

SEMI F61-0521

GUIDE FOR DESIGN AND OPERATION OF A SEMICONDUCTOR ULTRAPURE WATER SYSTEM

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NOTICE: Paragraphs entitled ‘NOTE:’ are not an official part of this Standard or Safety Guideline and are not intended to modify or supersede the official Standard or Safety Guideline. These have been supplied by the global technical committee to enhance the usage of the Standard or Safety Guideline.

NOTICE: The section symbol (§) is used to reference a numbered section, paragraph, or header and all subordinate paragraphs, headers, and embedded material (i.e., EXCEPTIONs, lists) therein. The paragraph symbol (§) is used to reference a particular numbered paragraph and embedded material therein. When duplicated (i.e., §§ and §§) the symbols are used to reference more than one section or paragraph, respectively.

1 Purpose

1.1 This Guide should be used in conjunction with SEMI F63 and SEMI F75. Together these Guides provide recommendations for facility engineers and other manufacturing professionals who are responsible for establishing programs to monitor and control the quality of their ultrapure water (UPW) systems through to point-of-use (POU).

1.2 This Guide describes the engineering and component requirements for a UPW system used in semiconductor manufacturing. It is intended to establish a common basis for developing detailed specifications for design, operations, certification, and monitoring of UPW and hot ultrapure water (HUPW) systems.

2 Scope

2.1 This Guide applies to advanced UPW systems used in semiconductor manufacturing facilities for supplying high purity water for wafer processing, chemical dilutions, and other facility applications. This Guide provides definitions used for identification of UPW system components and other commonly used terms associated with the semiconductor facility water systems.

2.2 This Guide provides reference to other relevant SEMI Standards that ensure quality and reliability of UPW systems. This Guide logically follows the series of SEMI Standards developed for UPW; which includes SEMI F63, a Standard defining the quality of UPW, and SEMI F75, a Standard for monitoring UPW.

2.3 This Guide provides recommendations for design and operation of the UPW system including treatment plant, distribution system, and the semiconductor manufacturing tool hook up.

2.4 This Guide addresses the testing and prequalification of high purity polymer materials used in UPW system equipment and distribution.

2.5 This Guide provides minimum definitions for site utilities needed to support the UPW system.

2.6 This Standard provides guidance for construction, qualification, and commissioning of new or recently upgraded UPW systems.

2.7 This Standard provides guidance on maintenance, operations, safety, and redundancy of the UPW systems. This Guide provides further quality information on critical components such as ion exchange resin and filter media.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 This Guide does not define the actual specifications generally negotiated between the user and the suppliers of the UPW system, against which water quality is tested and qualification is passed.

3.2 This Guide does not address the protocols and requirements defined by the suppliers concerning the installation of the UPW system.

3.3 The recommendations provided in this Guide are based upon information available at the time the Standard was prepared and on the experience of the group involved in the Standard development.

3.4 This Guide is limited to the scope of UPW treatment and distribution system; it does not address the considerations of the UPW materials and components within manufacturing tools.

3.5 This Guide focuses on the parameters and conditions which mitigate risks to manufacturing yield and UPW system performance; it does not deal with definitions that present opportunities for competitive intellectual properties of the technology providers.

3.6 In order to maintain the relevance of SEMI Standards, it is important that Standards be updated on a regular basis. In particular this Standard, and SEMI F63 and SEMI F75, will be updated at the same time to ensure continuity for the users of all three Standards. All three Standards will be reviewed and updated (if necessary) on a two-year cycle.

3.7 This Guide does not provide recommendations for the design or operation of POU specialty systems, such as carbonated UPW water, ozonated UPW water, low TOC UPW water, and low particle UPW Water.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI F19 — Specification for the Surface Condition of the Wetted Surfaces of Stainless Steel Components

SEMI F57 — Specification for Polymer Materials and Components Used in Ultrapure Water and Liquid Chemical Distribution Systems

SEMI F63 — Guide for Ultrapure Water System Used in Semiconductor Processing

SEMI F75 — Guide for Quality Monitoring of Ultrapure Water Used in Semiconductor Manufacturing

4.2 ASTM Standards¹

ASTM D5127 — Ultra-Pure Water Used in the Electronics and Semiconductor Industries

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

NOTE 1: This section focuses on definitions related to UPW system used in microelectronic industry and does not include common water treatment process technology definitions used elsewhere. UPW quality related definitions are included in SEMI F63.

5.1 Definitions

5.1.1 *deionized water (DI)* — any purified water that has level of ions reduced down to the resistivity of minimum 1 MΩ·cm. Although a commonly used term, this quality of water is not applicable for advanced semiconductor manufacturing.

5.1.2 *DI system* — a system that comprises one or multiple deionization steps to produce DI water. DI system treatment is typically based on one or combination of the following technologies: ion exchange, reverse osmosis, and EDI technologies.

5.1.2.1 *Discussion* — UPW Plant is a complex automated system. In order to provide effective communication when dealing with specific treatment steps and components additional definitions are required. The following definitions of the UPW system sections are based on treatment steps located in between major tanks typically used: raw water tank, permeate tank, and UPW Tank (see § 8.1, Figure 1).

5.1.2.2 Although typical design is based on the goal of producing and distributing single quality spec UPW, some fab or sub-fab users receive lower grade water, such as RO permeate or primary product. Such decisions are project specific.

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5.1.3 *high volume manufacturing (HVM)* — refers to full size production facilities as opposed to a pilot or technology development production line.

5.1.4 *final filter* — usually it is the final treatment step in a UPW system; used to remove particulates.

5.1.5 *make-up plant* — portion of the UPW system upstream of the UPW tank that supplies water in the polishing loop to replace UPW consumed by the fab.

5.1.6 *raw water* — any water available to the site for the production of UPW (from river, lake, ground, or ocean). Such water may or may not be treated and can also include reclaim water.

