Review of Water Use and Water Conservation Technology in High-Tech Industry

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Abstract

High-tech electronics industry is one of the star industries in Taiwan, which includes semicondustor foundry and manufactories of IC chips, TFT-LCD and LED. Microelectronics industry requires large quantity of ultrapure water (UPW) for various process uses. In chip manufacturing, besides fab capacity and yield, the size, line width and mask layer of the wafer directly impact the total water consumption of the plant. A large semiconductor or TFT-LCD manufacturing plant consumes couple thousand tons of water a day. In IC manufacturing process, most water is used in UPW cleaning and chemical mechanical polishing (CMP), which comprises 80 to 85% of the total water use. Another 5~20% is used in the center and local scrubbers or as the back-up water for the cooling towers. Therefore, process water and the water used in the utility system are the two prime targets for improvement in water conservation in microelectronics industry. Because the yield relies heavily on the quality of the UPW, usually between 17.5~18.5M-cm, the key to efficient water management lies on the operation mode of the water purification system, including the rate of pure water production, pure water supply system, back-wash frequency, selection of back-wash water source, reclamation of the spent backwash water

from mid- and back-stage, concentrates from the UF and RO processes, EDI electrode wastewater etc. This study intends to autopsy the water use and to identify the potential targets for water conservation for the high-tech industries, emphasizing on water balance efficiency, unit water consumption, water production rate, efficiency in segregation of spent rinse water, recycle of process water, and conductivity control of the blow-down from cooling towers.
Keywords: reclaimed water, water conservation, ultrapure water, reused water, concentrate, segregation of spent rinse water, recovery rate

1. Introduduction

High-tech electronics is one of the six most water-consuming industries. With the developments in economics and technology, the demand for high quality water is increasing tremendously. In respond to the escalating demand for water and the increasing scarcity in water sources along with the legislative restriction in building new dams, the Taiwan government has set a target for water conservation in individual industry. Many electronic industries have been required to raise their water recovery rates. In response, the Hsin-chu Science-based Industrial Park (HSIP) has adjusted its annual water conservation goal from two million tons in 2003 to ten million tons in 2007.

Wafer manufacturing and packaging industry comprise 80% of the IC industry in Taiwan. They consume large quantity of ultrapure water (UPW) in wafer cleaning which is a pivotal process in product yields. With the advancement in technology, the line width in wafer becomes narrower and the level of integration becomes thicker. To maintain good yield, more chemical cleaning and the accompanying more demand for the purity of the UPW are required, which contradicts the philosophy of green technology. High-tech industries are now seeking more efficient water reclamation system to meet the rapidly increasing demand for water quality and to reduce the water consumption simultaneously.

2. Water use and developments in water and wastewater treatment technology

2.1 Characteristics of water use in manufacturing process

Large quantity of UPW along with cleaning chemicals are used to rinse off the impurities from the wafer surface. With the development in electronics technology, the demand for UPW has grown at a phenomenal pace, driven by the size reduction in microchips, the high level of integration and the more planalized wafer surface. The traditional multi-stage batch cleaning method can no longer meet the requirement for 1-micron platform. In addition, the batch mode cleaning promotes cross pollution. The high water-consumption nature of the high-tech manufacturing is further challenged by the water shortage and environmental issue in Taiwan. Therefore, the industry must reduce the water consumption as well as increase the percentage of water reuse. The specification of water use in high-tech industry is given in Table 1.

Table 1 Roadmap of water use in high-tech manufacturing process

Year of Intrduction	2000	2003	2005	2007
Technology node (nm)	180	130	100	65
Total Oxidizable Carbon (ppb)	2	<1	<0.5	<0.4
Bacteria (CFU/L)	<1	<1	<1	<1
Total silica (ppb)	1	1	<0.5	<0.2
Cation / anion metals (ppt)	20	<20	10	<10
Particles>0.05μs (pcs/ml)	2	2	<1	<0.5

It is anticipated that wet cleaning remains the major cleaning mode for the wafer productions in the next few generations. The criteria for wafer surface cleanness are listed in Table 2.

Table 2 Criteria for wafer surface cleanness

Year of Intrduction	2003	2005	2007
Technology node (nm)	130	100	65
Critical particle diameter (nm)	50	40	32.5
Critical particle count (#/wafer)	59	97	82
Surface carbon (1010 atoms/cm2)	1.8	1.4	1.2
Back surface particle diameter (nm)	0.2	0.2	0.16
Back surface particle count (#/wafer)	600	400	200

Recently, many innovative technologies in cleaning such as cleaning under room temperature and washing by ozone and hydrochloric acid alternatively have been proposed to reduce the use of water and chemicals. In addition, the single-stage cleaning mode has replaced multi-stage cleaning to meet the demand for high purity and planarization. The production values per unit water consumption for IC manufacturing from year 1998 to 2000 is presented in Fig. 1 along with three other categories of manufacturing. The daily water consumptions by IC and TFT-LCD manufacturing are given in Fig. 2.

