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StandardGuide for Ultra-Pure Water Used in the Electronics and Semiconductor Industries[1]

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1. Scope

1.1 This guide provides recommendations for water quality related to electronics and semiconductor-industry manufacturing. Seven classifications of water are described, including water for line widths as low as 0.032 micron. In all cases, the recommendations are for water at the point of distribution (POD).

1.2 Water is used for washing and rinsing of semiconductor components during manufacture. Water is also used for cleaning and etching operations, making steam for oxidation of silicon surfaces, preparing photomasks, and depositing luminescent materials. Other applications are in the development and fabrication of solid-state devices, thin-film devices, communication lasers, light-emitting diodes, photo-detectors, printed circuits, memory devices, vacuum-tube devices, or electrolytic devices.

1.3 Users needing water qualities different from those described here should consult other water standards, such as Specification D1193 and Guide D5196.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1129 Terminology Relating to Water
D1193 Specification for Reagent Water
D1976 Test Method for Elements in Water by Inductively-Coupled Argon Plasma Atomic Emission Spectroscopy
D2791 Test Method for On-line Determination of Sodium in Water
D3919 Practice for Measuring Trace Elements in Water by Graphite Furnace Atomic Absorption Spectrophotometry
D4191 Test Method for Sodium in Water by Atomic Absorption Spectrophotometry
D4192 Test Method for Potassium in Water by Atomic Absorption Spectrophotometry
D4327 Test Method for Anions in Water by Suppressed Ion Chromatography
D4453 Practice for Handling of High Purity Water Samples
D4517 Test Method for Low-Level Total Silica in High-Purity Water by Flameless Atomic Absorption Spectroscopy
D5173 Test Method for On-Line Monitoring of Carbon Compounds in Water by Chemical Oxidation, by UV Light Oxidation, by Both, or by High Temperature Combustion Followed by Gas Phase NDIR or by Electrolytic Conductivity
D5196 Guide for Bio-Applications Grade Water
D5391 Test Method for Electrical Conductivity and Resistivity of a Flowing High Purity Water Sample
D5462 Test Method for On-Line Measurement of Low-Level Dissolved Oxygen in Water
D5542 Test Methods for Trace Anions in High Purity Water by Ion Chromatography
D5544 Test Method for On-Line Measurement of Residue After Evaporation of High-Purity Water
D5673 Test Method for Elements in Water by Inductively Coupled Plasma—Mass Spectrometry
D5996 Test Method for Measuring Anionic Contaminants in High-Purity Water by On-Line Ion Chromatography
D5997 Test Method for On-Line Monitoring of Total Carbon, Inorganic Carbon in Water by Ultraviolet, Persulfate Oxidation, and Membrane Conductivity Detection
F1094 Test Methods for Microbiological Monitoring of Water Used for Processing Electron and Microelectronic Devices by Direct Pressure Tap Sampling Valve and by the Presterilized Plastic Bag Method

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide refer to Terminology D1129.

[1] This guide is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.02 on Quality Systems, Specification, and Statistics.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *total bacterial counts, n*—total number of cultureable microorganisms present in the named sample, excluding obligate anaerobic organisms, determined in accordance with Test Methods F1094.

3.2.2 *total organic carbon (TOC), n*—carbon measured after inorganic-carbon response has been eliminated by one of the prescribed ASTM test methods.

4. Significance and Use

4.1 This guide recommends the water quality required for the electronics and microelectronics industries. High-purity water is required to prevent contamination of products during manufacture, since contamination can lead to an unacceptable, low yield of electronic devices.

4.2 The range of water purity is defined in accordance with the manufacturing process. The types of ultra-pure water are defined with respect to device line width. In all cases, the water-quality recommendations apply at the point of distribution.

4.3 The limits on the impurities are related to current contamination specifications and to available analytical methods (either performed in a suitable clean laboratory or by on-line instrumentation). On-line and off-line methods are used in accordance with current industry practice. Concentration of the sample may be required to measure the impurities at the levels indicated in Table 1.

5. Classification

5.1 Seven types of electronic-grade water are described in this guide. In all cases, the water-quality recommendations apply at the point of distribution.

5.1.1 *Type E-1*—This water is classified as microelectronic water to be used in the production of devices having line widths between 0.5 and 1.0 µm.

5.1.2 *Type E-1.1*—This water is classified as microelectronic water to be used in the production of devices having line widths between 0.25 and 0.35 µm.