5.1.7 *permeate water tank* — tank containing water treated by reverse osmosis in pre-treatment and other streams consistent with permeate quality.

5.1.8 *ultrapure water (UPW)* — purified water meeting microelectronic industry requirements documented in SEMI F63 and ASTM D5127 for the line width of one micrometer and smaller.

5.1.9 *UPW distribution loop* — the piping from the final filter of the polish system that distributes UPW to the end users and conveys the remainder to the inlet of the polish tank via UPW return.

5.1.10 *UPW return* — UPW sent to but not used by end users (returns to the UPW storage tank).

5.1.10.1 Points of measurement of the water quality in the polish loop:

5.1.10.1.1 *point of connection (POC)* — sample port near a take-off valve on the lateral used to connect to the manufacturing tool.

5.1.10.1.2 *point of distribution (POD)* — sample port near the outlet of the final filter.

5.1.10.1.3 *point of entry (POE)* — sample port near the feed connection to the manufacturing tool.

5.1.10.1.4 *point of process (POP)* — water in production chamber.

5.1.10.1.5 *point of use (POU)* — sample port within the tool near the entry to the process chamber.

5.1.11 *UPW supply* — UPW sent to end users.

5.1.12 *UPW system* — a production and distribution facility comprising of unit operations including deionization, reverse osmosis, dissolved gas control, organics treatment, and particles removal to meet requirements of UPW quality. UPW system equipment boundaries start at the feed to the raw water tank (if exists) or otherwise at the feed to the raw water pump. The system boundaries end at the point of connection valves supplying UPW to the manufacturing tool or any other fab or facility user utilizing UPW to support production.

5.1.13 *UPW tank* — tank that receives water from make-up plant and UPW return and then supplies water to the polish plant.

6 General Recommendations

6.1 *Materials* — Components of the UPW system should be comprised of materials appropriate to the application and conform to electrical, mechanical, and purity requirements of the UPW. Materials should also comply with the purity as defined by applicable SEMI Standards. See Appendix 1 for details on the material quality requirements.

6.2 *System Installation* — A UPW system is installed according to a protocol that ensures mechanical integrity, leak proof operation, and none (or minimal) contamination during installation. See Appendix 1 for details on the piping supports, welding, and other requirements for system installation.

6.3 *Acceptance Tests* — Acceptance tests are conducted on each subsystem. Such tests may include performance demonstrations, demonstrations of reliability criteria, and achievement of purity standards and are the basis for acceptance or rejection by the purchaser against a pre-negotiated set of criteria for system performance. See Appendix 2 for details on the UPW system qualification methodology.

6.4 *Monitoring* — UPW systems are monitored for continuing performance against desired and achievable levels of quality. Action limits are set to determine when system performance suggests that corrective action is required.

6.5 *UPW Specifications* — UPW systems should deliver a specified water quality on an ongoing basis. The guaranteed performance is established in advance between the UPW equipment supplier and the system owner. Both

qualification testing and monitoring testing use the guaranteed specifications to determine the parameters and levels of purity to be tested. SEMI F63 is the recommended reference Guide for UPW quality in advanced semiconductor manufacturing.

6.6 Recycle/Reclaim Opportunities — Opportunities for recycling and reclaiming water within a UPW system should be recognized during the design phase. Examples: Use of 1st pass reject for cooling tower make-up water, returning UF reject to the permeate tank or feed water tank, and many others.

7 Source Water

7.1 Raw Water — Raw water quality and sources are what drive the design of the pretreatment plant. Raw water quality should be thoroughly characterized to ensure effective design of the pretreatment plant. See Appendix 3 for recommendations on analysis of the raw water and interpretation of the analytical data which facilitates design of the UPW Pretreatment.

7.2 Municipal Drinking Water — Municipal drinking water from different sources (such as desalinized seawater or brackish lakes and wells) is the most common source for UPW systems. However, the treatment plans to make such water potable and compliant with drinking water regulations may pose a challenge to the UPW systems. For example: disinfection by-products may damage RO membranes; fine silt particles may clog membranes, hardness and silica may form scaling on the RO membranes; trace level of organics may cause fouling or may enhance bio-growth, causing bio-fouling.