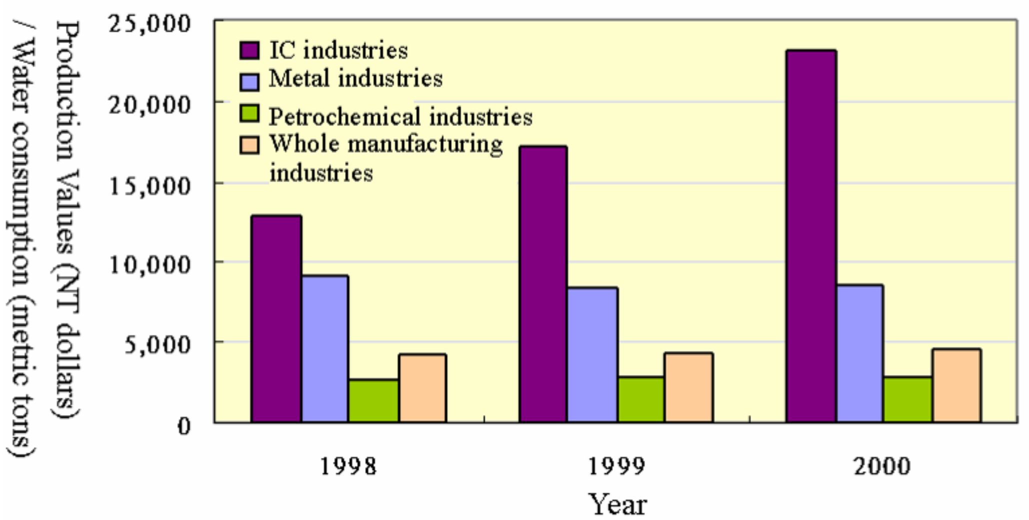

Fig. 1 Comparison of production values per unit water consumption among four categories of industry.

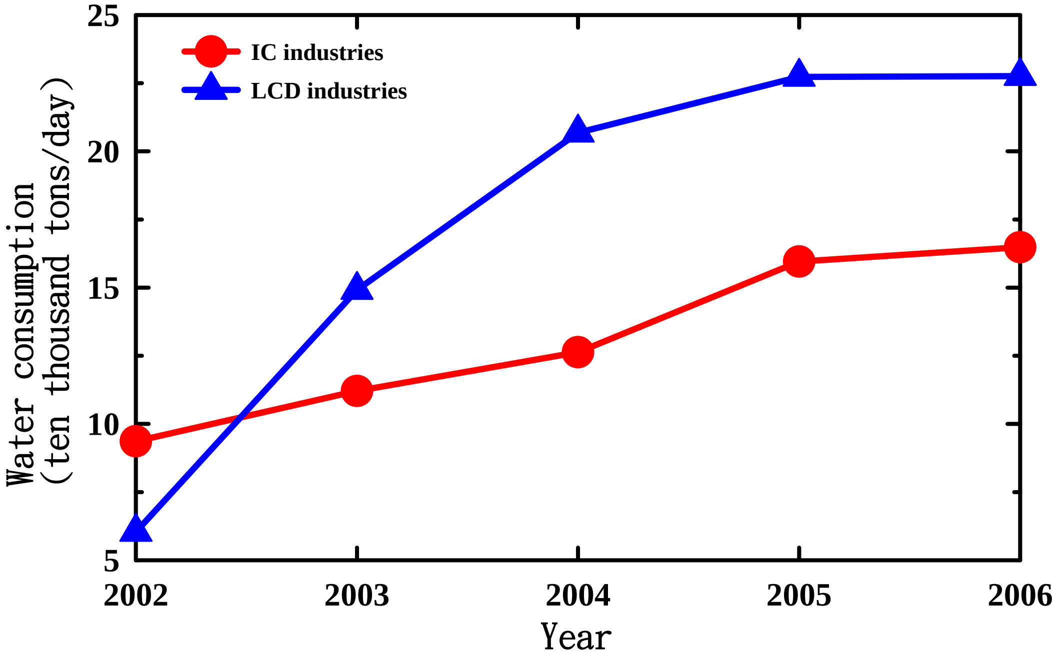

Fig. 2 Trends in the water consumption in IC and LCD industries between 2002 and 2006.

2.2 Evolution of water use and wastewater treatment in high-tech manufacturing

The trend in water use in developed countries has indicated their focus on water conservation. The aims are to enhance the efficiency of water use, to reduce the water cost and to develop new wastewater treatment technology. The NSF/SRC Enginner Research Center for Environmentally Benign Semiconductor Manufacturing of USA, cofounded by UC Berkeley, MIT,University of Arizona and Stanford University, has over thirty members, mostly world-class semiconductor manufacturers such as Intel, TI, HP and Applied Materials. The mission of the center is to research and develop new wastewater treatment and recycling technologies for electronics industry to minimize its environmental impact. In Taiwan, most researches in regard to water conservation in high-tech industries have been conducted in ITRI. The prospect of potential cleaning process and water treatment in semiconductor industries is revealed in Fig. 3 and Fig. 4.

The development of water treatment technologies in high-tech industries development is illustrated in Fig. 5. In response, ITRI has reviewed existing and potential technologies for wafer cleaning process and proposed the following list of prospectice research topics:

1.Removal of photo-resistance by ozone:

(1)High concentration ozone module at (O_3) > 50ppm.

