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MEETING WATER QUALIITY SPECIFICATIONS FOR 300 mm PROCESSING

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Biography

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Abstract

This paper reviews the historical ultrapure water specifications and compares them to the specifications for state of the art 300 mm manufacturing. As the design rule has evolved to 0.13 μm, the ultrapure water specifications have made similar evolutions. This paper discusses these evolutions and focuses on the state of the art technologies that are available to meet these specifications. Major components in the water system are discussed and their purpose is reviewed. In addition, environmental concerns, operating costs and plant productivity are also discussed. In conclusion, the authors give general considerations and advice on system design.

Data

As the wafer diameter increases from 200 mm to 300 mm a 2.25 increase of surface area per wafer is realized. This increases the number of chips that can be manufactured on a given wafer. The typical 300 mm fab investment is estimated to be approximately 2.9 billion USD, this is about two times the cost of a 200 mm fab. It is also estimated that the output of a 300 mm fab is about 2.25 that of a 200 mm fab. This added capacity per dollar invested is the significant driving force for the transition to 300 mm processing.

The price of DRAM has drastically decreased over the last year shrinking the profit margins of chip manufacturers.

The increase in productivity of a 300 mm plant is extremely important for a manufacturing facility to stay competitive.

In order to increase the speed and functionality of an integrated circuit (IC), the number of transistors per chip is constantly increasing. As predicted by Moore's law, the number of transistors per chip should double every 20 months. In keeping pace with this trend, the line width of an integrated circuit device correspondingly decreases. The current state of the art line width is 0.13 μm.

The increasing wafer size and decreasing design rule evolutions are taking place at the same time. These industry trends are adding a significant challenge to the design of an ultrapure water system.

In addition, the ecological impact that the fab has on the environment is also being evaluated. A semiconductor plant uses chemicals in each processing step. The treatment and disposal of these chemicals is a great concern to the fab designers. The scope of this paper does not include the treatment of these waste streams but touches on the ecological impact of the major water treatment equipment in the UPW system.

The quality of water used to manufacture a 200 mm or 300 mm wafer has remained relatively constant. A 300 mm wafer requires a larger consumption of water due to the larger surface area but for practical purposes, the water quality specification would most likely have remained the same. However, since the design rule is decreasing at the same time the wafer size is increasing, a significant change in the water specification has been proposed. Since the reduction in line width has the most significant impact on water quality it is important to compare the specifications associated with 0.13 μm and 0.18 μm manufacturing.

Two standards are typically referenced regarding the water quality specifications for ultrapure water. They are the ASTM standard D-1527 - 99 Standard Guide for Ultra Pure Water used in the Electronics and Semiconductor Industry and the Semi International Technology Roadmap for Semiconductors sponsored by International Sematech. The later specifications are summarized in Table 1.

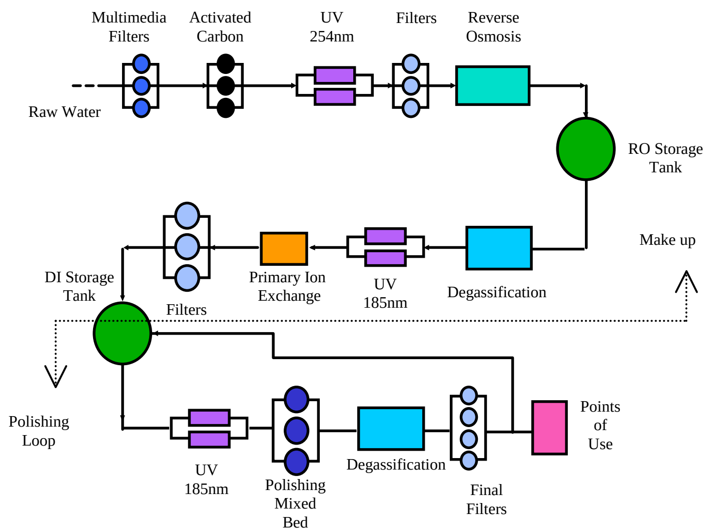
Table 1 – Sematech Roadmap

Parameter	**Line Width**	
	0.18	0.13
TOC (ppb)	2	1
Bacteria (CFU/L)	<1	<1
Total Silica (ug/L)	0.1	0.05
DO (ppb)	10	1
Particles (/ml)	<0.2 0.09 um	<0.2 0.065 um
Ions (ppt)	20	<20

As shown in Table 1, the specification for every contaminate with the exception of bacteria has decreased as the line width has decreased. The most significant change is an order of magnitude drop in dissolved oxygen and a 50% reduction in TOC and silica.