8 Major Treatment Processes

8.1 The following diagram provides UPW system definitions for the treatment blocks between the main system tanks:

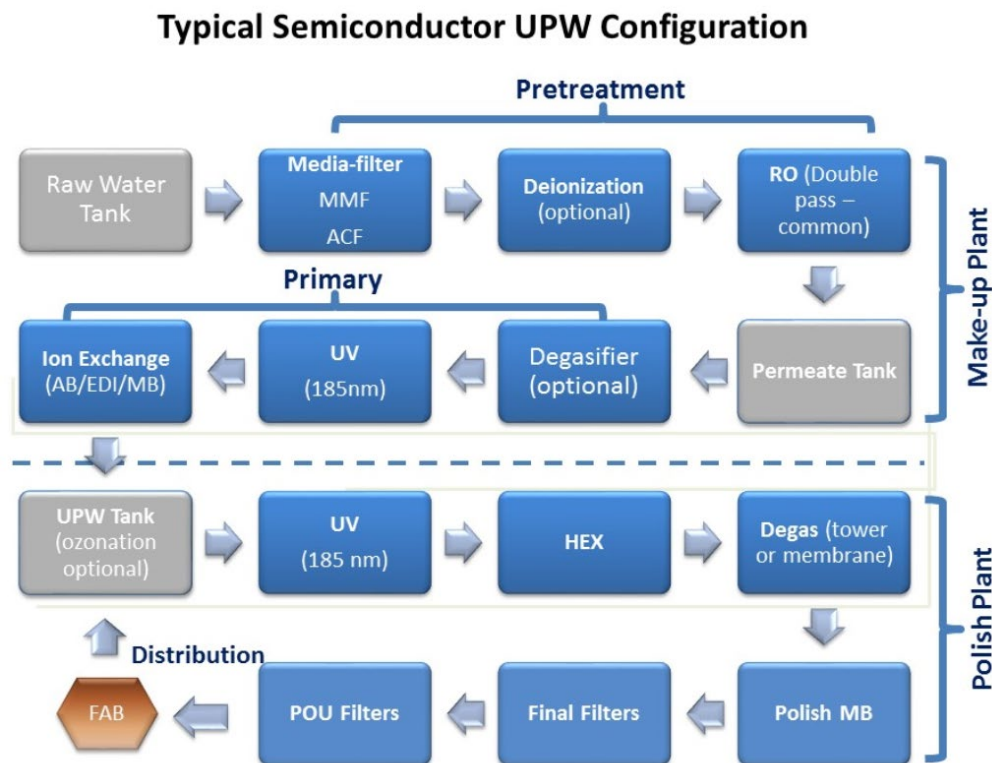


Figure 1
Typical UPW System Configuration

8.1.1 *Make-Up Plant* — The entire treatment system upstream of the UPW tank. The make-up plant produces replacement water to supplement losses caused by fab consumption, polish system maintenance, and normal system operation.

8.1.2 *Pretreatment* — The portion of the make-up plant upstream of the permeate tank which produces replacement water to supplement losses caused by fab consumption, fab permeate water consumption and downstream system maintenance.

8.1.3 *Primary System* — The portion of the make-up plant downstream of the permeate tank and upstream of UPW tank which treats the permeate water to the levels near target UPW quality.

8.1.4 *Polish Plant* — The treatment system downstream of the UPW tank that conducts final UPW purification. The most important function of the polish plant is particle removal and maintenance of recirculated-UPW purity. The polish plant is often located separately from the make-up plant adjacent to or within the fab building to reduce the length of expensive high purity piping.

8.2 *Pretreatment* — Includes all the water treatment steps ahead of the first pass of RO membrane treatment. The configuration of pretreatment is more dependent on the incoming water quality and site specific requirements than other major steps in the UPW system. Pretreatment steps are required to protect the membrane units from scaling with sparingly soluble salts, from fouling with living or nonliving suspended particles and from chemical attack by pH, oxidizing agents or other dissolved contaminants and to enhance performance of the RO. Examples of RO treatment include removal of hardness agents that allow increasing water efficiency and rejection of weakly acidic ions of boron, silicon, and organics under elevated pH conditions. Pretreatment equipment may include some, or a combination, of the following:

8.2.1 *Raw Water Tank* — The raw water tank contains enough water to provide a sufficient retention time to conduct troubleshooting activities during short term water-supply interruption.

8.2.2 *HEX* — Heat exchanger for dealing with seasonal temperature fluctuation necessary for providing stable RO flux and rejection.

8.2.3 *Various Filters* — Filters to protect RO membranes from debris include media filtration, micro filtration, ultrafiltration (bulk suspended solids removal) and 1 to 5 micron cartridge filtration.

8.2.4 *Activated Carbon Filtration (ACF)* — ACF is primarily used for removal of oxidizing agents. Alternatively reducing agents can be employed to neutralize oxidants.

8.2.5 *RO Scale Control* — RO scale control can be done by cation exchange (softening, to remove scale-forming cations) or through the addition of scale inhibitor chemicals (acids and/or chelating agents).

8.2.6 *CO₂ Removal* — CO₂ removal by degasification uses either a decarbonator (forced draft) or vacuum membrane degasifier located before or after RO.

8.3 *RO Membrane Treatment* — RO membrane treatment provides effective rejection of dissolved ions, organic compounds, silica, and almost complete rejection of suspended contaminants. However RO will not effectively reject dissolved gases and some low molecular weight neutral and non-ionic volatile organic compounds. Effective removal of weakly dissociated acids (organic, boric, and silicic) requires pH adjustment. To enhance the removal of contaminants RO units may be configured in a double-pass arrangement where permeate (treated water) from the first RO unit is sent to the second RO unit to be treated again. It is not uncommon for the permeate from a double-pass RO unit to have a resistivity value in the range of 1 Ω·cm, approaching ppb levels of organic and silica contaminants.

8.3.1 *Permeate Water Tank* — The permeate water tank stores permeate water and provides sufficient retention time to conduct normal maintenance and allow troubleshooting activities during interruption in water supply.

8.4 *Dissolved Gas and Volatiles Removal* — The removal of dissolved oxygen, carbon dioxide, other gases, and volatile organic compounds is a necessary treatment step. The removal of these contaminants is accomplished to acceptable levels by vacuum degasifiers or by membrane degasification units. The degasification equipment can be located in either or both the make-up and polish plants (depending upon cost considerations and final UPW spec requirements for dissolved gases).

8.5 *Polish* — The polish treatment section is designed for maintenance of UPW quality not for bulk removal. The primary water should be of UPW quality. TOC compounds that exit the primary ion exchange units are typically subjected to TOC-reducing UV irradiation to break them into ionized compounds to be removed by the polishing ion

exchange units. Design criteria for UV irradiation should accommodate the fact that 185 nm UV lamps produce hydrogen peroxide that is potentially detrimental to the downstream equipment and production. One critical role of polish is removal of particles. The final filter prior to distribution has a pore size determined by the final UPW quality particle size specification, dependent on the manufacturing process quality needs.

8.5.1 UPW Tank — The UPW tank provides equalization during peak consumption and also sufficient retention time to perform system maintenance and conduct troubleshooting activities during interruption in the water supply.

9 Distribution

NOTE 2: See Appendix 4 for details on distribution system design considerations.

9.1 Distribution — Distribution system has one or more loops. The loops ensure consistent high-purity water quality by continuously re-circulating UPW through appropriate piping from the final filters to the manufacturing areas and back to a tank located within the polish plant to be treated again.