(2)Bubbling ozone for 8-in and above chip manufacturing

(3)Development of PR removal tools in packaging process.

2.Dry cleaning:

(1)Confirmation tests for reactivity and uniformity of gas phase.

(2)Cleaning of large size glass material and high uniformity.

(3)Development of high uniformity photo-excitation platform for TFT-LCD.

3.Cleaning by super-critical fluid：

(1)Development of CNT-FED cleaning and activation module and recipe.

(2)SCCO$_2$supercritical carbon dioxide cleaning of three diode CNT-FED Field<3V/μm,Ja>10mA/cm^2.

(3)Development of high efficiency porous membrane module for water treatment.

(4)Development of purification technology of complex porous adsorbent：

4.Surface modification of environmentally friendly Germanium base material.

(1)Removal of micro-pollutants from Germanium surface.

(2)Roughness control of Germanium surface.

(3)Integrated test for Germanium parts.

5.Cleaning by organic water：

(1)Preservation of raw food by oxidizing organic water.

(2)Elemination of residual pesticides from vegetables and fruits by washing with organic water.

(3)Cleaning by oxidizing micro-bubbling.

(4)Organic farming with function water.

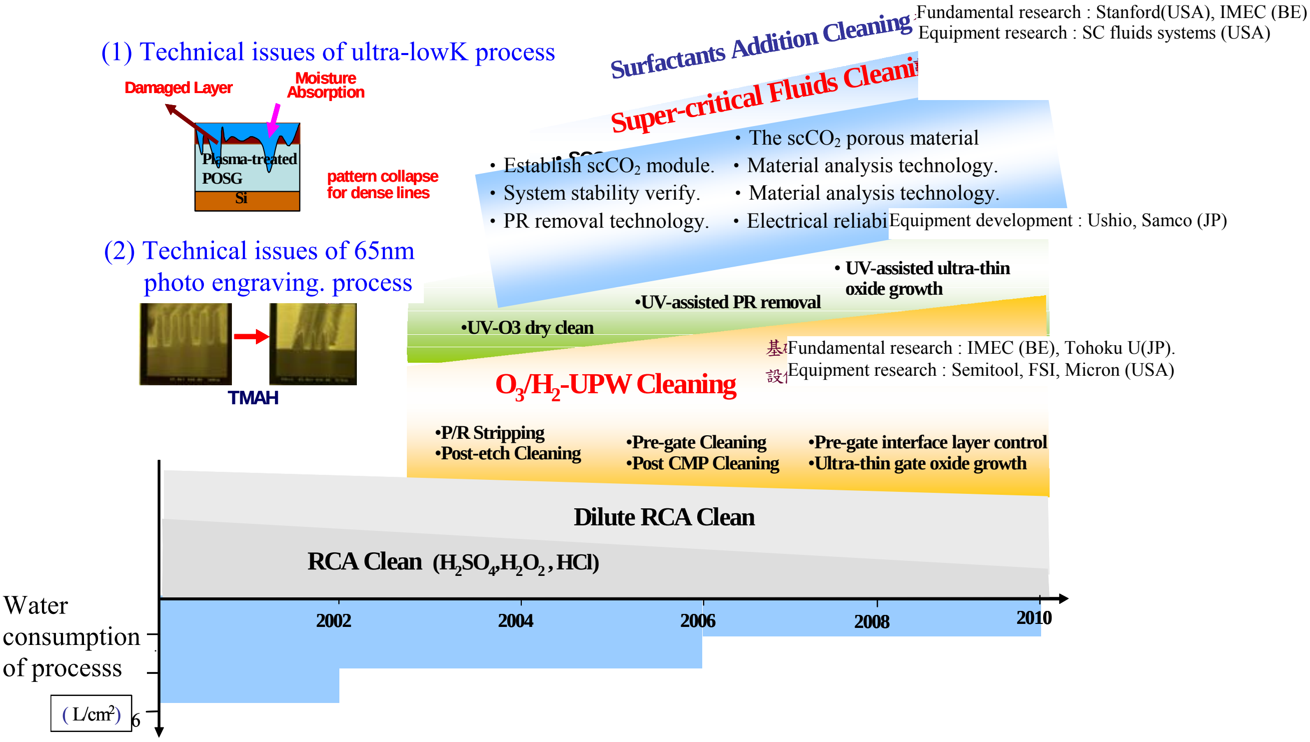

Fig. 3 Prospect of potential cleaning process in semiconductor industries.