5.1.3 *Type E-1.2*—This water is classified as microelectronic water to be used in the production of devices having line widths between 0.09 and 0.18 µm.

5.1.4 *Type E-1.3*—This water is classified as microelectronic water to be used in production of devices having line widths between 0.065 and 0.032µm. This type is the water of ultimate practical purity produced in large volumes, and is intended for the most critical microelectronic uses. ASTM Type E-1.3 is also identical to the SEMI (Semiconductor Equipment and Materials International) Guide for Ultrapure Water Used in Semiconductor Processing (F063), 2010 version.

5.1.5 *Type E-2*—This water is classified as microelectronic water to be used in the production of devices that have dimensions between 1 and 5 µm.

5.1.6 *Type E-3*—This grade of water is classified as macroelectronic water to be used in the production of devices having dimensions larger than 5 µm. This grade may be used to produce larger components and some small components not affected by trace amounts of impurities.

5.1.7 *Type E-4*—This grade may be classified as water used in preparation of plating solutions and for other applications where the water being used can be of lesser quality.

5.2 Components of the water system for producing electronic-grade water shall be grouped into five general process sections for the purpose of simplifying the organization of the components of the systems. These processes are described in 5.2.1-5.2.5.

5.2.1 *Pretreatment*—The processes in this category include the addition of various types of coagulants, precipitating agents, clarifiers, sedimentation tanks, and particulate-filtration systems (including sand filters, disposable filter elements, ultrafilter membranes, and other particle-removing systems). Adsorbent or entrapment beds may include greensand, activated carbon, and various synthetic materials specific for certain organic and inorganic impurities.

5.2.2 *Desalination*—This process is fundamental to the production of ultra-pure water of all grades, and may include more than one of the processes of ion exchange, reverse osmosis, electrodialysis, continuous electrodeionization, or all of the above. The size of the system governs the choice of the combination of desalination processes. Various configurations of the different processes should be considered, including two-bed and mixed-bed demineralization, multi-stage reverse osmosis employing various types of membranes, electrodeionization, and electrodialysis.

5.2.3 *Organic and Biological Removal Systems*—Removal of biological and organic contaminants is an important adjunct to any system used to prepare ultra-pure water. Dissolved organic compounds can accumulate in the system during the process as well as being present in the original water. Methods of minimizing biological contamination include the addition of hydrogen peroxide and ozone. Ultraviolet irradiation at the 185 nm wavelength provides intense energy for breaking chemical bonds and produces traces of ozone. The 185 nm light lyses bacteria and breaks down organic compounds to organic acids and carbon dioxide. Also formed are active intermediate reactants; the main such reactant is the hydroxyl radical, which inactivates bacteria. Variables such as water flow and degree of certain contaminants like turbidity, iron, and humic and fluvic acid should be considered to achieve the maximum effect from the irradiation. With the destruction of organics, TOC will be reduced. Therefore, 185 nm light should only be used upstream of the final ion-exchange component. Ultraviolet irradiation at 254 nm significantly reduces the growth of organisms by dislocating the DNA base pairs. This process prevents the bacteria from replicating. Membrane filters (including reverse osmosis and ultrafilters) may also remove biological impurities as well as organic molecules. Synthetic adsorbent columns ranging from porous resins to activated carbon may be effective in removing organics.

5.2.4 *Particulate Removal*—Particulate removal in the production of ultra-pure water is differentiated from pretreatment that removes gross suspended substances. Particles of all types (biological, organic, or inorganic) significantly interfere with the production of electronic components. Processes used to remove particulate matter generally consist of the use of a microporous membrane structure of flat, cylindrical, or pleated

TABLE 1 Requirements for Water at the Point of Distribution in the Electronics and Semiconductor Industries[A]