9.1.1 Ozone can be injected into the distribution loop during start-up and commissioning to ensure deactivation of bacteria left post installation and construction. Such ozonation should not be necessary after start-up in a well-designed and maintained UPW system (see Appendix 7 for filtration details).

9.1.2 Hot UPW System (HUPW) — HUPW is a subset of the UPW Plant and distribution system. Refer to Appendix 5 for details and important design considerations.

9.1.3 Dead-Leg — A dead leg is a section of the UPW distribution piping that under normal operational conditions has no flow. A dead leg should not be longer than three times its inner diameter.

9.1.4 Supply-to-Consumption Ratio — The supply-to-consumption ratio is the ratio of the total flowrate of UPW supply divided by the projected average tool consumption (typically defined as one of the design criteria for sizing polish and distribution system).

9.1.5 Maximum (or Peak) Consumption — Maximum/peak consumption is the maximum flowrate that can be consumed by the maximum number of fab tools and facility users at any one point in time.

9.2 Average Consumption — Average consumption is the flowrate calculated for all factory tools consumption as well as consumption by facility users over an extended period of time. Average consumption is needed for sizing equipment of the make-up plant, upstream to the UPW tank. The UPW tank provides sufficient storage to accommodate instances when short term peak demand exceeds the average design consumption.

9.3 Specific Definitions for UPW Distribution System

9.3.1 Supply — The piping and other distribution system components connecting UPW treatment system and the manufacturing tools/facility UPW users. Supply piping is located downstream (following direction of the flow) final filters and upstream to the UPW user equipment.

9.3.2 Return — The piping and other distribution system components connecting ends of supply piping and UPW tanks. The return piping located upstream to the UPW tank downstream to the break points (or termination points) between supply and return. The break points are various types of valves, orifices, or tubing that provide the required excess flowrate at the ends of supply lines to ensure no stagnation. Those break points provide pressure transition from supply pressure determined by the manufacturing tool pressure specification and return pressure determined by the UPW tank hydrostatic pressure.

9.3.3 Main Supply or Return Lines — The largest diameter pipelines that deliver UPW to the sub-fab. The main lines start immediately downstream of the final filters and extend to their first split into two or more pipelines. Full-size HVM facility may have more than one distribution loop and therefore more than one supply and return mains.

9.3.4 Lateral Piping — Sections of the distribution lines commonly installed beneath tools in the cleanroom bay and supporting UPW demand of those tools. The lateral piping provides take-off valves (at POC) to connect the tool to the UPW distribution. This connection is commonly referred to as ‘tool hook-up piping’.

9.3.5 Sub-Main Piping — The large diameter piping that connects the main line with the lateral piping. Sub-main piping may not exist if the lateral piping is connected directly to the main line.

10 General Process Considerations

10.1 UPW make-up plant design has matured over recent decades of semiconductor fab technology development. The main differences in the current UPW system designs are in the pretreatment process and are typically driven by the following factors:

10.1.1 Incoming water quality (see Appendix 3 for details of water quality concerns).

10.1.1.1 In most cases the water quality feeding UPW systems is within typical municipal water quality requirements. If it is not, additional pretreatment may be required (reclaim sources, etc.).

10.1.1.2 Water with a high number of suspended solids may require extensive filtration treatment such as MMF, UF, etc. Clear water may need minimum-to no-incoming filtration.

10.1.1.3 Underground water containing iron and manganese may require special oxidation filtration to remove the fouling contaminants.

10.1.2 Water conservation requirements may drive use of ion exchange in pretreatment to the RO. Use of ion exchange resins in pretreatment (before the RO) can improve the overall performance of UPW, but it contributes high salinity regeneration wastewater to the environment. Environmental permits limiting effluent total dissolved solids (TDS) may be the reason of using double pass RO without pretreatment.

10.1.2.1 *Double-Pass vs. Single-Pass Reverse Osmosis* — Advanced semiconductor manufacturing UPW systems frequently include double-pass RO—a configuration that allows for effective removal of weak ions such as boron and silica. Single-pass RO can be used when feed water contains a low content of weak ions or when ion exchange is used in pretreatment.

10.1.3 Removing CO₂ may reduce operating costs for frequent ion exchange resin regenerations and for caustic injection when pH control is necessary for optimized RO operation.

10.1.4 The primary deionization process may consist of either anion resin followed by mixed beds, or electro-deionization (EDI) followed by mixed bed resins. Choice of specific configuration depends on overall process configuration, UPW quality specifications, performance reliability requirements, environmental considerations (water efficiency and use of regeneration chemicals), and cost.

10.1.4.1 *Boron Control* — Boron in form of borate is the weakest inorganic anion present in the raw water and is the most difficult to control. Under conditions of neutral or low pH, more than half of the boron is in the form of non-dissociated boric acid which is not rejected by RO. Therefore, high pH conditions are required to enhance boron removal by RO. However, when pH >9, an increased leakage of sodium should be expected and taken into account when deciding on the capacity of the downstream deionization equipment. Also, the ion exchange capability of the ion exchange resin is limited by the weak ionic properties of boron, resulting in a chromatography effect where boron is slowly released by the resin and passes through the column. The boron leakage is particularly important for design and operation of the polishing system when the ion exchange resin is used for long periods of time without resin replacement or regeneration. Boron should therefore be removed in the primary loop if possible.

10.1.5 UV Considerations

10.1.5.1 TOC removal occurs in close proximity to the UV sleeve therefore the UV reactors should provide a sufficient surface area to allow the UV radiation to break down the TOC molecules.

10.1.5.2 Different types of treated organics may require different energies for their decomposition.

10.1.5.3 Use of oxidizing chemistry (i.e., ozone) may enhance TOC removal.

10.1.5.4 H₂O₂ is a UV by-product that may affect water quality and performance of the downstream equipment and manufacturing processes. H₂O₂ can be removed by platinum, palladium, or other catalyst beds. It is recommended to optimize TOC control by other treatment processes. This will reduce UV energy and thus minimize H₂O₂ formation and avoid additional costs and the possible side effects of adding additional catalytic units. Reducing UV energy will also help to reduce material degradation and potentially prolong the life of critical UPW components.

