

INTERNATIONAL  
TECHNOLOGY ROADMAP  
FOR  
SEMICONDUCTORS  
2006 UPDATE

YIELD ENHANCEMENT

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# YIELD ENHANCEMENT

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## SUMMARY

The Yield Enhancement ITWG updated the tables regarding the topics Defect Budget and Yield Model, Defect Detection and Characterization and Wafer Environment and Contamination Control for the 2006 electronic update. The key challenges remain similar as 2005. The most important challenge will be the signal-to-noise ratio for defect inspection tools. Currently, inspection systems are expected to detect defects of sizes scaling down in the same way or even faster as feature sizes requested by technology generations. Increasing the inspection sensitivity at the same time increases the challenge to find small but yield-relevant defects under a vast amount of nuisance, false defects. In parallel a low cost of ownership of the tools demands for high throughput inspection.

Other topics challenging the Yield Enhancement community are prioritized as follows:

- *High Throughput Logic Diagnosis Capability*—identification and tackling of systematic yield loss mechanisms.
- *Detection of Multiple Killer Defect Types*—and simultaneous differentiation at high capture rates, low cost of ownership and throughput.
- *High-Aspect-Ratio Inspection*—need for high-speed and cost-effective high aspect ratio inspection tools remains as the work around using e-beam inspection does not at all meet requirement for throughput and low cost.
- *Process Stability vs. Absolute Contamination Level Including the Correlation to Yield*—data, test structures, and methods are needed for correlating process fluid contamination types and levels to yield and determine required control limits.
- *In-line Defect Characterization and Analysis*—as an alternative to EDX analysis systems. The focus is on light elements, small amount of samples due to particle size and microanalysis
- *Wafer Edge and Bevel Control and Inspection*—in order to find the root cause inspection of wafer edge, bevel and apex on front and backside is needed
- *Data Management and Test Structures for Rapid Yield Learning*—to enable the rapid root-cause analysis of yield-limiting conditions
- *Development of Parametric Sensitive Yield Models*—including new materials, (OPC) – optical proximity correction and considering the high complexity of integration

The Yield Enhancement chapter consists of four subchapters as Yield Learning, Defect Budget and Yield Model, Defect Detection and Characterization, and Wafer Environment and Contamination Control. The major work during 2006 was the control and update of the tables. The changes summarizes as follows:

### **DEFECT BUDGET AND YIELD MODEL**

This update includes standardization of chip size for PWP calculation and correction of unmarked errors. Additionally, ‘Ymaterial’ is newly introduced to separate starting material based yield degradation from process based one. It is a solution against modification of yield equation previously proposed by FEP ITWG.

### **DEFECT DETECTION AND CHARACTERIZATION**

The table 113 was checked carefully against latest developments for defect inspection and detection. Discussions and adjustments regarding the estimation of impact of roughness on non patterned inspection and definitions for coordinate precision were performed.

### **WAFER ENVIRONMENT AND CONTAMINATION CONTROL**

Table 115 has been updated especially in discussions with Lithography and Front-end processing working groups. It needs to be considered that the table does not only consider contaminations but also wafer environment process variables, which can be yield determining similar to contaminants. New process materials will continue to drive the list of ionic and other elemental impurities to be specified and monitored. Accurate liquid particle measurements continue to be a challenge at current and future device geometries. Organic contaminations require continued attention since many parameters used to specify and monitor are still not specific enough and do not pinpoint the contamination mechanisms clearly enough.

## 2 Yield Enhancement

Table 108 Definitions for the Different Interface Points **UPDATED**

	<i>POS</i> Delivery Point of Gas/Chemical Supplier	<i>POD</i> Outlet of Central Facility System	<i>POC</i> Submain or VMB/VMP Take off Valve	<i>POE</i> Entry to Equipment or Sub Equipment	<i>POU</i> Entry to the Process Chamber	<i>POP</i> Contact with Wafer
<i>Interfaces</i>	<i>SEMI Standards Focus Area</i>	<i>ITRS Factory Integration Facilities Group Focus Area</i>		<i>ITRS Factory Integration Equipment Group Focus Area</i>		<i>ITRS Front End Processes, Lithography, Interconnect TWG Focus Area</i>
Ultrapure water	Raw water	Outlet of final filtration in UPW plant	Outlet of submain take off valve	Inlet of wet bench or subequipment	Inlet of wet bench bath, spray nozzle, or connection point to piping, which is also used for other chemicals	Wafer in production
Process chemicals	Chemical drum/tote/bulk supply	Outlet of final filtration of chemical distribution unit	Outlet of VMB valve	Inlet of wet bench or intermediate tank	Inlet of wet bench bath or spray nozzle	Wafer in production
Specialty gases	Gas cylinder or bulk specialty gas systems	Outlet of final filtration of gas cabinet	Outlet of VMB valve	Inlet of equipment	Inlet of chamber (outlet of MFC)	Wafer in production
Bulk gases	Bulk gas delivered on site or gas generator	Outlet of final filtration/purification	Outlet of submain take off valve or VMB valve	Inlet of equipment/subequipment	Inlet of chamber (outlet of MFC)	Wafer in production
Cleanroom and AMC	Outside air	Outlet of make-up air handling unit	Outlet of filters in cleanroom ceiling	Inlet to mini-environment or sub equipment for AMC, outlet of the tool filter for particles	Gas/air in vicinity to wafer/substrate	Wafer/substrate in production (AMC/SMC)

*POD*—point of delivery    *POC*—point of connection    *POE*—point of entry    *POU*—point of use    *VMB*— valve manifold box  
*VMP*— valve manifold post    *UPW*—ultra pure water    *MFC*—mass flow controller    *AMC*—airborne molecular contamination  
*SMC*—surface molecular contamination

## DIFFICULT CHALLENGES

Table 109 Yield Enhancement Difficult Challenges

<i>Difficult Challenges ≥ 32 nm</i>	<i>Summary of Issues</i>
<i>Signal-to-noise ratio</i> —Increasing the inspection sensitivity at the same time increases the challenge to find small but yield relevant defects under a vast amount of nuisance, false defects. The key of a successful inspection result is, besides achieved sensitivity, the ease to get to the defects of interest (DOI).	Filtering and use of ADC is a potential solution Reduction of background noise from detection units and samples to improve the sensitivity of systems Need to improve signal to noise ratio to delineate defect from process variation Where does process variation stop and defect start?
<i>High throughput logic diagnosis capability</i> —The irregularity of features makes logic areas very sensitive to systematic yield loss mechanisms such as patterning marginalities across the lithographic process window.	Before reaching random-defect limited yields, the systematic yield loss mechanisms should be efficiently identified and tackled through logic diagnosis capability designed into products and systematically incorporated in the test flow Potential issues can arise due to different ATPG flows to accommodate; ATE architecture that can lead to significant test time increase when logging the number of vectors necessary for the logic diagnosis to converge, and logic diagnosis run time per die
<i>Detection of multiple killer defects</i> —Differentiation of multiple killer defect types is necessary at high capture rates, low cost of ownership and throughput.	Existing techniques trade-off throughput for sensitivity, but at predicted defect levels, both throughput and sensitivity are necessary for statistical validity Reduction of inspection costs is crucial in view of CoO Ability to detect particles at critical size may not exist Detection of line edge roughness due to subtle process variation Electrical and physical failure analysis for killer defects at high capture rate, high throughput and high precision
<i>High aspect ratio inspection</i> —Need for high-speed	Poor transmission of energy into bottom of via and back out to detection system.

and cost-effective high aspect ratio inspection tools remains. The interim approach using e-beam inspection does not meet the requirements for throughput and low cost.	To detect rapidly defects at $\frac{1}{2}\times$ ground rule (GR) associated with high-aspect-ratio contacts, vias, and trenches, and especially defects near or at the bottoms of these features Large number of contacts and vias per wafer
<i>Difficult Challenges &lt; 32 nm</i>	<i>Summary of Issues</i>
<i>Process stability versus absolute contamination level including the correlation to yield</i> —Data, test structures, and methods are needed for correlating process fluid contamination types and levels to yield and determine required control limits.	Methodology for employment and correlation of fluid/gas types to yield of a standard test structure/product Relative importance of different contaminants to wafer yield Define a standard test for yield/parametric effect Definition of maximum process variation (control limits)
<i>Inline defect characterization and analysis</i> —As alternative to EDX analysis systems [1]. The focus is on light elements, small amount of samples due to particle size, and microanalysis.	The sampling probe should show minimum impact as surface damage or destruction of SEM image resolution Supply of information of chemical state and bonding especially of organics is recommended Small volume technique adapted to the scales of technology generations Capability to distinguish between the particle and the substrate signal
<i>Wafer edge and bevel control and inspection</i> —Defects and process problems around wafer edge and wafer bevel can cause yield problems.	Find the root cause inspection of wafer edge, bevel and apex on the wafer front and backside
<i>Rapid yield learning requires efficient data management and suitable test structures</i> —Enabling rapid root-cause analysis of yield-limiting conditions. With increasing process complexity and fewer yield learning cycles with each subsequent technology generation it would be impossible to achieve historic yield ramps and mature yield levels.	Development of automated, intelligent structures, analysis, and reduction algorithms that correlate facility, design, process, test, and WIP data Need of tools and methods for short yield learning cycles
<i>Development of parametric sensitive yield models including new materials</i> —OPC and considering the high complexity of integration. The models must comprehend greater parametric sensitivities, ultra-thin film integrity, impact of circuit design, greater transistor packing, etc.	Develop test structures for new technology generations Address complex integration issues Model ultra-thin film integrity issues Improve scaling methods for front-end processes including increased transistor packing density