In order to better discuss the advances in an ultrapure water system (UPW), it is important to review the purpose of each device in the system. Figure 1 shows a typical UPW system. The system is typically described in two parts. The make up system and the final polishing loop system.

Figure 1 Typical UPW System



—*Makeup system*
Generally speaking, the makeup system will consist of the following equipment, however, the system design is greatly dependent on the inlet water quality.

Raw water enters the system. In this system the raw water is treated with a multi media filter to remove any large contaminants. It is then treated with activated carbon to remove the bulk of the organic material. This is followed by ultraviolet sterilization (UV), filtration and reverse osmosis membrane filtration (RO). Due to the different raw water sources, the pretreatment system will vary from plant to plant.

After the RO membranes the water is fed into an RO storage tank. From the RO tank the water is degassified to remove gasses and volatile organic compounds. It is then treated with UV to break down organic compounds. It is then treated with ion exchange to remove ions, filtered again and fed into a DI storage tank. This process is typically referred to as the make up system.

—*Final polishing loop system*
The final polishing loop system is designed to continuously purify the water. The loop is designed to constantly flow water through the final purification equipment so the water is never stagnant.

Since gasses have been removed from the water prior to this step, the DI storage tank is typically blanketed with nitrogen. From the DI storage tank the water is again treated with UV, ion exchange, degassified again and filtered. This water is constantly recirculated in a loop. This portion is called the final polishing loop. Water is drawn off the loop as needed for use in the fab.

As shown in Table 1, the specification for every major component has been reduced. The most significant is an order of magnitude drop in the level of dissolved oxygen in the water. The specifications for silica and TOC have both been reduced by 50%. These specifications require special design considerations in the UPW system.

The following is a brief description of the major components in a UPW system. It is important to understand the function of each device and how they interact with each other to purify the water. Some pieces will be ineffective without the others and the whole system depends on the performance of each device.

—*Multimedia filter:*
A multimedia filter consists of a bed of fine particles. Water flows through the

bed. Particles are trapped on the surface and excluded from passing through the bed. When the pressure drop across the bed becomes high, the bed is back-flushed and the contaminates are washed away with the back-flowing water. Multimedia filters are very effective in removing bulk contamination from the water. This protects the equipment downstream from being rapidly fouled with particles.

—*Activated carbon*

Activated carbon is commonly used in the make up water system to remove the bulk of the organic and chlorinated compounds. Activated carbon removes contaminates from the water by adsorption. Adsorption is attraction of molecular species to the surface of the activated carbon. The carbon is activated by roasting the carbon in an oven and driving off any volatile substances. Activated carbon has a very high surface area so the adsorption properties of the material are high.

—*UV 254*

There are two types of UV lights. Low pressure and medium pressure. Low pressure lights emit essentially two wavelengths. 185 and 254 nm. The lower the wavelength, the higher the energy of the light wave.

$E = hc/\lambda$.

E = energy
h = Planks constant
c = speed of light
λ = wavelength

Medium pressure lights emit a broader band of wavelengths and on a UV energy per watt basis add more energy to the water.

In the case of a 254-nm lamp, the 185-nm wavelength is filtered out of the emitted light by use of a 'doping compound' applied to the quartz sleeve. This is done to irradiate the water with a single wavelength. The objective at this point is to destroy bacteria only. A 185 nm wavelength UV light has the ability to break the molecular chains of larger organic material. At this point in the UPW system this is not advisable. The RO membrane downstream will remove large organic molecules and may allow the smaller molecules to pass through the membrane. In order to take full advantage of the RO downstream, it is recommended to use only 254 nm UV light at this point.

Ultraviolet light with a wavelength of 254 nm is very effective at breaking the chain of a DNA molecule. Once a DNA molecule chain is broken, an organism is unable to reproduce. This in effect stops the growth and ultimately kills the bacteria in the system.

A 254 nm UV light is typically put downstream of an activated carbon bed. A carbon bed is very efficient at removing chlorine from the water. Once the chlorine is removed, an excellent living environment for bacteria can be found in the carbon bed. The UV light downstream of the bed prevents bacteria from contaminating the equipment downstream.