10.2 Polish Plant Design Considerations

10.2.1 Most polish systems contain UPW tanks, pumps, degasification modules, UV, polish mixed beds, and the final filters. The unit sequence, specific design details, materials of construction, and equipment sizing may vary.

10.2.2 The material of construction may affect water quality. Use SEMI F57 (Standard for quality of high purity polymer materials) when making decisions on the choice of the materials. Stainless steel is recommended to be minimized (see Appendix 1 for more details).

10.3 *Special Considerations* — Several parameters are not capable of being monitored at the levels that advanced semiconductor processes require. As the result the following proactive control measures are recommended:

10.3.1 SEMI F63 and IRDS recommend monitoring and controlling particles in the feed to the final filters of the UPW polish system. The target level is defined by SEMI F63.

10.3.2 SEMI F63 and IRDS recommend monitoring and controlling silica in the feed to the UPW polish system for advanced manufacturing facilities. The target level is defined by SEMI F63.

10.3.3 SEMI F63 and IRDS recommend monitoring and controlling metals in the feed to the UPW polish system for advanced manufacturing facilities producing image sensors. The target level is defined by SEMI F63.

10.3.4 SEMI F63 recommends monitoring and controlling particles in final UPW quality at POC. The smallest critical size of the particles depends on the node size and best available metrology.

10.3.5 Particle precursors (see SEMI F63) control requires special attention. Material (example ion exchange resin, filters, distribution system components) used in UPW system may leach high molecular weight compounds. There is a possibility that low molecular weight contaminants may form particles/residue on the wafer. However, it is expected that traditional way of monitoring NVR, TOC, and ionic compounds will address the issue of low molecular weight contamination control. For highly sensitive applications, the treatment process should be optimized to minimize effect of the particle precursors.

NOTE 3: The method of monitoring particle precursors is included in SEMI F63.

NOTE 4: There is a limited amount of information that exists to define particle precursors.

10.3.6 Reliability of the polishing loop is particularly important as shutdown of the loop may have significant and extended impact on the fab operation. Reliability is facilitated by an uninterrupted power supply, equipment redundancy, effective maintenance, etc. (see Appendix 6 for more details).

10.3.7 The polish system capacity should be optimized to ensure cost-effective and reliable operation. The capacity of the system should take into account when considering fab UPW consumption, pressure control, minimum by-pass flows (to maintain cleanliness), and the maintenance flows needed for rinsing the polish system components.

10.4 Distribution design considerations include the following:

10.4.1 Maintaining pressure at the tools.

10.4.2 Delivering unchanged UPW quality.

10.4.3 Maintaining UPW quality throughout the system (including UPW return).

10.4.4 System integrity and reliability.

10.4.5 Special consideration in the overall system design should be given to the choice of material of construction, thermal expansion of the piping, piping supports, pressure control scheme, and minimum flow sizing criteria and by-pass configurations.

10.5 *Specific Equipment Considerations*

10.5.1 The UPW system employs a number of different replaceable filters with the final filters being the most important. See Appendix 7 for detail recommendations for the choice and performance evaluation of the filters.

10.5.2 Choice of ion exchange resin is critical. See Appendix 8 for details of risks and recommendations.

11 UPW System Utilities

11.1 UPW system utilities provide electricity, cooling, heating, nitrogen gas, and other critical resources required for sustainable operation of UPW system. See Appendix 9 for more details.

12 Quality Assurance and Quality Control (QAQC)

12.1 QAQC definitions are especially important during start up and commissioning of the new or upgraded UPW plant. Effective definition of QAQC plan can reduce cost and time of the construction projects, while enabling UPW quality compliance. See Appendix 2 for more details.

13 System Documentation

13.1 A list of the system documentation required from the UPW vendor upon the project completion should be included in the scope definition for the project. See Appendix 10 for more details.

14 UPW System Reliability and Redundancy

14.1 UPW System redundancy recommendations are described in Appendix 6.

15 Safety Considerations

15.1 Safety of UPW system construction and operation is critical in the semiconductor industry. See Appendix 11 for details of safety considerations.

16 UPW System Maintenance and Operation

16.1 Details of effective maintenance and operations plans for advanced critical UPW systems are described in Appendix 12.

17 Related Documents

17.1 *SEMI Standards and Safety Guidelines*

SEMI C79 — Guide to Evaluate the Efficacy of Sub-15 nm Filters Used in Ultrapure water (UPW) Distribution Systems

SEMI C93 — Guide for Ultrapure Water System Used in Semiconductor Processing

SEMI E49 — Guide for High Purity and Ultrahigh Purity Piping Performance, Subassemblies, and Final Assemblies

SEMI F31 — Guide for Bulk Chemical Distribution Systems

SEMI S2 — Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment

17.2 *Other Documents*

ITRS — International Technology Roadmap for Semiconductors – Reports for Yield Section²

IRDS — International Roadmap for Devices and Systems³

² <http://www.itrs2.net>

³ <https://irds.ieee.org/>

APPENDIX 1

RECOMMENDED MATERIALS OF CONSTRUCTION: CHOICE, PURITY, HANDLING, JOINING, AND INSPECTION

NOTICE: The material in this Appendix is an official part of SEMI F61 and was approved by full letter ballot procedures on May 16, 2017.

A1-1 General — Polish Plant and Distribution

A1-1.1 Recommended piping materials in polish and post-polish portion of a UPW system include the following high purity options: high purity (HP) PVDF, HP PFA, electro-polished (10 Ra) 316L stainless steel, PTFE (expanded, gaskets), PFA (gasket and valves), gaskets and seals, FPM, final filters (ultrafilters and/or cartridge filters), HP valves for water service, HP lined butterfly valves, HP diaphragm valves, needle (sample ports, PFA), ¼ turn ball valves (PFA).