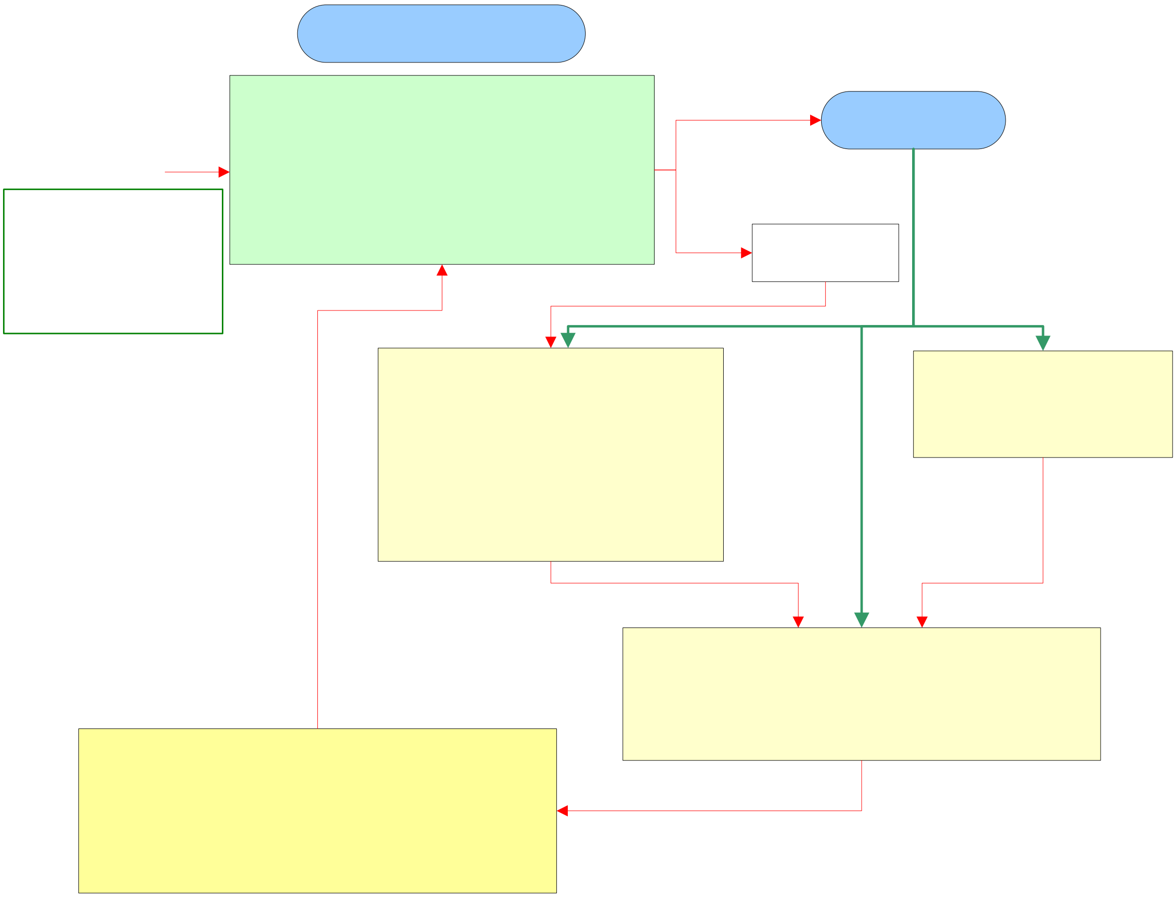

Fig. 4 The development of water treatment technologies in high-tech industries.

New processes and materials are being developed to meet the future trend for zero pollution, resource conservation, environmental protection and sustainable development as illustrated in Fig.5.

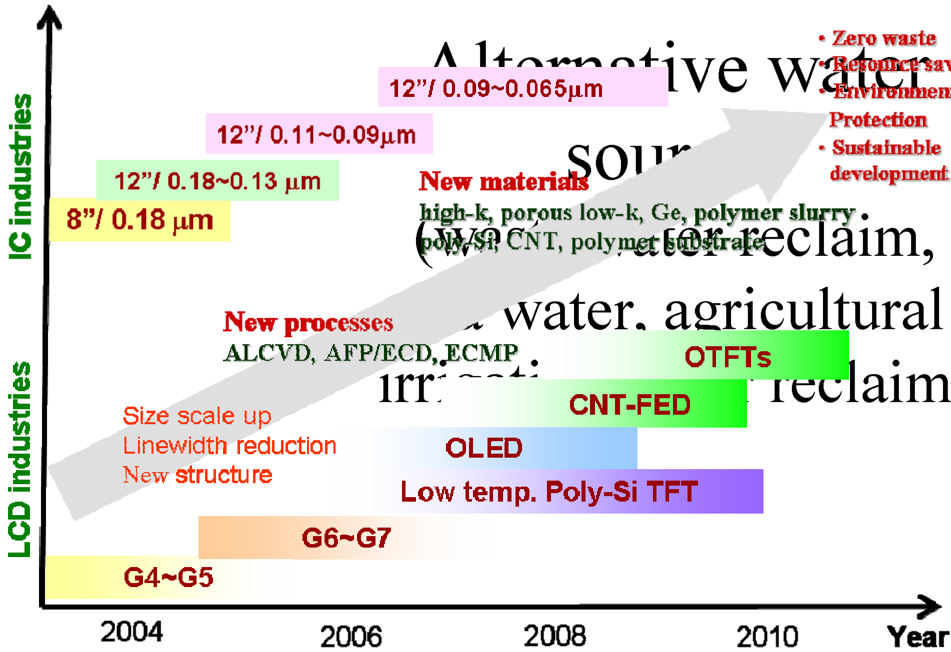

Fig. 5 The future trend of development in IC and LCD industries.