—*RO prefilters*

A wide range of prefiltration can be used upstream of the RO membrane system. The type and rating of the filter will depend on the water quality. The prefiltration can range from a 5.0 um filters to an ultrafiltration membrane

(UF). UF membranes are similar to RO membranes but allow much larger molecules to pass through. This gives them a high flux rate as compared to RO membranes.

RO prefilters are used to prevent rapid fouling of the RO membranes.

—*Reverse Osmosis Membranes*
There is a wide range of RO membranes commercially available. These membranes are semi-permeable membranes that allow water molecules to pass through and exclude the passage of dissolved salts. These membranes operate under a high pressure in order to overcome the osmotic pressure across the membrane.

The water is essentially split into two streams. The permeate, which is the water the passes through the membrane and the reject, which is the water that contains a concentration of dissolved solids that does not pass through the membrane. The permeate is used to manufacture the ultrapure water and the reject is treated or disposed of.

Depending on the water quality and membrane type and configuration, as much as 98% of the ions can be removed from the water. In addition, the RO membrane will remove medium to large size organic molecules.

—*Degassification*
Degassification is the removal of dissolved gasses from the water. Dissolved oxygen, nitrogen, carbon dioxide and volatile organics can be removed with this device.

When a gas comes in contact with water, it will tend to dissolve into the water. The total amount of gas that dissolves in the water is proportional to the pressure of the gas. A degassifier lowers the pressure of the gas in contact with water and creates a driving force to remove the dissolved gas from the water.

—*UV 185*
A 185 nm wavelength light is used to break the molecular structure of organic molecules. Once broken these ions for carbon dioxide and charged particles. Not all organic bonds can be broken by 185 nm light. For example, this wavelength does not have enough energy to break a carbon chlorine bond so a compound such as chloroform is not effected by UV irradiation.

The UV does not actually remove any compounds but breaks the molecular chains of the organic molecules.

UV 185 is always immediately followed by ion exchange to remove the ionic species formed when the molecular chains are broken

—*Primary Ion Exchange:*
The general principle of ion exchange is the exchange of a hydrogen ion or hydroxide ion for another positively or negatively charged ion in the water.

This is accomplished with either resin beads in a tank or more recently with a continuous electrodeionization process (commonly denoted as CDI, EDI or CEDI). CEDI technology utilizes ion-selective membranes, ion exchange resin and an electrical current for the removal of dissolved ions in water. A DC current is used as the driving force to remove ions from the water.

—*Final Filters*

The final filtration step is typically accomplished using a UF membrane. Typical rating will be 50,000 or 100,000 molecular weight cutoff (MWCO). In some systems a 0.1 um membrane may be used. The final filter is used to remove any contaminates that may have been introduced into the water. They are typically the last device the water sees before it goes into the clean room and contacts the wafer.

All of these technologies work together to produce high purity water.
Since the TOC and oxygen levels have had the most significant change in 0.13µm manufacturing these contaminants deserve special attention.

—*TOC*

The lower specification of TOC in water poses a significant challenge. Careful analysis of the source water will make this specification possible. Since TOC is such a broad classification of compounds, it is important to know what compounds are present in the water. For example, chloroform, a byproduct of chlorine and humic acids is difficult to remove. It is a very small molecule that will pass through an RO membrane, is not effected by UV and is not efficiently removed by ion exchange. Activated carbon and degassification have the best removal efficiencies for this compound. Other organic material such as bromoform is decomposed by the action of UV and is removed by ion exchange. The combination of carbon bed, UV and ion exchange are typically used to remove this organic compound. It is important to understand what organic compounds are in the water when designing the UPW system.

—*Dissolved Oxygen*

The order of magnitude decrease in the dissolved oxygen in the water is a difficult specification to meet unless the proper system design is employed.

Unlike the other contaminates in the water, the UPW system is surrounded by oxygen in the air. Special precautions must be made in order to prevent the oxygen from recontaminating the UPW. Conventionally vacuum towers were used to remove the dissolved oxygen from the water. More recently membrane contactors have been introduced into the industry as an alternative technology. Membrane contactors are clean compact devices that can be placed in the final polishing loop of the UPW. This is vital when trying to achieve less than 1.0 ppb at the point of use.