A1-1.2 The manufacturer should be able to certify that all materials are HP and traceable based on respective SEMI Standards. The manufacturer should be able to demonstrate that all materials (manufactured product and raw materials) are tested periodically (representing normal use of raw materials and equipment) using SEMI C79 (for filter cleanliness), SEMI F57 and SEMI E49 testing methodologies using certified laboratories. All tested HP polymer materials should meet the SEMI F57 standard and all tested HP stainless steel components should meet SEMI F19 requirements.

A1-2 Piping and Conveyance

A1-2.1 Major piping materials for UPW should be PVDF for polish and distribution. Poly-propylene (PP) is commonly used in pre-polish and UPW return applications.

A1-2.2 All HP materials should be cleaned at the manufacturer or manufactured in a certified ISO Class 5 at 0.5 µ (class 100) clean room. There should be a chain-of-material control from raw materials to finished product. If cleaned, the cleaning should be finished with UPW of at least 17.5 MΩ·cm water, with TOC <10 ppb, and total ion content of <100 ppb. Gaskets should not contribute particles during system operation. All cut edges should be die cut in a clean area with a controlled environment. All HP materials should come from the manufacturer double-bagged and marked as certified for HP service. Bagging should be a special clean material and not contribute any contamination to the product.

A1-2.3 *PVDF and PFA Pipe and Fittings* — HP PVDF pipe should come double-bagged. It should be marked on the outer bag as ‘HP PVDF’ and the pipe should be marked on the pipe with lot number and part number in a permanent manner. Pipe should also have protective caps. Both bags should be intact when the product is picked for use.

A1-2.4 *Isolation Valves* — This includes all lateral isolation valves off the main, all tool isolation valves off the lateral and any future isolation valve. All valves need to be HP grade. They should only have wetted parts that meet the acceptable materials listed in first section. They should be tested at the manufacturer for bubble tight and should not have any grease or lubricant used in assembly of the valve. It is strongly recommended that any terminating valve be a lug body type such that it can be installed with nothing on the downstream side. It is further recommended that a future valve have a blind flange installed on the downstream side to prevent opening. All future valves need to be properly supported. Valves should come double-bagged and marked for HP service.

A1-2.5 Materials need to be manufactured for intended purposes (not all grades are acceptable). They should be cut and capped as part of the extruder process to prevent dirt and debris from getting into pipe and fittings. They should be stored indoors in a controlled environment. Welding should be done with either IR butt fusion or noncontact heat fusion with feed forward and backward control. All welds should be traceable back to the worker and the machine. Fusion factors should be recorded for future reference and should include the material, size, date, and fusion parameters.

A1-2.6 For return piping materials of a lower standard may be used to reduce system cost. For the UPW return system this could be standard grade PVDF or high quality PP. The same rules apply to installation and material handling as for the polish loop except the materials will not be double-bagged BUT the materials should still be handled the same manner; that is, only unpack what you need immediately and the work environment should be clean and controlled.

A1-3 Prefabrication

A1-3.1 Prefabrication should be done in a cleanroom or at least a clean environment. The complete pieces should be capped and bagged over the ends using a clean polyethylene sheet or bag and cleanroom-approved tape. Care should be taken in transport and handling as unintended stress may occur. The same guidelines for handling and work should be followed as above. The cleanroom should preferably be ISO Class 7 at 0.5 μ (class 10,000). There should be no metal working or painting going on in the clean area. Special clothing and footwear that are not exposed to general shop conditions should be worn.

A1-4 Installation of HP Materials

A1-4.1 *HP PVDF* — HP PVDF should be joined using noncontact infrared (IR) high temperature fusion. The operator should be trained and certified by the manufacturer of the pipe, valves, and fittings. The welding device should have an input for the operator and the material to be joined (PP or PVDF with size and class [10 bars or 16 bars]). The welding machine should be able to measure and compensate the ambient temperature. Once material and size are entered, the machine should be able to automatically calculate overlap of the weld and weld time and cool down time. At the end of the fusion cycle the weld machine should be able to record that the weld met the specified conditions and print out the calibration info, operator info, weld machine info, material info, weld quality and the date and time for every weld. At the end of the fusion cycle a label should be printed providing traceability back to the printout and indicate that the weld was OK. The operator should be responsible to ensure for the weld is acceptable by visual inspection (e.g., the shape of the weld beads, the k-factor, etc.). The weld inspection criteria should be defined by the manufacturer such that an operator or QA/QC person can judge that the weld is acceptable via visual inspection.

A1-5 Mechanical Joints

A1-5.1 Flanged mechanical joints should use a gasket that is equal to the ID of the fitting $\pm 1\%$. This ensures that there is neither impingement to flow nor any crevice at the joint. The flange backing ring should have a special shaped ID that directs the closing force toward the ID of the joint. This ensures that the applied forces are closing the gap in the joint and not opening the gap in the joint when tightened. Pipes need to be aligned within 1/8 in. in all directions. The joint is not intended to compensate for misalignment.

A1-6 Thermal Plastic Union Joints

A1-6.1 For PFA tubing mechanical connections flare type connectors should be used. For tubing 1/4 in. and below standard wall thickness a mechanical flaring tool may be used. For all other tubing, leak free connections should be used; that is, a heated flaring system. All tubing should be cut with a tubing cutter and be square.

A1-6.2 Union joints on piping need to be made of HP materials. They should not exceed 2 inches. They should have an HP grade O-ring. They should be installed as a butt-fusion joint. Alignment is critical with this type of joint. The joint halves should be square face-to-face and should be <3 mm out of alignment. Flange joints are a better option for anything over 32 mm (1 in.). Do not over tighten union nuts as they are prone to failure.