ADC—automatic defect classification

[1] Cross-link to Metrology chapter

## TECHNOLOGY REQUIREMENTS

### YIELD MODEL AND DEFECT BUDGET

Table 110 Defect Budget Technology Requirement Assumptions **UPDATED**

<i>Product</i>	<i>MPU</i>	<i>DRAM</i>
<i>Yield Ramp Phase</i>	<i>Volume Production</i>	<i>Volume Production</i>
<i>Y<sub>OVERALL</sub></i>	<b>75%</b>	<b>85%</b>
<i>Y<sub>RANDOM</sub></i>	<b>83%</b>	<b>89.50%</b>
<i>Y<sub>SYSTEMATIC</sub></i>	<b>90%</b>	<b>95%</b>
<b>ADD</b> <i>Y<sub>material</sub></i>	<b>&gt;99%</b>	<b>&gt;99%</b>
<b>ADD</b> <i>Chip Size</i>	<b>140 mm<sup>2</sup></b>	<b>88 mm<sup>2</sup></b>
<i>Cluster Parameter</i>	<b>2</b>	<b>2</b>

#### 4 Yield Enhancement

Table 111a Yield Model and Defect Budget MPU Technology Requirements—Near-term Years *UPDATED*

Year of Production	2005	2006	2007	2008	2009	2010	2011	2012	2013
DRAM ½ Pitch (nm) (contacted)	80	70	65	57	50	45	40	35	32
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted) [A]	90	78	68	59	52	45	40	35	32
MPU Physical Gate Length (nm)	32	28	25	23	20	18	16	14	13
Critical Defect Size (nm)	45	39	34	29.5	26	22.5	20	18	16
Chip Size (mm <sup>2</sup> ) [B]	111	88	140	111	88	140	111	88	140
Overall Electrical D <sub>0</sub> (faults/m <sup>2</sup> ) at Critical Defect Size Or Greater [C]	2210	2210	2210	2210	2210	2210	2210	2210	2210
<b>WAS</b> Random D <sub>0</sub> (faults/m <sup>2</sup> ) [D]	1757	2214	1395	1757	2214	1395	1757	2214	1395
<b>IS</b> Random D <sub>0</sub> (faults/m <sup>2</sup> ) [D]	1395	1395	1395	1395	1395	1395	1395	1395	1395
Number of Mask Levels [E]	33	33	33	35	35	35	35	35	37
<b>WAS</b> Random Faults/Mask	53	67	42	50	63	40	50	63	38
<b>IS</b> Random Faults/Mask	42	42	42	40	40	40	40	40	38
MPU Random Particles per Wafer pass (PWP) Budget (defects/m <sup>2</sup> ) for Generic Tool Type Scaled to 45 nm Critical Defect Size or Greater									
CMP clean	276	207	157	112	87	65	51	42	31
CMP insulator	667	501	381	270	210	157	124	101	75
CMP metal	755	567	431	306	238	178	141	114	85
Coat/develop/bake	120	90	69	49	38	28	22	18	14
CVD insulator	594	446	339	241	187	140	111	90	67
CVD oxide mask	780	586	445	316	246	184	145	118	88
Dielectric track	189	142	108	77	60	45	35	29	21
Furnace CVD	338	254	193	137	106	80	63	51	38
Furnace fast ramp	307	230	175	124	97	72	57	46	35
Furnace oxide/anneal	198	149	113	80	62	47	37	30	22
Implant high current	264	199	151	107	83	62	49	40	30
Implant low/medium current	242	182	138	98	76	57	45	36	27
Inspect PLY	246	185	140	100	77	58	46	37	28
Inspect visual	264	199	151	107	83	62	49	40	30
Lithography cell	205	154	117	83	65	48	38	31	23
Lithography stepper	194	145	111	78	61	46	36	29	22
Measure CD	230	173	132	93	73	54	43	35	26
Measure film	198	149	113	80	62	47	37	30	22
Measure overlay	184	138	105	74	58	43	34	28	21
Metal CVD	360	271	206	146	113	85	67	54	41
Metal electroplate	187	140	107	76	59	44	35	28	21
Metal etch	800	601	457	324	252	189	149	121	90
Metal PVD	411	309	235	167	129	97	77	62	46
Plasma etch	728	547	416	295	229	172	136	110	82
Plasma strip	336	253	192	136	106	79	63	51	38
RTP CVD	220	166	126	89	69	52	41	33	25
RTP oxide/anneal	144	108	82	58	45	34	27	22	16
Test	57	42	32	23	18	13	11	9	6
Vapor phase clean	506	380	289	205	159	119	94	76	57
Wafer handling	23	17	13	9	7	5	4	3	3
Wet bench	329	247	188	133	104	78	61	50	37

Table 111b Yield Model and Defect Budget MPU Technology Requirements—Long-term Years *UPDATED*

Year of Production	2014	2015	2016	2017	2018	2019	2020
DRAM ½ Pitch (nm) (contacted)	28	25	22	20	18	16	14
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted) [A]	28	25	22	20	18	16	14
MPU Physical Gate Length (nm)	11	10	9	8	7	6	6
Critical Defect Size (nm)	14	12.5	11.5	10	9	8	7
Chip Size (mm <sup>2</sup> ) [B]	111	88	140	111	88	140	111
Overall Electrical D <sub>0</sub> (faults/m <sup>2</sup> ) at Critical Defect Size Or Greater [C]	2210	2210	2210	2210	2210	2210	2210
<b>WAS</b> Random D <sub>0</sub> (faults/m <sup>2</sup> ) [D]	1757	2214	1395	1757	2214	1395	1757
<b>IS</b> Random D <sub>0</sub> (faults/m <sup>2</sup> ) [D]	1395	1395	1395	1395	1395	1395	1395
Number of Mask Levels [E]	37	37	37	39	39	39	39
<b>WAS</b> Random Faults/Mask	47	60	38	45	57	36	45
<b>IS</b> Random Faults/Mask	38	38	38	36	36	36	36
MPU Random Particles per Wafer pass (PWP) Budget (defects/m <sup>2</sup> ) for Generic Tool Type Scaled to 45 nm Critical Defect Size or Greater							
CMP clean	24	19	16	12	9	7	6
CMP insulator	58	46	39	28	23	18	14
CMP metal	65	52	44	32	26	20	15
Coat/develop/bake	10	8	7	5	4	3	2
CVD insulator	51	41	35	25	20	16	12
CVD oxide mask	67	54	45	33	26	21	16
Dielectric track	16	13	11	8	6	5	4
Furnace CVD	29	23	20	14	11	9	7
Furnace fast ramp	26	21	18	13	10	8	6
Furnace oxide/anneal	17	14	12	8	7	5	4
Implant high current	23	18	15	11	9	7	5
Implant low/medium current	21	17	14	10	8	6	5
Inspect PLY	21	17	14	10	8	7	5
Inspect visual	23	18	15	11	9	7	5
Lithography cell	18	14	12	9	7	5	4
Lithography stepper	17	13	11	8	7	5	4
Measure CD	20	16	13	10	8	6	5
Measure film	17	14	12	8	7	5	4
Measure overlay	16	13	11	8	6	5	4
Metal CVD	31	25	21	15	12	10	7
Metal electroplate	16	13	11	8	6	5	4
Metal etch	69	55	47	33	27	21	16
Metal PVD	36	28	24	17	14	11	8
Plasma etch	63	50	42	30	25	19	15
Plasma strip	29	23	20	14	11	9	7
RTP CVD	19	15	13	9	7	6	5
RTP oxide/anneal	12	10	8	6	5	4	3
Test	5	4	3	2	2	2	1
Vapor phase clean	44	35	29	21	17	14	10
Wafer handling	2	2	1	1	1	1	0
Wet bench	28	23	19	14	11	9	7

Notes for Tables 111a and b:

[A] As defined in the ORTC Tables 1a and 1b.

[B] As defined in the ORTC Tables 1g and 1h.

[C] Based on assumption of 75% overall volume production yield.

[D] As shown in the ORTC Tables 5a and 5b. Based on assumption of 83% Random Defect Limited Yield (RDLY).

[E] As shown in the ORTC Tables 5a and 5b.