3. Rational water recovery rate

In Taiwan, minimum water recovery has been imposed on the high-tech manufacturers. An even higher water recovery is required for those newly built plants. The fulfillment of the target water recovery is used as the basis for the evaluation of the new strategic industries. However, water recovery can not reflect the true water use. Some fabs manipulate the calculation of water recovery by using different mathematical models. Comparison of water recoveries, as a result, becomes a mere formality.

Current method for water recovery calculation does not guarantee plants with high water recovery being more environmentally-friendly. However, when the government set an unrealistically high water recovery, the manufacturers are forced to advance the level of wastewater treatment. Any increase in water recovery implies a considerable increase in expense for water reclamation while the technology for wastewater treatment must be improved. A statistic on the variation of component cost with water recovery rate in semiconductor manufacturers of Japan indicates that the lowest total treatment cost occurred at 75% water recovery, as revealed in Table 3 and Fig. 6. As a result, most manufacturers automatically adjust the water recovery to 75% although the Japanese Government did not clearly authorize the water recovery. The calculation was based on the water rate of Japan. By replacing it with the water rate of Taiwan, the water rate of the lowest cost shifts to zero, a indication that the water rate of Taiwan is too low to reflect the actual supply and demand of water use. In other words, there is no incentive for water conservation. On the other hand, the calculation on Japanese semiconductor manufacturering has come to a conclusion that the capital cost for a fab for 100% water recovery is twice that for zero water recovery, suggesting that zero discharge does not conform to economic efficiency.

Table 3 Water treatment cost of various recovery rate in semiconductor manufactory in Japan.

Cost unit : yen (Japan)

Recovery Rate（%）	0%	30%	50%	75%	100%
Initial Cost	100	105	130	130	200
Electric Power	150	150	125	125	200
Chemical, Steam, Cooling water	100	75	75	75	250
Supplies / Consumables	250	250	275	275	300
TOC reduction equipments	0	0	75	125	150
Outsourcing	0	0	0	0	125
City Water	450	425	225	150	30
Total Cost	**950**	**900**	**775**	**750**	**1055**

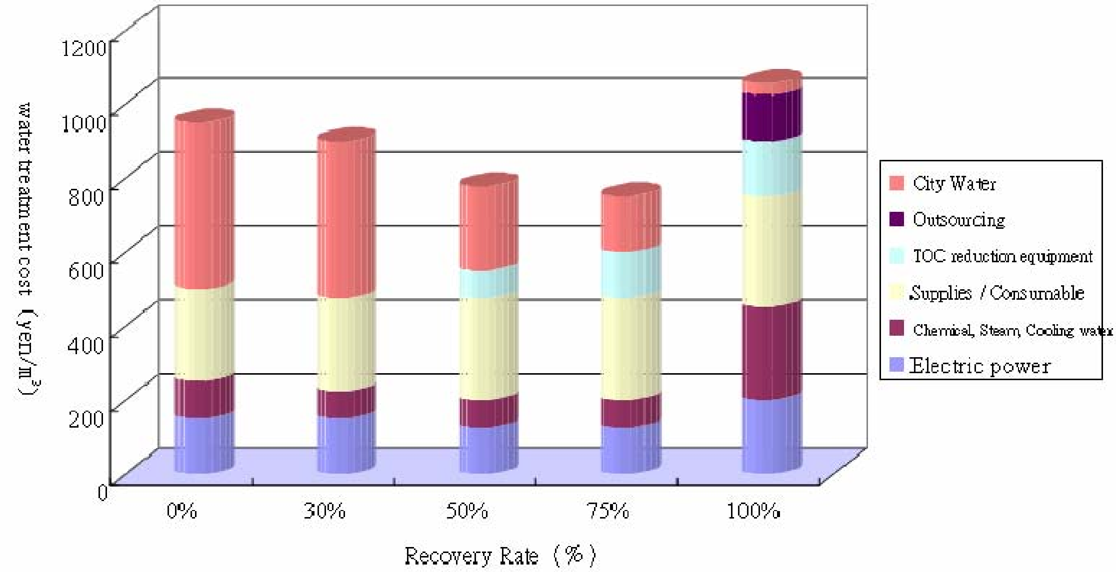

Fig. 6 Water treatment cost of various recovery rate in semiconductor manufactory in Japan.

Therefore, to increse the efficiency of water use by means of water reuse, the water recovery rate must be rationized. Indices for water recovery must be clearly defined and characterized to draw up a reasonable formula for water recovery calculation to reflect the efficiency of water use and to serve as a tool for promoting efficient water use. A joint research by ITRI and the HSIP has concluded a rational water recovery rate of 70~75% for the high-tech industry. The economic benefits evaluation of water conservation of a typical high-tech industry in Taiwan is shown in Fig. 7.