A1-7 Receiving and Inspection

A1-7.1 For all PVDF and PFA tubing all materials should be inspected upon delivery, both the outer bag and the inner bag should be intact with no tears or holes. Proper marking for intended service should be confirmed as well. After inspection all materials need to be placed in clean bins or containers which should protect from dirt and contamination. Prior to use the outer bag should be removed and the inner bag wiped with a cleanroom wipe with at least 10% IPA to clean. The part can then be transferred into the clean assembly area.

A1-8 Moving Materials into the Clean Assembly/Fabrication Area

A1-8.1 After cleaning the outer bag remove it from the inner bag at the clean area pass-through. Immediately transfer it into the clean area. Once inside the clean area remove the inner bag only immediately prior to use. Only remove bags from the number of parts that may be needed that day. For pipe if the need is for a partial piece of pipe, remove the bag but retain the end cap. After cutting off the needed length re-cap and put the pipe back onto the rack.

A1-9 Filtration Materials

A1-9.1 As the primary job for filtration is to remove particles from the product, and as these materials are the last part of the treatment, they should NOT contribute any contamination to the system. Like the other materials in the

polish system these require very closely controlled material control from the manufacture of the raw materials to the handling of the raw materials to the use of the raw materials, the manufacturing process and equipment, the manufacturing environment and the post manufacturing handling and packaging. SEMI F57 can be used to confirm cleanliness of the filtration material.

A1-9.2 The materials common to final filters are: nylon, PP, PVDF, and poly-sulfone. The filter should reside in a housing of some sort. For cartridge-type filtration it will be a stainless steel pressure vessel using 316L, EP to a 10 Ra finish. Cross flow filter modules will come as a sub-assembly and should only be installed when the system is ready to start testing.

A1-10 Gaskets

A1-10.1 If PTFE gaskets are used, only expanded PTFE or PTFE encapsulated gaskets are recommended as the pure form of fluorinated polymer (an overcoat material). Gaskets should be pure, and meet or exceed SEMI F57 requirements. They should be manufactured in a clean environment. The gasket should be able to form a seal when compressed. Gaskets should be designed such that the force to seal does not exceed the strength of the pipe material or the bolts. This is specifically an issue for expanded per-fluoro compounds that are non-resilient. Use of any non-compressible material is not recommended. Per-fluoro (PFA, PTFE, ECTFE, and ETFE) compounds can be used as an over-coat of an elastomer or lining in other systems, such as tanks, vessels, pumps, valves, etc. For gaskets that are a two-part system with an inert material over-molded onto a resilient elastomer, there should be no exposure of the elastomer to the fluid.

A1-10.2 *FPM, EPDM, VITON, Silicon*

A1-10.2.1 It is important that these materials be clean and controlled. Refer to SEMI F51 for elastomer material cleanliness testing. There are many forms of each of these and care should be taken to select high grade materials from reputable manufacturers that understand the intended application and need for low or non-contaminating product.

A1-10.2.2 FPM is the international abbreviation according to DIN/ISO.

A1-10.2.3 FKM is the short form for the fluoro-elastomer category according to the American standard ASTM.

A1-10.2.4 Viton® is the registered trademark of DuPont Performance Elastomers.

Table A1-1 Elastomer Material Compatibility

	<i>Nitrile Rubber</i>	<i>Neoprene Rubber</i>	<i>EPDM Rubber</i>	<i>Fluoroelastomers FKM/FPM (such as Viton®)</i>	<i>Silicone</i>	<i>Clear Silicone (such as Silastic Clear medical grade)</i>	<i>Perfluoroelastomers FFKM (such as Kalrez®)</i>	<i>Perfluorocompounds PFA/PTFE/ECTFE/ECTFE (such as Teflon®, GORE®, Halar® etc.)</i>	<i>XXXXelastomers (such as Chemraz®)</i>	<i>Yyyelastomers (such as zzzz)</i>
Pretreatment System	A	A	R	A	A	A	A	A	A	
Primary System	N/A	N/A	A	R	A	A	A	A	A	
Polish UPW	N/A	N/A	N/A	A	A	R	A	R	A	
Ozonated UPW	N/A	N/A	N/A	N/A	A	N/A	A	R	A	
Hot UPW	N/A	N/A	A	N/A	N/A	R	N/A	R	N/A	
Acid (HCl)	N/A	N/A	N/A	R	N/A	N/A	N/A	R	R	
Caustic	N/A	N/A	A	N/A	N/A	N/A	N/A	A	R	

#1 N/A = Not Acceptable. A = Acceptable. R = Recommended.

#2 PTFE, ETFE, ECTFE, etc. should only be used in the modified version (expanded or encapsulated).

A1-10.2.5 EPDM rubber (ethylene propylene diene monomer [M-class] rubber) is the designation given for a saturated polymer chain of the polymethylene type, consisting of ethylene, propylene, and diene. The M refers to its classification in ASTM D1418.

A1-10.2.6 FKM (by ASTM D1418 standard) (equivalent to FPM by ISO/DIN 1629 standard) is the designation for about 80% of fluoroelastomers as defined in ASTM D1418. They provide additional heat and chemical resistance.

A1-10.2.7 Viton® is a brand of synthetic rubber and fluoropolymer elastomer commonly used in O-rings, chemical-resistant gloves, and other molded or extruded goods. The name is a registered trademark of The Chemours Company. Viton fluoroelastomers are categorized under the ASTM D1418 and ISO 1629 designation of FKM.

A1-10.2.8 DuPont™ Kalrez® perfluoroelastomer parts (FFKM) resist over 1,800 different chemicals while offering the high temperature stability of PTFE (327°C). They are used in highly aggressive chemical processing, semiconductor wafer fabrication, pharmaceutical, oil and gas recovery, and aerospace applications.