## 6 Yield Enhancement

Table 112a Yield Model and Defect Budget DRAM Technology Requirements—Near-term Years *UPDATED*

Year of Production		2005	2006	2007	2008	2009	2010	2011	2012	2013
	DRAM ½ Pitch (nm) (contacted) [A]	80	70	65	57	50	45	40	36	32
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32
	MPU Physical Gate Length (nm)	32	28	25	23	20	18	16	14	13
	Critical Defect Size (nm)	<b>40</b>	<b>35</b>	<b>32.5</b>	<b>28.5</b>	<b>25</b>	<b>22.5</b>	<b>20</b>	<b>17.5</b>	<b>16</b>
	Chip Size (mm <sup>2</sup> ) [B]	<b>88</b>	<b>139</b>	<b>110</b>	<b>74</b>	<b>117</b>	<b>93</b>	<b>74</b>	<b>117</b>	<b>93</b>
	Cell Array Area (%) at Production [B]	<b>63%</b>	<b>63%</b>	<b>63%</b>	<b>56%</b>	<b>56%</b>	<b>56%</b>	<b>56%</b>	<b>56%</b>	<b>56%</b>
	Non-core Area (mm <sup>2</sup> )	<b>32</b>	<b>51</b>	<b>41</b>	<b>32</b>	<b>51</b>	<b>41</b>	<b>32</b>	<b>51</b>	<b>41</b>
<b>WAS</b>	Overall Electrical D <sub>0</sub> (faults/m <sup>2</sup> ) at critical defect size or greater [C]	<b>5220</b>	<b>3288</b>	<b>4143</b>	<b>5219</b>	<b>3288</b>	<b>4143</b>	<b>5219</b>	<b>3288</b>	<b>4143</b>
<b>IS</b>	Overall Electrical D <sub>0</sub> (faults/m <sup>2</sup> ) at critical defect size or greater [C]	<b>5220</b>	<b>5220</b>	<b>5220</b>	<b>4389</b>	<b>4389</b>	<b>4389</b>	<b>4389</b>	<b>4389</b>	<b>4389</b>
<b>WAS</b>	Random D <sub>0</sub> (faults/m <sup>2</sup> ) [D]	<b>3517</b>	<b>2216</b>	<b>2791</b>	<b>3516</b>	<b>2215</b>	<b>2791</b>	<b>3516</b>	<b>2215</b>	<b>2791</b>
<b>IS</b>	Random D <sub>0</sub> (faults/m <sup>2</sup> ) [D]	<b>3517</b>	<b>3517</b>	<b>3517</b>	<b>2957</b>	<b>2957</b>	<b>2957</b>	<b>2957</b>	<b>2957</b>	<b>2957</b>
	Number of Mask Levels [E]	<b>24</b>	<b>24</b>	<b>24</b>	<b>24</b>	<b>24</b>	<b>26</b>	<b>26</b>	<b>26</b>	<b>26</b>
<b>WAS</b>	Random Faults/Mask	<b>147</b>	<b>92</b>	<b>116</b>	<b>147</b>	<b>92</b>	<b>107</b>	<b>135</b>	<b>85</b>	<b>107</b>
<b>IS</b>	Random Faults/Mask	<b>147</b>	<b>147</b>	<b>147</b>	<b>123</b>	<b>123</b>	<b>114</b>	<b>114</b>	<b>114</b>	<b>114</b>
<i>DRAM Random Particle per Wafer pass (PWP) Budget (defects/m<sup>2</sup>) for Generic Tool Type Scaled to -40 nm Critical Defect Size or Greater</i>										
<b>WAS</b>	CMP clean	<b>1808</b>	<b>872</b>	<b>872</b>	<b>872</b>	<b>445</b>	<b>419</b>	<b>417</b>	<b>201</b>	<b>201</b>
<b>IS</b>	CMP clean	<b>1808</b>	<b>1384</b>	<b>1194</b>	<b>772</b>	<b>594</b>	<b>444</b>	<b>351</b>	<b>269</b>	<b>225</b>
<b>WAS</b>	CMP insulator	<b>1400</b>	<b>675</b>	<b>675</b>	<b>675</b>	<b>344</b>	<b>324</b>	<b>323</b>	<b>156</b>	<b>156</b>
<b>IS</b>	CMP insulator	<b>1400</b>	<b>1072</b>	<b>924</b>	<b>598</b>	<b>460</b>	<b>344</b>	<b>272</b>	<b>208</b>	<b>174</b>
<b>WAS</b>	CMP metal	<b>2145</b>	<b>1035</b>	<b>1035</b>	<b>1035</b>	<b>528</b>	<b>497</b>	<b>495</b>	<b>239</b>	<b>239</b>
<b>IS</b>	CMP metal	<b>2145</b>	<b>1642</b>	<b>1416</b>	<b>916</b>	<b>705</b>	<b>527</b>	<b>416</b>	<b>319</b>	<b>266</b>
<b>WAS</b>	Coat/develop/bake	<b>559</b>	<b>270</b>	<b>270</b>	<b>270</b>	<b>138</b>	<b>130</b>	<b>129</b>	<b>62</b>	<b>62</b>
<b>IS</b>	Coat/develop/bake	<b>559</b>	<b>428</b>	<b>369</b>	<b>239</b>	<b>184</b>	<b>137</b>	<b>108</b>	<b>83</b>	<b>69</b>
<b>WAS</b>	CVD insulator	<b>1552</b>	<b>748</b>	<b>748</b>	<b>748</b>	<b>382</b>	<b>360</b>	<b>358</b>	<b>173</b>	<b>173</b>
<b>IS</b>	CVD insulator	<b>1552</b>	<b>1188</b>	<b>1025</b>	<b>663</b>	<b>510</b>	<b>381</b>	<b>301</b>	<b>231</b>	<b>193</b>
<b>WAS</b>	CVD oxide mask	<b>1905</b>	<b>919</b>	<b>919</b>	<b>919</b>	<b>469</b>	<b>441</b>	<b>439</b>	<b>212</b>	<b>212</b>
<b>IS</b>	CVD oxide mask	<b>1905</b>	<b>1459</b>	<b>1258</b>	<b>813</b>	<b>626</b>	<b>468</b>	<b>370</b>	<b>283</b>	<b>237</b>
<b>WAS</b>	Dielectric track	<b>784</b>	<b>378</b>	<b>378</b>	<b>378</b>	<b>193</b>	<b>182</b>	<b>181</b>	<b>87</b>	<b>87</b>
<b>IS</b>	Dielectric track	<b>784</b>	<b>600</b>	<b>518</b>	<b>335</b>	<b>258</b>	<b>193</b>	<b>152</b>	<b>116</b>	<b>97</b>
<b>WAS</b>	Furnace CVD	<b>1072</b>	<b>517</b>	<b>517</b>	<b>517</b>	<b>264</b>	<b>248</b>	<b>247</b>	<b>119</b>	<b>119</b>
<b>IS</b>	Furnace CVD	<b>1072</b>	<b>821</b>	<b>708</b>	<b>458</b>	<b>352</b>	<b>263</b>	<b>208</b>	<b>159</b>	<b>133</b>
<b>WAS</b>	Furnace fast ramp	<b>1009</b>	<b>487</b>	<b>487</b>	<b>487</b>	<b>248</b>	<b>234</b>	<b>233</b>	<b>112</b>	<b>112</b>
<b>IS</b>	Furnace fast ramp	<b>1009</b>	<b>773</b>	<b>666</b>	<b>431</b>	<b>331</b>	<b>248</b>	<b>196</b>	<b>150</b>	<b>125</b>
<b>WAS</b>	Furnace oxide/anneal	<b>808</b>	<b>390</b>	<b>390</b>	<b>390</b>	<b>199</b>	<b>187</b>	<b>186</b>	<b>90</b>	<b>90</b>
<b>IS</b>	Furnace oxide/anneal	<b>808</b>	<b>619</b>	<b>533</b>	<b>345</b>	<b>265</b>	<b>198</b>	<b>157</b>	<b>120</b>	<b>100</b>
<b>WAS</b>	Implant high current	<b>939</b>	<b>453</b>	<b>453</b>	<b>453</b>	<b>231</b>	<b>218</b>	<b>217</b>	<b>105</b>	<b>105</b>
<b>IS</b>	Implant high current	<b>939</b>	<b>719</b>	<b>620</b>	<b>401</b>	<b>308</b>	<b>231</b>	<b>182</b>	<b>140</b>	<b>117</b>
<b>WAS</b>	Implant low/medium current	<b>895</b>	<b>432</b>	<b>432</b>	<b>432</b>	<b>220</b>	<b>208</b>	<b>207</b>	<b>100</b>	<b>100</b>
<b>IS</b>	Implant low/medium current	<b>895</b>	<b>685</b>	<b>591</b>	<b>382</b>	<b>294</b>	<b>220</b>	<b>174</b>	<b>133</b>	<b>111</b>
<b>WAS</b>	Inspect PLY	<b>1225</b>	<b>591</b>	<b>591</b>	<b>591</b>	<b>301</b>	<b>284</b>	<b>283</b>	<b>136</b>	<b>136</b>
<b>IS</b>	Inspect PLY	<b>1225</b>	<b>938</b>	<b>809</b>	<b>523</b>	<b>402</b>	<b>301</b>	<b>238</b>	<b>182</b>	<b>152</b>
<b>WAS</b>	Inspect visual	<b>1264</b>	<b>610</b>	<b>610</b>	<b>610</b>	<b>311</b>	<b>293</b>	<b>292</b>	<b>141</b>	<b>141</b>
<b>IS</b>	Inspect visual	<b>1264</b>	<b>968</b>	<b>834</b>	<b>540</b>	<b>415</b>	<b>310</b>	<b>245</b>	<b>188</b>	<b>157</b>
<b>WAS</b>	Lithography cell	<b>1048</b>	<b>506</b>	<b>506</b>	<b>506</b>	<b>258</b>	<b>243</b>	<b>242</b>	<b>117</b>	<b>117</b>
<b>IS</b>	Lithography cell	<b>1048</b>	<b>802</b>	<b>692</b>	<b>447</b>	<b>344</b>	<b>257</b>	<b>203</b>	<b>156</b>	<b>130</b>
<b>WAS</b>	Lithography stepper	<b>697</b>	<b>336</b>	<b>336</b>	<b>336</b>	<b>171</b>	<b>162</b>	<b>161</b>	<b>78</b>	<b>78</b>
<b>IS</b>	Lithography stepper	<b>697</b>	<b>534</b>	<b>460</b>	<b>298</b>	<b>229</b>	<b>171</b>	<b>135</b>	<b>104</b>	<b>87</b>
<b>WAS</b>	Measure CD	<b>1047</b>	<b>505</b>	<b>505</b>	<b>505</b>	<b>258</b>	<b>243</b>	<b>242</b>	<b>117</b>	<b>117</b>