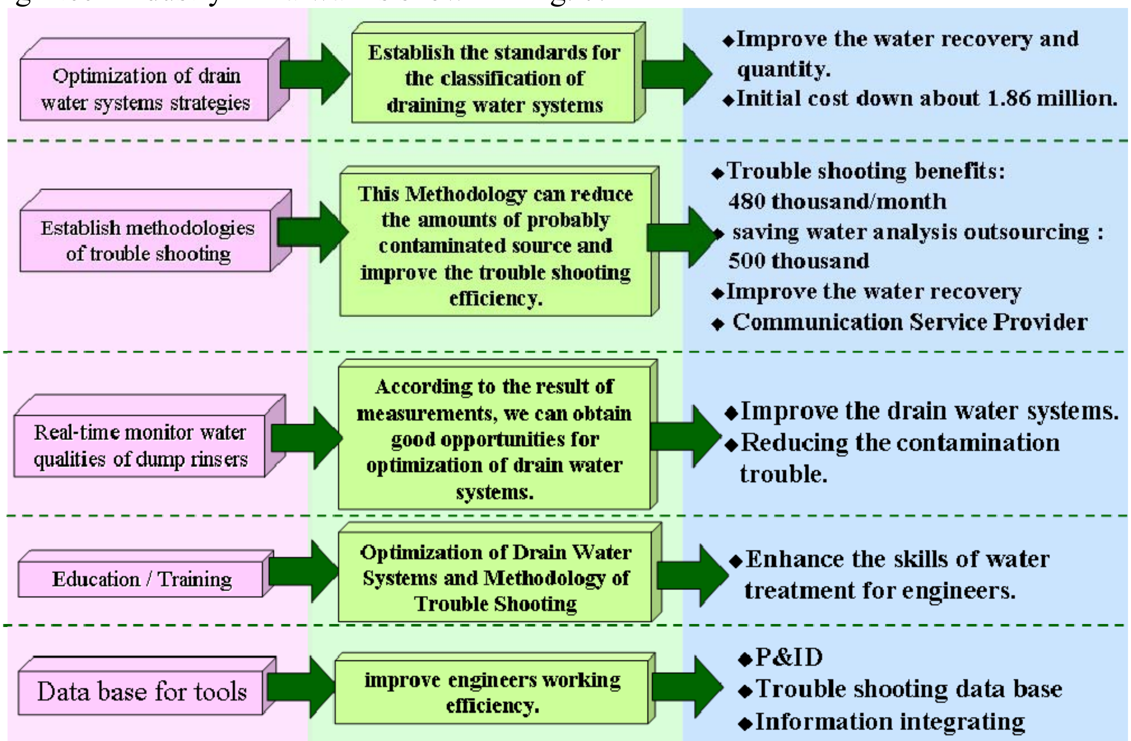

Fig. 7 Economic benefit evaluation of water conservation in a high-tech industry.

4. Efficiency in drain water segregation and trouble shooting

The segregation of spent rinse waters with different pollutant concentration and the water standards for water reuse are closely related to the water recovery rate. In general, TOC and conductivity are used as the criteria for water reuse. The scheme of drain water systems optimization is given in Fig.8.