Parameter	Type E-1	Type E-1.1	Type E-1.2[B]	Type E-1.3[B]	Type E-2	Type E-3	Type E-4
Linewidth (microns)	1.0–0.5	0.35–0.25	0.18–0.09	0.065–0.032	5.0–1.0	>5.0	—
Resistivity, 25°C (On-line)	18.1	18.2	18.2	18.2	16.5	12	0.5
TOC (µg/L) (on-line for <10 ppb)	5	2	1	1	50	300	1000
On-line dissolved oxygen (µg/L)	25	10	3	10	—	—	—
On-Line Residue after evaporation (µg/L)	1	0.5	0.1		—	—	—
On-line particles/L (micron range)							
>0.05 µm				500[C]			
0.05–0.1		1000	200	N/A[C]	—	—	—
0.1–0.2	1000	350	<100	N/A	—	—	—
0.2–0.5	500	<100	<10	N/A	—	—	—
0.5-1.0	200	<50	<5	N/A	—	—	—
1.0	<100	<20	<1	N/A	—	—	—
SEM particles/L (micron range)							
0.1–0.2	1000	700	<250	N/A	—	—	—
0.2–0.5	500	400	<100	N/A	3000	—	—
0.5–1	100	50	<30	N/A	—	10 000	—
10	<50	<30	<10	N/A	—	—	100 000
Bacteria in CFU/Volume							
100 mL Sample	5	3	1	N/A	10	50	100
1 L Sample			10	1			
10 L Sample				1			
Silica – total (µg/L)	5	3	1	0.5	10	50	1000
Silica – dissolved (µg/L)	3	1	0.5	0.5	—	—	—
Anions and Ammonium by IC (µg/L)							
Ammonium	0.1	0.10	0.05	0.050	—	—	—
Bromide	0.1	0.05	0.02	0.050	—	—	—
Chloride	0.1	0.05	0.02	0.050	1	10	1000
Fluoride	0.1	0.05	0.03	0.050	—	—	—
Nitrate	0.1	0.05	0.02	0.050	1	5	500
Nitrite	0.1	0.05	0.02	0.050	—	—	—
Phosphate	0.1	0.05	0.02	0.050	1	5	500
Sulfate	0.1	0.05	0.02	0.050	1	5	500
Metals by ICP/MS (µg/L)							
Aluminum	0.05	0.02	0.005	0.001	—	—	—
Antimony				0.001			
Arsenic				0.001			
Barium	0.05	0.02	0.001	0.001	—	—	—
Boron[D]	0.3	0.1	0.05	0.050	—	—	—
Cadmium				0.010			
Calcium	0.05	0.02	0.002	0.001	—	—	—
Chromium	0.05	0.02	0.002	0.001	—	—	—
Copper	0.05	0.02	0.002	0.001	1	2	500
Iron	0.05	0.02	0.002	0.001	—	—	—
Lead	0.05	0.02	0.005	0.001	—	—	—
Lithium	0.05	0.02	0.003	0.001	—	—	—
Magnesium	0.05	0.02	0.002	0.001	—	—	—
Manganese	0.05	0.02	0.002	0.010	—	—	—
Nickel	0.05	0.02	0.002	0.001	1	2	500
Potassium	0.05	0.02	0.005	0.001	2	5	500
Sodium	0.05	0.02	0.005	0.001	1	5	1000
Strontium	0.05	0.02	0.001		—	—	—
Tin				0.010			
Titanium				0.010			
Vanadium				0.010			
Zinc	0.05	0.02	0.002	0.001	1	5	500
Temperature Stability (K)				±1			
Temperature Gradient (K/10 min)				<0.1			
Dissolved Nitrogen On-line (mg/L)				8-18			
Dissolved Nitrogen Stability (mg/L)				±2			

[A] The user should be advised that analytical data often are instrument dependent and technique dependent. Thus, the numbers in Table 1 are only guidelines. This table will be revised whenever the semiconductor industry develops new linewidths, thereby keeping the guidelines current.

[B] Values shown in Type E-1.3 are a result of aligning ITRS risk factors of known contaminates to the production processes found in current semiconductor processing for the linewidth of interest and may differ in a few cases to those found in Type E-1.2. Users who wish to use the higher numbers for Type E-1.2 water should feel free to do so.

All values are equal to or less than with the exception of Resistivity.

[C] Particle metrology has not kept pace with the decreasing line-width of semiconductor manufacturing. Current line-widths require the ability to monitor 20-nm particles. However, existing Optical Particle Counters (OPCs) are only capable of detecting 50-nm particles with a counting efficiency of <5%, and a background count (noise level) of 500 particles per liter. Particle-counting statistics become important as count levels approach the noise level. Therefore, the OPC setup and performance must be optimized. Particle levels must consistently be within the noise level of any OPC (regardless of any specified level).

[D] Boron is monitored only as an operational parameter for monitoring the ion-exchange beds.

configuration. The Final Filters are preceded by a bank of Prefilters with a 2× larger pore size. Ultrafilters and reverse-osmosis units may also be used for final filtration. The choice of the particular membrane depends in part upon the pore size,