Year of Production		2005	2006	2007	2008	2009	2010	2011	2012	2013
	DRAM ½ Pitch (nm) (contacted) [A]	80	70	65	57	50	45	40	36	32
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32
	MPU Physical Gate Length (nm)	32	28	25	23	20	18	16	14	13
IS	Measure CD	1047	<u>802</u>	<u>691</u>	<u>447</u>	<u>344</u>	<u>257</u>	<u>203</u>	<u>156</u>	<u>130</u>
WAS	Measure film	984	475	475	475	242	228	227	110	110
IS	Measure film	984	<u>753</u>	<u>650</u>	<u>420</u>	<u>323</u>	<u>242</u>	<u>191</u>	<u>146</u>	<u>122</u>
WAS	Measure overlay	958	462	462	462	236	222	221	107	107
IS	Measure overlay	958	<u>733</u>	<u>632</u>	<u>409</u>	<u>315</u>	<u>235</u>	<u>186</u>	<u>142</u>	<u>119</u>
WAS	Metal CVD	986	476	476	476	243	229	227	110	110
IS	Metal CVD	986	<u>755</u>	<u>651</u>	<u>421</u>	<u>324</u>	<u>242</u>	<u>191</u>	<u>146</u>	<u>122</u>
WAS	Metal electroplate	750	362	362	362	185	174	173	83	83
IS	Metal electroplate	750	<u>574</u>	<u>495</u>	<u>320</u>	<u>246</u>	<u>184</u>	<u>146</u>	<u>111</u>	<u>93</u>
WAS	Metal etch	1816	876	876	876	447	421	419	202	202
IS	Metal etch	1816	<u>1390</u>	<u>1199</u>	<u>775</u>	<u>597</u>	<u>446</u>	<u>352</u>	<u>270</u>	<u>226</u>
WAS	Metal PVD	1083	522	522	522	266	251	250	121	121
IS	Metal PVD	1083	<u>829</u>	<u>715</u>	<u>462</u>	<u>356</u>	<u>266</u>	<u>210</u>	<u>161</u>	<u>135</u>
WAS	Plasma etch	1923	928	928	928	473	446	444	214	214
IS	Plasma etch	1923	<u>1472</u>	<u>1269</u>	<u>821</u>	<u>632</u>	<u>472</u>	<u>373</u>	<u>286</u>	<u>239</u>
WAS	Plasma strip	1475	711	711	711	363	342	340	164	164
IS	Plasma strip	1475	<u>1129</u>	<u>974</u>	<u>630</u>	<u>485</u>	<u>362</u>	<u>286</u>	<u>219</u>	<u>183</u>
WAS	RTP CVD	964	465	465	465	237	223	222	107	107
IS	RTP CVD	964	<u>738</u>	<u>636</u>	<u>412</u>	<u>317</u>	<u>237</u>	<u>187</u>	<u>143</u>	<u>120</u>
WAS	RTP oxide/anneal	706	341	341	341	174	164	163	79	79
IS	RTP oxide/anneal	706	<u>541</u>	<u>466</u>	<u>301</u>	<u>232</u>	<u>173</u>	<u>137</u>	<u>105</u>	<u>88</u>
WAS	Test	138	66	66	66	34	32	32	15	15
IS	Test	138	<u>106</u>	<u>91</u>	<u>59</u>	<u>45</u>	<u>34</u>	<u>27</u>	<u>21</u>	<u>17</u>
WAS	Vapor phase clean	2042	985	985	985	502	473	471	227	227
IS	Vapor phase clean	2042	<u>1563</u>	<u>1348</u>	<u>872</u>	<u>671</u>	<u>502</u>	<u>396</u>	<u>303</u>	<u>254</u>
WAS	Wafer handling	58	28	28	28	14	13	13	6	6
IS	Wafer handling	58	<u>44</u>	<u>38</u>	<u>25</u>	<u>19</u>	<u>14</u>	<u>11</u>	<u>9</u>	<u>7</u>
WAS	Wet bench	1463	705	705	705	360	339	337	163	163
IS	Wet bench	1463	<u>1120</u>	<u>966</u>	<u>625</u>	<u>481</u>	<u>359</u>	<u>284</u>	<u>217</u>	<u>182</u>

## 8 Yield Enhancement

Table 112b Yield Model and Defect Budget DRAM Technology Requirements—Long-term Years *UPDATED*