In addition, membrane contactor systems are compact and easily expandable. This allows them to be installed near the other water treatment equipment in the fab. This saves on piping and allows a much smaller system to be designed. The ease of expandability allows the system to be designed to meet increasing water demands in the event of a fab expansion.

Every connection, seal or tank is a possible contamination point for oxygen to dissolve back into the water. It is essential that the degassification system be installed as close to the point of use as possible.

When designing a system there are several important considerations in addition to meeting the specifications that merit discussion. They include the environmental impact of the system, the ability of the system to support the productivity of the manufacturing facility and the overall operating costs of the system.

—*Meeting environmental concerns:*
It is the important to consider the ecological impacts that the manufacturing plant will have on the surrounding environment.

A recent trend in the industry has been the use of CEDI. This technology can often be used to replace conventional ion exchange resin systems in the makeup system. This can have a significant impact on the amount of chemicals used for regeneration. Ion exchange is typically regenerated using acids and bases. This regeneration is typically followed by a water flush.

CEDI technologies eliminate the use of regeneration chemicals, and dramatically reduce the amount of waste water generated by the UPW system in the facility. The elimination of on site regeneration of ion-exchange resins also reduces the operating costs of the UPW system due to savings in chemical cost and waste treatment cost.

—*Operating costs*
When comparing systems built by different water treatment companies it is important to carefully review the operating costs of a system. A low initial cost may have a much higher operating costs.

For example, a typical system will include two stages of degassification. One in the makeup and one in the final polishing loop. A conventional vacuum tower may have a low initial costs, however the electrical consumption and cooling water costs may be significantly higher than a membrane based degassification system. The vacuum tower may end up costing a plant much more to operate and drive up operating costs.

In the case of ion exchange, the same can be said for CEDI. The initial costs of an ion exchange system are less than a CEDI system, however the chemical consumption and waste will be significant for a resin system.

—*Productivity*
In the semiconductor industry, the cost for having a plant shut down is extremely high. It is important to select systems that have a rapid startup design. At least one time per year the plant will be shut down for routine maintenance. A well designed system will startup very quickly.

It is also important to select a design that can operate without needing to be shutdown. Redundant pumps and equipment are highly recommended.

The design shown in Figure 1 has the ability to start up very quickly for two reasons. One, the CEDI system does not experience the ionic leakage that is present at the startup and shut down of each regeneration cycle of a resin system. Secondly, an oxygen removal system is installed in the polishing loop. Deoxygenation of the UPW using this concept is immediate. If the deoxygenation system is only in the makeup system it may take several days to dilute the oxygen rich water in the polishing loop.

Conclusions

Meeting the new requirements of the 0.13 µm 300 mm processing is a difficult challenge. With an understanding of the raw water quality and how the basic water treatment equipment available today operates, these specifications can be met.

In order to meet the new specifications, the following advice can be given.

1. Analyze the source water and know what types of organic material are present. With this knowledge, the system can be designed to meet a spec of 1.0 ppb TOC.
2. Place the degassification system as close to the point of use as possible. This will remove any oxygen that was reintroduced into the system.

When evaluating the environmental concerns consider:

1. Chemical treatment and disposal costs
2. Power required to operate the system
3. Cooling water consumption

When evaluating operating costs:

1. Look at all utility costs: cooling water, electrical and steam

When evaluating plant productivity consider:

1. How often a system must be shut down
2. Redundancy
3. How fast a system can start up

The water system shown in this paper is a highly simplified designed used to illustrate the basic functions of each unit operation. It is vital to consult with reputable water treatment companies on the design. UPW system design consists of only a few technologies, but they are used in conjunction with each other to remove contaminates from the water. A reputable water treatment company will have the skill base and knowledge to properly size and design each piece of equipment.

Two technologies that have rapidly gained acceptance over the last five years. These technologies include CEDI and membrane based degassification. These technologies have been instrumental in allowing a plant to meet the specifications for 0.13 µm technology and have helped improve the environmental impact the plant has on the surrounding area. In addition they have helped increase the productivity and lower the operating costs associated with the plant. Advances in RO membrane design and ion exchange properties have had similar impacts that can benefit the system.

Reputable water treatment companies can explore these technologies and options for the fab. Every water system is different and care should be taken in the design.

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