A1-11 High Purity Stainless Steel Applications

A1-11.1 Certified 316L, passivated and electropolished to a 10 Ra finish is recommended for HP wet applications. This is typically found around UV, large pump headers, pumps housing and impeller, pressure control valves, check valves, sample valves, the vacuum degasifier, and filter housings (see SEMI F19, Stainless Steel Surface Finishes). Use of stainless steel piping and components should be minimized, especially downstream polish Mixed Beds.

A1-12 Material Handling (i.e., high purity welding environment) and Joining Requirements

A1-12.1 Environment

A1-12.1.1 Welding should be performed in a cleanroom, preferably ISO Class 7 at 0.5 μ (class 10,000) or better. There should be no metal work occurring in the area of PVDF or PFA joining. All materials that come into the cleanroom should have the outer bag removed prior to passing into the cleanroom. The second bag should be removed only prior to immediate use. All materials in the cleanroom should be stored in clean containers with lids. All equipment should be wiped down with dilute IPA prior to entering the cleanroom to remove any surface dirt and oils. After all the work is done in the cleanroom the sub-assemblies should be covered on any open end with clean polyethylene bag or sheet and the cover taped on using cleanroom certified tape. Only then should it be removed from

the cleanroom to a place for safe storage. If a cleanroom is not available, joining should be done in a clean area with hard walls and a sealed floor. There should not be any metal work occurring in that room (grinding, welding or painting).

A1-12.2 *Material Handling*

A1-12.2.1 All materials should come from the supplier marked as 'HP' or equal. All materials should be double-bagged with the part number clearly shown on both the inner and outer bag. Each part should be inspected to make sure that neither the part nor the packaging has been damaged.

A1-12.2.2 Prior to passing the part into the production area the outer bag should be wiped with a cleanroom wipe wetted with DI water. Then the outer bag can be cut with a scissor and removed. Immediately pass the part into the cleanroom.

A1-12.2.3 This applies for PVDF, PFA and HP SS.

A1-12.3 *IR Butt Fusion Joining for PVDF or PFA*

A1-12.3.1 Use only machines approved/recommended by the material manufacturer. Machines should only be non-contact IR butt fusion machines. Plate heater machines which contact the part should not be allowed. Only vendor recommended clean wipes should be used for cleaning ends prior to welding. The welding machine should be able to specify the material type, size, wall thickness, and part type (fitting or pipe) in the set up. It should require inputs for room conditions (temperature and humidity) and the name and certification number of the person doing the weld. It should be capable of printing out the weld data on a tag which should contain as a minimum the date, the material welded, the time of day, the welder machine number, and the name of the person doing the weld. This should also be stored in an internal memory that can be accessed later. The weld label should then be placed at the just completed joint if it is a successful weld. The machine should reject any weld that does not conform to the weld requirements as defined by the manufacturer during each weld; for example, end surface trimming and squaring, if the heat time is not correct, or the cool down time is not correct, wall offset, or the closing force is not correct, etc.

A1-12.3.2 The welding machine manufacturer or the material manufacturer should give clear direction on how to visually inspect every weld upon completion to determine if it is acceptable. The criteria should include weld bead shape, foreign material imbedded in weld, weld bead consistency around whole weld, pipe offset, pipe flatness at weld, etc. Every weld should be inspected by the person welding and the contractor QA/QC person. At the end of the project every weld should have a tag.

APPENDIX 2

ULTRAPURE WATER SYSTEM QUALIFICATION GUIDELINES

NOTICE: The material in this Appendix is an official part of SEMI F61 and was approved by full letter ballot procedures on May 16, 2017.

A2-1 Defining the Scope for Analytical Work

A2-1.1 When designing a UPW system, it is important that the project-specified water quality requirements are aligned between the UPW system provider and the end user. SEMI F63 provides recommended water quality specification for the advanced semiconductor facility. Other generations of technologies may consider ASTM D5127 specification for reference. SEMI F63 also provides additional information about the risks associated with situations when the specified levels are exceeded.

A2-1.2 The scope of the analytical work is determined by water quality requirements and the project specific requirements for the system commissioning. Typical questions addressed, when defining commissioning requirements include:

- Using online vs. grab sample analyses (depends on the water quality spec and available analytical equipment).
- Duration of the final system commissioning (i.e., 30 days of in-compliance operation).
- Location of the samples and the number of samples to be taken during final commissioning.
- Use of duplicates to eliminate wrong readings due to sampling errors.
- Typical analytical instruments to be used for commissioning.
- Certified labs for off line analytical results.

A2-2 Qualification Testing Recommendations

A2-2.1 When qualifying new or recently modified UPW system, the following qualification areas should be considered:

- Make-up plant qualification. Qualifying the make-up plan helps to mitigate risks for start-up of the polish plant. Generally the make-up plant is started first.
- Polish plant qualification represents the ability of the UPW system to produce UPW at certain quality.
- Distribution system qualification may be important by itself. Although the UPW system may be able to meet the specified quality requirements, new distribution system components are known to add contamination (be it dissolved ions or particles) during first months of operation.

NOTE 5: To minimize commissioning schedule it may be required to rinse the polish distribution with a small external UPW source while qualifying the make-up plant.

A2-2.2 It is recommended to initiate the qualification testing when the system has rinsed to resistivity specification. It is recommended to conduct preliminary tests for the following parameters, before initiating the final compliance testing program:

- Bacteria (typical after construction contamination—may require sanitization).
- Boron and silica (may indicate ion exchange issues due to quality of resin or start-up issues).
- Online Particles and TOC (may indicate leaching from polisher resins, potting glue from UF).

A2-2.3 Samples are typically collected weekly for a period of four weeks to measure UPW quality stability. For critical parameters, it is recommended to sample in duplicates. If the water quality is stable, a routine monitoring program may be initiated. Monthly sampling is typical frequency of the grab sample analysis for routine monitoring.

A2-2.4 It is also common that some of the parameters, such as bacteria, fail during the initial compliance testing.