Year of Production		2014	2015	2016	2017	2018	2019	2020
	DRAM ½ Pitch (nm) (contacted) [A]	28	25	22	20	18	16	14
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	28	25	22	20	18	16	14
	MPU Physical Gate Length (nm)	11	10	9	8	7	6	6
	Critical Defect Size (nm)	14	12.5	11	10	9	8	7
	Chip Size (mm <sup>2</sup> ) [B]	74	117	93	74	117	93	74
	Cell Array Area (%) at Production [B]	56%	56%	56%	56%	56%	56%	56%
	Non-core Area (mm <sup>2</sup> )	32	51	41	32	51	41	32
<b>WAS</b>	Overall Electrical D <sub>0</sub> (faults/m <sup>2</sup> ) at critical defect size or greater [C]	5219	3288	4143	5219	3288	4143	5219
<b>IS</b>	Overall Electrical D <sub>0</sub> (faults/m <sup>2</sup> ) at critical defect size or greater [C]	<u>4389</u>	<u>4389</u>	<u>4389</u>	<u>4389</u>	<u>4389</u>	<u>4389</u>	<u>4389</u>
<b>WAS</b>	Random D <sub>0</sub> (faults/m <sup>2</sup> ) [D]	3516	2215	2791	3516	2215	2791	3516
<b>IS</b>	Random D <sub>0</sub> (faults/m <sup>2</sup> ) [D]	<u>2957</u>	<u>2957</u>	<u>2957</u>	<u>2957</u>	<u>2957</u>	<u>2957</u>	<u>2957</u>
	Number of Mask Levels [E]	26	26	26	26	26	26	26
<b>WAS</b>	Random Faults/Mask	135	85	107	135	85	107	135
<b>IS</b>	Random Faults/Mask	<u>114</u>	<u>114</u>	<u>114</u>	<u>114</u>	<u>114</u>	<u>114</u>	<u>114</u>
<i>DRAM Random Particle per Wafer pass (PWP) Budget (defects/m<sup>2</sup>) for Generic Tool Type Scaled to -40 nm Critical Defect Size or Greater</i>								
<b>WAS</b>	CMP clean	201	103	100	100	53	53	51
<b>IS</b>	CMP clean	<u>172</u>	<u>137</u>	<u>106</u>	<u>88</u>	<u>71</u>	<u>56</u>	<u>43</u>
<b>WAS</b>	CMP insulator	156	79	78	78	41	41	40
<b>IS</b>	CMP insulator	<u>133</u>	<u>106</u>	<u>82</u>	<u>68</u>	<u>55</u>	<u>43</u>	<u>33</u>
<b>WAS</b>	CMP metal	239	122	119	119	63	63	61
<b>IS</b>	CMP metal	<u>204</u>	<u>163</u>	<u>126</u>	<u>104</u>	<u>84</u>	<u>67</u>	<u>51</u>
<b>WAS</b>	Coat/develop/bake	62	32	31	31	16	16	16
<b>IS</b>	Coat/develop/bake	<u>53</u>	<u>42</u>	<u>33</u>	<u>27</u>	<u>22</u>	<u>17</u>	<u>13</u>
<b>WAS</b>	CVD insulator	173	88	86	86	46	45	44
<b>IS</b>	CVD insulator	<u>148</u>	<u>118</u>	<u>91</u>	<u>75</u>	<u>61</u>	<u>48</u>	<u>37</u>
<b>WAS</b>	CVD oxide mask	212	108	106	106	56	56	54
<b>IS</b>	CVD oxide mask	<u>181</u>	<u>144</u>	<u>112</u>	<u>92</u>	<u>75</u>	<u>59</u>	<u>45</u>
<b>WAS</b>	Dielectric track	87	45	43	43	23	23	22
<b>IS</b>	Dielectric track	<u>75</u>	<u>59</u>	<u>46</u>	<u>38</u>	<u>31</u>	<u>24</u>	<u>19</u>
<b>WAS</b>	Furnace CVD	119	61	59	59	32	31	30
<b>IS</b>	Furnace CVD	<u>102</u>	<u>81</u>	<u>63</u>	<u>52</u>	<u>42</u>	<u>33</u>	<u>25</u>
<b>WAS</b>	Furnace fast ramp	112	57	56	56	30	30	29
<b>IS</b>	Furnace fast ramp	<u>96</u>	<u>76</u>	<u>59</u>	<u>49</u>	<u>40</u>	<u>31</u>	<u>24</u>
<b>WAS</b>	Furnace oxide/anneal	90	46	45	45	24	24	23
<b>IS</b>	Furnace oxide/anneal	<u>77</u>	<u>61</u>	<u>47</u>	<u>39</u>	<u>32</u>	<u>25</u>	<u>19</u>
<b>WAS</b>	Implant high current	105	53	52	52	28	28	27
<b>IS</b>	Implant high current	<u>89</u>	<u>71</u>	<u>55</u>	<u>46</u>	<u>37</u>	<u>29</u>	<u>22</u>
<b>WAS</b>	Implant low/medium current	100	51	50	50	26	26	25
<b>IS</b>	Implant low/medium current	<u>85</u>	<u>68</u>	<u>53</u>	<u>43</u>	<u>35</u>	<u>28</u>	<u>21</u>
<b>WAS</b>	Inspect PLY	136	70	68	68	36	36	35
<b>IS</b>	Inspect PLY	<u>116</u>	<u>93</u>	<u>72</u>	<u>59</u>	<u>48</u>	<u>38</u>	<u>29</u>
<b>WAS</b>	Inspect visual	141	72	70	70	37	37	36
<b>IS</b>	Inspect visual	<u>120</u>	<u>96</u>	<u>74</u>	<u>61</u>	<u>50</u>	<u>39</u>	<u>30</u>
<b>WAS</b>	Lithography cell	117	60	58	58	31	31	30
<b>IS</b>	Lithography cell	<u>100</u>	<u>79</u>	<u>62</u>	<u>51</u>	<u>41</u>	<u>33</u>	<u>25</u>
<b>WAS</b>	Lithography stepper	78	40	39	39	21	20	20
<b>IS</b>	Lithography stepper	<u>66</u>	<u>53</u>	<u>41</u>	<u>34</u>	<u>27</u>	<u>22</u>	<u>17</u>
<b>WAS</b>	Measure CD	117	59	58	58	31	31	30

Year of Production		2014	2015	2016	2017	2018	2019	2020
	DRAM ½ Pitch (nm) (contacted) [A]	28	25	22	20	18	16	14
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	28	25	22	20	18	16	14
	MPU Physical Gate Length (nm)	11	10	9	8	7	6	6
<b>IS</b>	Measure CD	<u>100</u>	<u>79</u>	<u>61</u>	<u>51</u>	<u>41</u>	<u>33</u>	<u>25</u>
<b>WAS</b>	Measure film	<u>110</u>	<u>56</u>	<u>55</u>	<u>55</u>	<u>29</u>	<u>29</u>	<u>28</u>
<b>IS</b>	Measure film	<u>94</u>	<u>75</u>	<u>58</u>	<u>48</u>	<u>39</u>	<u>31</u>	<u>23</u>
<b>WAS</b>	Measure overlay	<u>107</u>	<u>54</u>	<u>53</u>	<u>53</u>	<u>28</u>	<u>28</u>	<u>27</u>
<b>IS</b>	Measure overlay	<u>91</u>	<u>73</u>	<u>56</u>	<u>46</u>	<u>38</u>	<u>30</u>	<u>23</u>
<b>WAS</b>	Metal CVD	<u>110</u>	<u>56</u>	<u>55</u>	<u>55</u>	<u>29</u>	<u>29</u>	<u>28</u>
<b>IS</b>	Metal CVD	<u>94</u>	<u>75</u>	<u>58</u>	<u>48</u>	<u>39</u>	<u>31</u>	<u>23</u>
<b>WAS</b>	Metal electroplate	<u>83</u>	<u>43</u>	<u>42</u>	<u>42</u>	<u>22</u>	<u>22</u>	<u>21</u>
<b>IS</b>	Metal electroplate	<u>71</u>	<u>57</u>	<u>44</u>	<u>36</u>	<u>29</u>	<u>23</u>	<u>18</u>
<b>WAS</b>	Metal etch	<u>202</u>	<u>103</u>	<u>101</u>	<u>101</u>	<u>53</u>	<u>53</u>	<u>51</u>
<b>IS</b>	Metal etch	<u>173</u>	<u>138</u>	<u>107</u>	<u>88</u>	<u>71</u>	<u>56</u>	<u>43</u>
<b>WAS</b>	Metal PVD	<u>121</u>	<u>61</u>	<u>60</u>	<u>60</u>	<u>32</u>	<u>32</u>	<u>31</u>
<b>IS</b>	Metal PVD	<u>103</u>	<u>82</u>	<u>64</u>	<u>53</u>	<u>43</u>	<u>34</u>	<u>26</u>
<b>WAS</b>	Plasma etch	<u>214</u>	<u>109</u>	<u>107</u>	<u>107</u>	<u>57</u>	<u>56</u>	<u>54</u>
<b>IS</b>	Plasma etch	<u>183</u>	<u>146</u>	<u>113</u>	<u>93</u>	<u>76</u>	<u>60</u>	<u>46</u>
<b>WAS</b>	Plasma strip	<u>164</u>	<u>84</u>	<u>82</u>	<u>82</u>	<u>43</u>	<u>43</u>	<u>42</u>
<b>IS</b>	Plasma strip	<u>140</u>	<u>112</u>	<u>87</u>	<u>72</u>	<u>58</u>	<u>46</u>	<u>35</u>
<b>WAS</b>	RTP CVD	<u>107</u>	<u>55</u>	<u>53</u>	<u>53</u>	<u>28</u>	<u>28</u>	<u>27</u>
<b>IS</b>	RTP CVD	<u>92</u>	<u>73</u>	<u>57</u>	<u>47</u>	<u>38</u>	<u>30</u>	<u>23</u>
<b>WAS</b>	RTP oxide/anneal	<u>79</u>	<u>40</u>	<u>39</u>	<u>39</u>	<u>21</u>	<u>21</u>	<u>20</u>
<b>IS</b>	RTP oxide/anneal	<u>67</u>	<u>54</u>	<u>41</u>	<u>34</u>	<u>28</u>	<u>22</u>	<u>17</u>
<b>WAS</b>	Test	<u>15</u>	<u>8</u>	<u>8</u>	<u>8</u>	<u>4</u>	<u>4</u>	<u>4</u>
<b>IS</b>	Test	<u>13</u>	<u>10</u>	<u>8</u>	<u>7</u>	<u>5</u>	<u>4</u>	<u>3</u>
<b>WAS</b>	Vapor phase clean	<u>227</u>	<u>116</u>	<u>113</u>	<u>113</u>	<u>60</u>	<u>60</u>	<u>58</u>
<b>IS</b>	Vapor phase clean	<u>194</u>	<u>155</u>	<u>120</u>	<u>99</u>	<u>80</u>	<u>63</u>	<u>49</u>
<b>WAS</b>	Wafer handling	<u>6</u>	<u>3</u>	<u>3</u>	<u>3</u>	<u>2</u>	<u>2</u>	<u>2</u>
<b>IS</b>	Wafer handling	<u>6</u>	<u>4</u>	<u>3</u>	<u>3</u>	<u>2</u>	<u>2</u>	<u>1</u>
<b>WAS</b>	Wet bench	<u>163</u>	<u>83</u>	<u>81</u>	<u>81</u>	<u>43</u>	<u>43</u>	<u>41</u>
<b>IS</b>	Wet bench	<u>139</u>	<u>111</u>	<u>86</u>	<u>71</u>	<u>57</u>	<u>45</u>	<u>35</u>

Notes for Tables 112a and b:

[A] As defined in the ORTC Tables 1a and 1b.

