4]. Most of these contaminations have been generated or/and coming from the environment around the Fab. We considered ultra pure water (UPW) as an important environmental source of particle contamination. UPW is used in many process steps like wet etch, cleaning steps, and lithography. To define realistic specifications for the wafer environment, it is essential to determine the impact of contamination coming from the UPW.

For detection and monitoring of particulate defects in the process line dedicated optical inspection tools are used that are based on light scattering principles [5]. A laser beam scans 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 defects added are measured.
- In inline monitoring, production wafers are inspected after all critical process steps.

In this study, first we statistically investigate the possible relation between the particle concentration in UPW and defects measurements with offline monitoring. Secondly, the relation between the particle contamination in UPW and defectivity data of a mature product in the Fab is analyzed.

2. Materials and methods

2.1. Method to analyze particle counts in UPW

Two water treatment plants provide UPW required for IC production to two Fabs of NXP semiconductors. The amount of particle counts in UPW coming out of two installations is measured by using particle-counting tools. In Fab-I particle measuring systems “optical particle counter HSLIS M50e” and in Fab-II “laser particle counter: ultra DI50” are installed. Both of these tools are capable to detect particles down to 50 nm (Latex Sphere Equivalents). Tool

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M50e gives daily average value of the particles per liter of UPW. While in the DI50, every 40 min data is collected. After particle detection, UPW is supplied directly to different tools without any further filtration.

All 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 by both tools [6]. 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 given size does not mean actual size. This size can deviate of the reported size by a factor of two [7].

2.2. Method to analyze offline defects in Fab-I

Process steps considered in this study are litho and cleaning. In both Fabs, 15–30 different mask steps are involved in typical silicon technology. Cleaning tools increase the yield by reducing the contamination level on the surface of the wafer. A typical silicon technology involves 50–60 cleaning steps. The performance of litho tools and cleaning tools is monitored offline on a weekly basis. Particles on the surface of the wafers are measured using the KLA Tencor 6200.

2.3. Method to analyze yield in Fab-II

A mature product (product-X) manufactured in the Fab-II with a die area of 50.1 mm^2 (with minimum feature size 0.35 μm) is selected. 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. In this case, particles are monitored on the surface of the wafers using KLA SP1 Classic.

Four process steps have been selected for this study. The pregate 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.

2.4. Statistical methods

Linear regression is considered to be the easiest 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 10^3 cm) and intercept (unity defects/cm^2) 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 such hypothesis is larger than 97.7% [9].

However, linear regression between particle counts in UPW and offline defects in process tools is not possible because

- Particle count data in Fab-I is an average value per day so it is possible that peaks of particles appeared in UPW at a different time than the monitor process is performed.
- Defects generated in process tools can be due to other process problems than particles in UPW. This means that the set of wafer defects is larger than the (partially) overlapping set of particle data.

Therefore a "2-proportion test" has been used. This compares a proportion from a single sample of data against a known proportion in order to evaluate the relation between two data. In a "2-proportion test", the *p*-value with the confidence interval (C.I.) of 95% is determined. The hypothesis test (sample proportion is larger than known proportion) was considered significant if its *p*-value is less than 0.05.

3. Results

3.1. Relation between particle counts in UPW and offline defects in Fab-I

In Fig. 1, the amount of particle counts in UPW and defects generated by a cleaning tool (Clean-1) are plotted against the dates of monitoring over the year. Data of UPW was measured every day over a year but the cleaning tools are checked only once or twice in a week. Data is only plotted if both measurements on the same day are available. This figure indicates that in some cases when the particles level in the UPW increases the defects added in the cleaning tools are also higher.

Similarly in Fig. 2, the amount of particle counts in UPW and defects generated by a litho tool (Litho-1) are plotted against the dates of monitoring over year. This figure shows that there are fluctuations both in the particles present in UPW and in litho defects. Compared to the cleaning tool, the relation in litho tool is more obvious. Eleven times large peaks coincide in both data. This suggests that

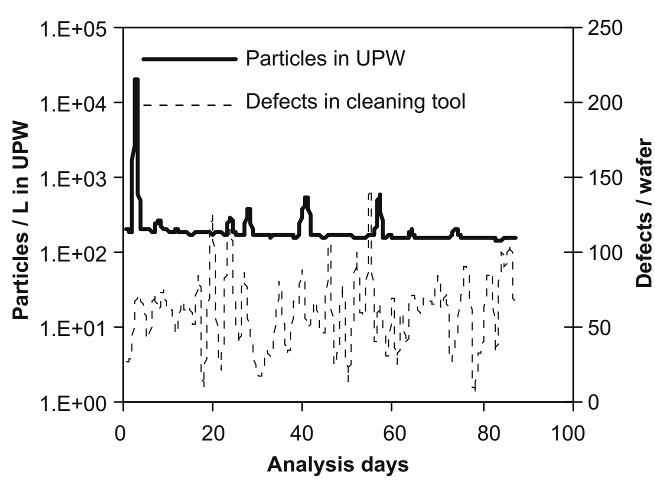

Fig. 1. UPW particle monitored data and defects in cleaning tool sorted by date in Fab-I.

Table 1
Typical particle performance of Fab, measured with different tools.

Fab	Particle measuring tool	Sampling time	Typical readings (particles/L)			
			50 nm	100 nm	150 nm	200 nm
Fab-I	HSLIS M50e	Daily	1600 (300)	900 (80)	200 (100)	50 (20)
Fab-II	DI 50	40 min	300 (50)	150 (30)	100 (20)	50 (20)