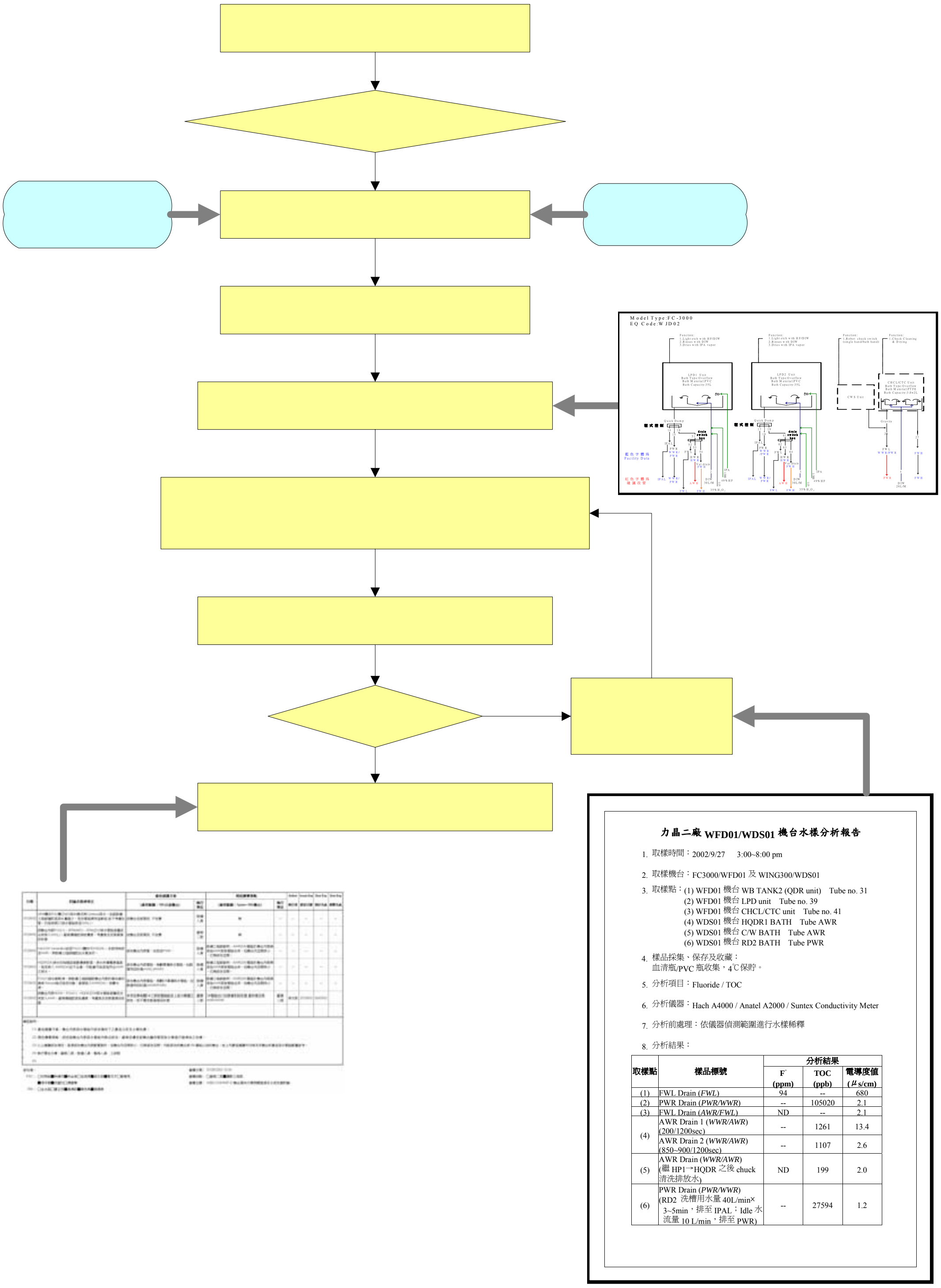

Fig. 8 Optimization of drain water systems

Different streams of spent water are segregated by the automatic monitoring system for treatment and reuse. To lower the risk of contamination by the recycled rinse water, the fab is recommended to incorporate a system for trouble shooting and an automatic control system like the one given in Fig. 9.