[B] As defined in the ORTC Tables 1c and 1d.

[C] Based on assumption of 89.5% (RDLY).

[D] As shown in the ORTC Tables 5a and 5b. Based on assumption of 89.5% RDLY.

[E] As shown in the ORTC Tables 5a and 5b.

10 Yield Enhancement

DEFECT DETECTION AND CHARACTERIZATION

Table 113a Defect Detection Technology Requirements—Near-term Years *UPDATED*

Year of Production		2005	2006	2007	2008	2009	2010	2011	2012	2013	
DRAM ½ Pitch (nm) (contacted)		80	70	65	57	50	45	40	35	32	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)		90	76	67	60	54	48	42	38	34	
<i>Patterned Wafer Inspection, PSL Spheres * at 90% Capture, Equivalent Sensitivity (nm) [A, B]</i>											
WAS	Process R&D at 300 cm <sup>2</sup> /hr (1 “200 mm wafer”/hr)	40	35	32.5	28.5	25	22.5	20	17.5	16	0.5 × DR
IS	Process R&D at 300 cm <sup>2</sup> /hr (0,4 “300 mm wafer”/hr)	40	35	32.5	28.5	25	22.5	20	17.5	16	0.5 × DR
ADD	<u>Process R&amp;D at 300 cm<sup>2</sup>/hr with 50 % Capture rate</u>	-	21	19.5	17.1	15	13.5	12	10.5	9.6	0.3 × DR
WAS	Yield ramp at 1200 cm <sup>2</sup> /hr (4 “200 mm wafer”/hr)	64	56	52	45.6	40	36	32	28	25.6	0.8 × DR
IS	Yield ramp at 1200 cm <sup>2</sup> /hr (1,7 “300 mm wafer”/hr)	64	56	52	45.6	40	36	32	28	25.6	0.8 × DR
WAS	Volume production at 3000 cm <sup>2</sup> /hr (10 “200 mm wafer”/hr)	◆ 80	70	65	57	50	45	40	35	32	1.0 × DR
IS	Volume production at 3000 cm <sup>2</sup> /hr (4,3 “300 mm wafer”/hr)	◆ 80	70	65	57	50	45	40	35	32	1.0 × DR
WAS	Tool matching (% variation tool to tool) [C]	◆ 5	3	3	3	3	2	2	2	2	
IS	Tool matching (% variation tool to tool) [C]	◆ 5	◆ 5	5	5	5	5	5	5	5	
ADD	<u>Defect coordinate precision [µm] note</u>	-	2.45	2.275	1.995	1.75	1.575	1.4	1.225	1.12	35x DR
Wafer edge exclusion (mm)		2	2	2	2	2	2	2	2	2	
Cost of ownership (\$/cm <sup>2</sup> )		0.078	0.078	0.078	0.078	0.078	0.078	0.08	0.078	0.078	
<i>High Aspect Ratio Feature Inspection: Defects other than Residue, Equivalent Sensitivity in PSL Diameter (nm) at 90% Capture Rate *[D, E]</i>											
Sensitivity without speed requirement		80	70	65	57	50	45	40	35	32	1.0 × DR
WAS	Process verification at 300 cm <sup>2</sup> /hr (1 “200 mm wafer”/hr)	◆ 80	70	65	57	50	45	40	35	32	1.0 × DR
IS	Process verification at 300 cm <sup>2</sup> /hr (0,4 “300 mm wafer”/hr)	◆ 80	◆ 70	65	57	50	45	40	35	32	1.0 × DR
ADD	<u>Process verification at 300 cm<sup>2</sup>/hr at 50% capture rate</u>	-	42	39	34.2	30	27	24	21	19.2	0.6 × DR
WAS	Volume manufacturing at 1200 cm <sup>2</sup> /hr (4 “200 mm wafer”/hr)	◆ 80	70	65	57	50	45	40	35	32	1.0 × DR
IS	Volume manufacturing at 1200 cm <sup>2</sup> /hr (1,7 “300 mm wafer”/hr)	◆ 80	◆ 70	65	57	50	45	40	35	32	1.0 × DR
CoO HARI (\$/cm <sup>2</sup> )		0.388	0.388	0.388	0.388	0.388	0.388	0.388	0.388	0.388	
<i>Unpatterned, PSL Spheres at 90% Capture, Equivalent Sensitivity (nm) [F, G]</i>											
WAS	Metal film	64	56	52	45.6	40.0	36.0	32.0	28.0	25.6	0.8 × DR
IS	<u>Poly Si and</u> metal films	64	84	78	68.4	60	54	48	42	38.4	1,2 × DR
WAS	Bare silicon and non-metal film	40	35	32.5	28.5	25	22.5	20	17.5	16	0,5 × DR

Year of Production		2005	2006	2007	2008	2009	2010	2011	2012	2013	
DRAM ½ Pitch (nm) (contacted)		80	70	65	57	50	45	40	35	32	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)		90	76	67	60	54	48	42	38	34	
<i>Patterned Wafer Inspection, PSL Spheres * at 90% Capture, Equivalent Sensitivity (nm) [A, B]</i>											
<b>IS</b>	Bare silicon <del>and non-metal film</del>	40	35	32.5	28.5	25	22.5	20	17.5	16	0.5 x DR
<b>ADD</b>	Other smooth film	-	56	52	45.6	40	36	32	28	25.6	0.8 x DR
<b>ADD</b>	Throughput at sensitivity for all layers [wfr/hrs]	-	60	60	70	70	80	80	90	90	
Wafer backside (defect size, nm) [H]		400	350	325	285	250	225	200	175	160	5.0 x DR
CoO (\$/cm <sup>2</sup> )		0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	
Wafer edge exclusion (mm)		2	2	2	2	2	2	2	2	2	
<i>Defect Review (Patterned Wafer)</i>											
Resolution (nm) * [I]		2	1.8	1.6	1.4	1.3	1.125	1	0.875	0.8	
Coordinate accuracy (nm) at resolution [J]		800	700	650	570	500	450	400	350	320	10 x DR
<b>WAS</b>	Speed at ADR without ADC	960	1200	1200	1200	1200	1200	1200	1200	1200	
<b>IS</b>	Speed at ADR wo ADC (defects/hrs)	960	1200	1200	1200	1200	1200	1200	1200	1200	
<i>Automatic Defect Classification at Defect Review Platform * [K]</i>											
<b>WAS</b>	Redetection: minimum defect size (nm)	32	28	26	22.8	20	18	16	14	12.8	0.4 x DR
<b>IS</b>	Redetection: minimum defect size (nm)	32	28	26	22.8	20	18	16	14	12.8	0.4 x DR
<b>WAS</b>	Number of defect types [L]	◆10	10	10	15	15	15	15	15	20	
<b>IS</b>	Number of defect types [L]	◆10	◆10	10	10	10	10	10	10	10	
<b>WAS</b>	Speed (defects/hours) w ADC	◆720	720	720	720	720	720	720	720	720	
<b>IS</b>	Speed (defects/hours) w ADC	◆720	720	720	720	720	720	720	720	720	
<b>WAS</b>	Speed w/elemental (defects/hours)	◆360	360	360	360	360	360	360	360	360	
<b>IS</b>	Speed w/elemental (defects/hours)	◆360	◆360	360	360	360	360	360	360	360	
<b>WAS</b>	Number of defect types (inline ADC) [M]	◆10	10	10	10	10	10	10	10	10	
<b>IS</b>	Number of defect types (inline ADC) [M]	◆10	◆10	10	10	10	10	10	10	10	
<i>Wafer inspection on multilayer product wafer of top and bottom bevel, APEX and 3 mm wafer edge exclusion</i>											
<i>PSL spheres at 90% capture rate, Equivalent sensitivity (nm) [N, O]</i>											
<b>WAS</b>	Sensitivity [nm] without speed requirement at 50% capture rate	◆400	350	325	285	250	225	200	175	160	5 x DR
<b>IS</b>	Sensitivity [nm] without speed requirement at 50% capture rate	◆400	◆350	325	285	250	225	200	175	160	5 x DR
<b>WAS</b>	Sensitivity [nm] at 100 wafer/hrs	◆2000	1750	1625	1425	1250	1125	1000	875	800	25 x DR
<b>IS</b>	Sensitivity [nm] at 100 wafer/hrs	◆2000	◆1750	1625	1425	1250	1125	1000	875	800	25 x DR
Defect classes, ADC [P]		3	5	5	5	10	10	10	10	10	
<b>WAS</b>	Tool matching (% variation tool-to-tool)	◆10%	10%	10%	10%	5%	5%	5%	5%	5%	
<b>IS</b>	Tool matching (% variation tool-to-tool)	◆10%	◆10%	10%	10%	5%	5%	5%	5%	5%	
CoO [\$/300 mm wafer]		1	1	1	0.9	0.8	0.8	0.8	0.8	0.8	

\*PSL—polystyrene latex (spheres utilized to simulate defects of known size during sizing calibration) ADR—automatic defect review

## 12 Yield Enhancement

Table 113b Defect Detection Technology Requirements—Long-term Years *UPDATED*

Year of Production		2014	2015	2016	2017	2018	2019	2020	
DRAM ½ Pitch (nm) (contacted)		28	25	22	20	18	16	14	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)		30	27	24	21	19	17	15	
<i>Patterned Wafer Inspection, PSL Spheres * at 90% Capture, Equivalent Sensitivity (nm) [A, B]</i>									
<b>WAS</b>	Process R&D at 300 cm <sup>2</sup> /hr (1 “200 mm wafer”/hr)	14	12.5	11	10	9	8	7	0.5 × DR
<b>IS</b>	Process R&D at 300 cm <sup>2</sup> /hr (0,4 “300 mm wafer”/hr)	14	12.5	11	10	9	8	7	0.5 × DR
<b>ADD</b>	<u>Process R&amp;D at 300 cm<sup>2</sup>/hr with 50 % Capture rate</u>	<u>8.4</u>	<u>7.5</u>	<u>6.6</u>	<u>6</u>	<u>5.4</u>	<u>4.8</u>	<u>4.2</u>	<u>0.3 x DR</u>
<b>WAS</b>	Yield ramp at 1200 cm <sup>2</sup> /hr (4 “200 mm wafer”/hr)	22.4	20	17.6	16	14.4	12.8	11	0.8 × DR
<b>IS</b>	Yield ramp at 1200 cm <sup>2</sup> /hr (1,7 “300 mm wafer”/hr)	22.4	20	17.6	16	14.4	12.8	11	0.8 × DR
<b>WAS</b>	Volume production at 3000 cm <sup>2</sup> /hr (10 “200 mm wafer”/hr)	28	25	22	20	18	16	14	1.0 × DR
<b>IS</b>	Volume production at 3000 cm <sup>2</sup> /hr (4,3 “300 mm wafer”/hr)	28	25	22	20	18	16	14	1.0 × DR
<b>WAS</b>	Tool matching (% variation tool to tool) [C]	2	2	2	2	2	2	2	
<b>IS</b>	Tool matching (% variation tool to tool) [C]	<u>5</u>	<u>5</u>	<u>5</u>	<u>5</u>	<u>5</u>	<u>5</u>	<u>5</u>	
<b>ADD</b>	<u>Defect coordinate precision [µm] note</u>	<u>0.98</u>	<u>0.875</u>	<u>0.77</u>	<u>0.7</u>	<u>0.63</u>	<u>0.56</u>	<u>0.49</u>	<u>35x DR</u>
	Wafer edge exclusion (mm)	2	2	2	2	2	2	2	
	Cost of ownership (\$/cm <sup>2</sup> )	0.078	0.078	0.078	0.078	0.078	0.078	0.078	
<i>High Aspect Ratio Feature Inspection: Defects other than Residue, Equivalent Sensitivity in PSL Diameter (nm) at 90% Capture Rate *[D, E]</i>									
	Sensitivity without speed requirement	28	25	22	20	18	16	14	1.0 × DR
<b>WAS</b>	Process verification at 300 cm <sup>2</sup> /hr (1 “200 mm wafer”/hr)	28	25	22	20	18	16	14	1.0 × DR
<b>IS</b>	Process verification at 300 cm <sup>2</sup> /hr (0,4 “300 mm wafer”/hr)	28	25	22	20	18	16	14	1.0 × DR
<b>ADD</b>	<u>Process verification at 300 cm<sup>2</sup>/hr at 50% capture rate</u>	<u>16.8</u>	<u>15</u>	<u>13.2</u>	<u>12</u>	<u>10.8</u>	<u>9.6</u>	<u>8.4</u>	<u>0.6 x DR</u>
<b>WAS</b>	Volume manufacturing at 1200 cm <sup>2</sup> /hr (4 “200 mm wafer”/hr)	28	25	22	20	18	16	14	1.0 × DR
<b>IS</b>	Volume manufacturing at 1200 cm <sup>2</sup> /hr (1,7 “300 mm wafer”/hr)	28	25	22	20	18	16	14	1.0 × DR
	CoO HARI (\$/cm <sup>2</sup> )	0.388	0.388	0.388	0.388	0.388	0.388	0.388	
<i>Unpatterned, PSL Spheres at 90% Capture, Equivalent Sensitivity (nm) [F, G]</i>									
<b>WAS</b>	Metal film	22.4	20.0	17.6	16.0	14.4	12.8	11.0	0.8 x DR
<b>IS</b>	<u>Poly Si and</u> metal films	<u>33.6</u>	<u>30</u>	<u>26.4</u>	<u>24</u>	<u>21.6</u>	<u>19.2</u>	<u>16.8</u>	<u>1,2 x DR</u>
<b>WAS</b>	Bare silicon and non-metal film	14	12.5	11	10	9	8	7	0,5 x DR
<b>IS</b>	Bare silicon <del>and non-metal film</del>	14	12.5	11	10	9	8	7	0,5 x DR
<b>ADD</b>	<u>Other smooth film</u>	<u>22.4</u>	<u>20</u>	<u>17.6</u>	<u>16</u>	<u>14.4</u>	<u>12.8</u>	<u>11.2</u>	<u>0,8 x DR</u>
<b>ADD</b>	<u>Throughput at sensitivity for all layers [wfr/hrs]</u>	<u>100</u>	<u>100</u>	<u>110</u>	<u>110</u>	<u>120</u>	<u>120</u>	<u>130</u>	-
	Wafer backside (defect size, nm) [H]	140	125	110	100	90	80	70	5.0 x DR

<i>Year of Production</i>	2014	2015	2016	2017	2018	2019	2020	
DRAM ½ Pitch (nm) (contacted)	28	25	22	20	18	16	14	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	30	27	24	21	19	17	15	
CoO (\$/cm <sup>2</sup> )	0.004	0.004	0.004	0.004	0.004	0.004	0.004	
Wafer edge exclusion (mm)	2	2	2	2	2	2	2	
<i>Defect Review (Patterned Wafer)</i>								
Resolution (nm) * [I]	0.7	0.625	0.55	0.5	0.45	0.4	0.35	
Coordinate accuracy (nm) at resolution [J]	280	250	220	200	180	160	140	10 x DR
<b>WAS</b> Speed at ADR without ADC	1200	1200	1200	1200	1200	1200	1200	
<b>IS</b> Speed at ADR wo ADC (defects/hrs)	1200	1200	1200	1200	1200	1200	1200	
<i>Automatic Defect Classification at Defect Review Platform * [K]</i>								
<b>WAS</b> Redetection: minimum defect size (nm)	11.2	10	8.8	8	7.2	6.4	5.6	0.4 x DR
<b>IS</b> Redetection: minimum defect size (nm)	11.2	10	8.8	8	7.2	6.4	5.6	0.4 x DR
<b>WAS</b> Number of defect types [L]	20	20	25	25	25	25	25	
<b>IS</b> Number of defect types [L]	10	10	10	10	10	10	10	
<b>WAS</b> Speed (defects/hours) w ADC	720	720	720	720	720	720	720	
<b>IS</b> Speed (defects/hours) w ADC	720	720	720	720	720	720	720	
<b>WAS</b> Speed w/elemental (defects/hours)	360	360	360	360	360	360	360	
<b>IS</b> Speed w/elemental (defects/hours)	360	360	360	360	360	360	360	
<b>WAS</b> Number of defect types (inline ADC) [M]	10	10	10	10	10	10	10	
<b>IS</b> Number of defect types (inline ADC) [M]	10	10	10	10	10	10	10	
<i>Wafer inspection on multilayer product wafer of top and bottom bevel, APEX and 3 mm wafer edge exclusion</i>								
<i>PSL spheres at 90% capture rate, Equivalent sensitivity (nm) [N, O]</i>								
Sensitivity [nm] without speed requirement at 50% capture rate	140	125	110	100	90	80	70	5 x DR
Sensitivity [nm] at 100 wafer/hrs	700	625	550	500	450	400	350	25 x DR
Defect classes, ADC [P]	10	10	10	10	10	10	10	
Tool matching (% variation tool-to-tool)	5%	5%	3%	3%	3%	3%	3%	
CoO [\$/300 mm wafer]	0.8	0.7	0.7	0.7	0.7	0.7	0.7	

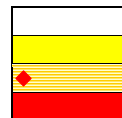
\*PSL—polystyrene latex (spheres utilized to simulate defects of known size during sizing calibration) ADR— automatic defect review

Manufacturable solutions exist, and are being optimized

Manufacturable solutions are known

Interim solutions are known

Manufacturable solutions are NOT known



## 14 Yield Enhancement

Notes for Tables 113a and b:

[A] Patterned wafer scan speed is required to be at least  $300 \text{ cm}^2/\text{hour}$  for process R&D mode,  $1,200 \text{ cm}^2/\text{hour}$  for yield ramp mode, and, at least,  $3,000 \text{ cm}^2/\text{hour}$  for volume production mode. Existing solutions do not achieve these targets at the above mentioned sensitivity requirement. The table indicates the approximate number of 200 mm wafers per hour. To obtain the approximate 300 mm wafers per hour, multiple the wafers/hour rate by .435. (Example:  $3000 \text{ cm}^2/\text{hr}$  is about 10, 200 mm wafers and 4.3, 300 mm wafers).