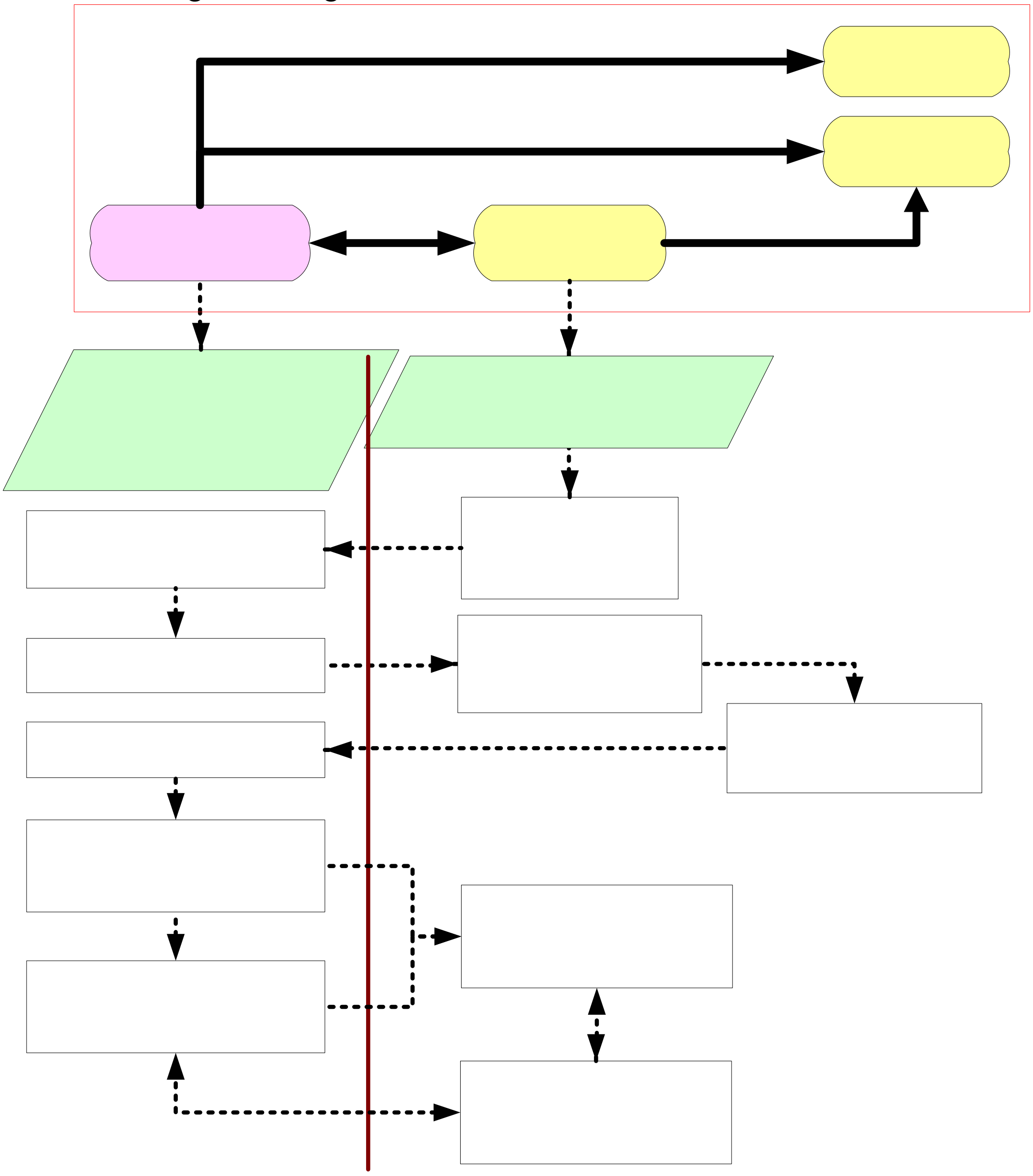

Fig. 9 The procedure for trouble shooting.

5. Assessment of potential water conservation targets

5.1 Unit water consumption

Unit water consumption must be compared on the same product and the same front-end utilization, as well as the age of the production station and the function in raw and drain water. A year 2005 survey conducted by the industrial park shows that the average unit water consumption for 6-in, 8-in and 12-in wafers are 0.79, 4 and 7.3 tons/wafer

respectively. The unit water consumption for LED crystal is 0.2266 ton/wafer, for nickel-plated aluminum plate is 0.025 ton/wafer, and for wireless card is 0.94 liter/set. Average nitrogen consumption is 0.00052 L/T. The front-end utilizations of plants used in the survey are all above 80%.

5.2 Production rate of water purification system

In electronic industry, water purification system is a critical component which produces the ultra-pure water for wafer cleaning. The water use and discharge of the UPW system affect the water consumption and water recovery tremendously. Therefore, analysis and control of the pure water production is extremely important to efficient water conservation. Low water production wastes water resources, while high water production shortens the membrane life and increases the cost for water purification. Therefore, the operation parameters must be optimized. Most water purification systems target their water production rate in the range of 65% to 85%, depending upon the original design of the system.

5.3 Efficiency in drain water segregation

Different streams of spent water from wet stations are separated by concentration. The criteria for either collection or discharge is determined by each plant. The quality and volume of the recovered water are closely related to the water recovery of the process. Therefore, each plant must establish an efficient drain water segregation system. The survey conducted by the HSIP has pointed out that most fabs experience an uneven distribution of stream segregation, normally between 11 and 100%, among which 47% are under 50% efficiency.

5.4 Backflow water

Backflow water is the pure water which flow through the process yet is not used due to low front-end utilization, over production of pure water, or idle station. The backflow water is either recycled back to the water purification tank or overflow into discharge. The survey mentioned in the previous section has found that the UPW production is usually preset at 1.5 to 4 times the actual need for processing. The discharge of backflow water means a waste of water resource. Although the water can be conserved by recycling back to the water purification system, energy is still wasted. Therefore, the plant should control the water production carefully in compliance to the water need for processing. A safe ratio for water production/processing water need is between 1.5 and 2.

5.5 Conductivity control of blow-down

Most plants in the industrial park adopt the cleaner stream of concentrate from the membrane treatment (ROR) as back-up water for cooling towers. The conductivity of the ROR is around 30 to 50 μS/cm. By setting the conductivity of blow-down at around 1000 μS/cm, the tower concentration cycle is 20, which surpasses the requirement for water conservation, namely, 4 to 5 concentration cycle. However, there is still room for further increase in concuctivity. In general, the conductivity of the blow-down can be controlled at 1800 to 2000 μS/cm. Most fabs in HISP set the conductivity control between 1000 μS/cm and 1800 μS/cm, although some manufacturers have no control at all. Conductivity control of the blow down may be an alternative for cooling tower operation.

6. Summary

1.Because C/T (Cooling Tower) and wet scrubbers are the major water uses in the public utility system of the high-tech industry, the optimization of their operation plays an important role in water conservation. Optimal operation curves of C/T and scrubber in regards to operation parameters including water quality of C/T (EC, Ca and pH), concentration cycle,temperature of the cooling tower effluent, and pH for recycling water in wet scrubber,must be established.

2.The water recovery criteria for plants built after 1999 is set as 85%. Some manufacturers,however, have trouble reaching the target till now. For those who have successfully raised the reclamation rate from 75% to 85%, the cost has severely over the benefit of investment. The key technology lies at the reclamation of the Cu-CMP and scrubber discharge. These manufacturers should be recognized and their experience in water conservation can be shared with others. In the mean time, the Science Park Administration needs to rationize the recovery criteria as well as to encourage the achievement by rewards.

3.If without treatment,the internal recycling water of the scrubber and any pre-set internal recycling process water should not be included in the calculation of water balance. However, most manufacturers in the science park include these streams in the calculation in order to raise the calculated recovery rate.

4.To meet the water recovery criteria set by the science park administration, the manufacturers must invest heavily before they can acquire an effective technology for water reclamation. The administration can consider to establish a reasonable investment technology and reclamation guideline to achieve the goal for water conservation without sacrificeing the profit.

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