[B] Patterned wafer nuisance defect rate shall be lower than 5% in all process phases. False counts in the R&D phase less than 5%, and less than 1% in the yield ramp and volume production phase. Nuisance is defined as an event indicated and a defect is present, just not the type of interest. These maybe significant and could be studied at a later date. The defect classifier must consider the defect type and assign significance. False is defined at an event is indicated, but no defect can be seen using the review optics path of the detection tool, which supports recipe setup validation.)

[C] Metric % variation tool-to-tool in number of non-matching defects/total number of defects from standard tool.

Procedure: Recipe sensitivity set on first (standard) tool with false <5. Transfer this recipe without changes and perform ten runs with a wafer containing a minimum of 30 defects.

[D] High Aspect Ratio is defined as for contacts 15:1.

[E] HARI defects are already considered "killers" at any process stage, but defined at the contact/via levels for full feature size capture. Hence, minimum defect sensitivity was stipulated as  $1.0 \times$  technology generation at all stages of production. Physically uninterrupted coverage of the bottom of a contact by a monolayer of material or more is the model to be detected. If in the future, detection tools can determine size, shape, or remaining material on the order of  $0.3 \times$  technology generation, this will more adequately match known experience for resistance changes. Scan speed for HARI tools have been broken out into process verification and volume production types. Process verification usually refers to SEM-type tools (but not necessarily in the future) and includes voltage contrast capability. The table indicates the approximate number of 200 mm wafers per hour. To obtain the approximate 300 mm wafers per hour, multiple the wafers/hour rate by .435.

[F] Un-patterned wafer defect detection tools will be required to scan 200 (300 mm or equivalent) wafers per hour at nuisance and false defect rates lower than 5%, for each individually.

[G] Must meet haze and crystal originated pit (COP) requirements specified in the Front End Processes chapter Starting Materials section of the Roadmap.

[H] Sensitivity requirement agreed with Lithography TWG. Might need to be revised with implementation of EUV lithography. Optical review capability of backside results is a requirement.

[I] Resolution of defect review is defined as  $0.05 \times$  Sensitivity at pattern inspection R&D.

[J] Driver is the defect size.

[K] Assumptions: 5,000 wafer starts per week, defects per wafer based on surface preparation at front end of line (FEOL), leading to defects per hour that need review, 100% ADC.

[L] Defect classifications need to meet: Repeatability 95 %, Accuracy 90 %, Purity 90 %.

[M] Defect classifications need to meet: Repeatability 95 %, Accuracy 80 %, Purity 80 %.

[N] Review capability: optical review capability at the tool but also offline SEM review is necessary.

[O] An industry standard result file is needed also for SEM review capability. Result file containing coordinate and angular information to also allow prior level subtraction, also add images from tool in result file.

[P] The first three ADC classes to start with: chips, surface particle large, surface particle small. The fourth ADC class should be blisters.

## YIELD LEARNING

Table 114a Yield Learning Technology Requirements—Near-term Years

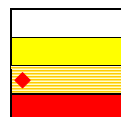
Year of Production	2005	2006	2007	2008	2009	2010	2011	2012	2013
DRAM ½ Pitch (nm) (contacted)	80	70	65	57	50	45	40	36	32
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32
MPU Physical Gate Length (nm)	32	28	25	22	20	18	16	14	13
Wafer size (mm)	300	300	300	300	300	300	300	450	450
Number of mask levels	33	33	33	35	35	35	35	35	35
Number of processing steps	543	556	570	583	596	610	623	636	650
<i>Process R&amp;D at 300 mm wafer/hr, sampling rate at 100% [A]</i>									
Patterned wafer inspection sensitivity (nm) during yield ramp	40.0	35.0	32.5	28.5	25.0	22.5	20.0	17.5	16.0
Wafer out volume (pcs) of yield learning to 30% at R&D [B]	4525	4633	4750	4858	4967	5083	5192	5300	5417
Defect sourcing complexity factor (1E15) [C]	64	85	101	135	179	226	292	876	1071
Yield improve % per inspection	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
<i>Yield ramp from 30% to 70% at 300 mm wafer/hr, sampling rate at 50% [A]</i>									
Patterned wafer inspection sensitivity (nm) during yield ramp	64.0	56.0	52.0	45.6	40.0	36.0	32.0	28.0	25.6
Wafer out volume (pcs) of yield learning from 30% to 70% [D]	9050	9267	9500	9717	9933	10167	10383	10600	10833
Defect sourcing complexity factor (1E15) [C]	25	33	40	53	70	88	114	342	418
Yield improve % per inspection	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
<i>Yield ramp from 70% to base line (85%) at 300 mm wafer/hr, sampling rate at 20% [A]</i>									
Patterned wafer inspection sensitivity (nm) during yield ramp	◆80.0	70.0	65.0	57.0	50.0	45.0	40.0	35.0	32.0
Wafer out volume (pcs) of yield learning from 70% to baseline [E]	◆13575	13900	14250	14575	14900	15250	15575	15900	16250
Defect sourcing complexity factor (1E15) [C]	10	13	15	20	27	34	44	131	161
Yield improve % per inspection	◆TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

Manufacturable solutions exist, and are being optimized

Manufacturable solutions are known

Interim solutions are known

Manufacturable solutions are NOT known

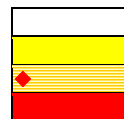


16 Yield Enhancement

Table 114b Yield Learning Technology Requirements—Long-term Years

Year of Production	2014	2015	2016	2017	2018	2019	2020
DRAM ½ Pitch (nm) (contacted)	28	25	22	20	18	16	14
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	28	25	22	20	18	16	14
MPU Physical Gate Length (nm)	11	10	9	8	7	6	6
Wafer size (mm)	450	450	450	450	450	450	450
Number of mask levels	37	37	37	37	39	39	39
Number of processing steps	663	676	690	704	717	730	743
<i>Process R&amp;D at 300 mm wafer/hr, sampling rate at 100% [A]</i>							
Patterned wafer inspection sensitivity (nm) during yield ramp	14.0	12.5	11.0	10.0	9.0	8.0	7.0
Wafer out volume (pcs) of yield learning to 30% at R&D [B]	5525	5633	5750	5867	5975	6083	6192
Defect sourcing complexity factor (1E15) [C]	1427	1825	2406	2970	3734	4812	6397
Yield improve % per inspection	TBD	TBD	TBD	TBD	TBD	TBD	TBD
<i>Yield ramp from 30% to 70% at 300 mm wafer/hr, sampling rate at 50% [A]</i>							
Patterned wafer inspection sensitivity (nm) during yield ramp	22.4	20.0	17.6	16.0	14.4	12.8	11.2
Wafer out volume (pcs) of yield learning from 30% to 70% [D]	11050	11267	11500	11733	11950	12167	12383
Defect sourcing complexity factor (1E15) [C]	557	713	940	1160	1459	1880	2499
Yield improve % per inspection	TBD	TBD	TBD	TBD	TBD	TBD	TBD
<i>Yield ramp from 70% to base line (85%) at 300 mm wafer/hr, sampling rate at 20% [A]</i>							
Patterned wafer inspection sensitivity (nm) during yield ramp	28.0	25.0	22.0	20.0	18.0	16.0	14.0
Wafer out volume (pcs) of yield learning from 70% to baseline [E]	16575	16900	17250	17600	17925	18250	18575
Defect sourcing complexity factor (1E15) [C]	214	274	361	446	560	722	960
Yield improve % per inspection	TBD	TBD	TBD	TBD	TBD	TBD	TBD

Manufacturable solutions exist, and are being optimized  
 Manufacturable solutions are known  
 Interim solutions are known  
 Manufacturable solutions are NOT known



Notes for Tables 114a and b:

[A]. Wafer out volume of yield learning to 30% at R&D: Assume 1/3 of total process steps are critical and need to fine tune the processes for sourcing systematic defect reduction at R&D period. One step with one lot and 25 wafers in a lot.

[B]. Defect sourcing complexity factor: Total wafers \* sampling rate\* 1/ sensitivity

[C]. Yield improvement % by each inspection layer: Yield improvement% in R&D period \* 1/defect complexity factor

[D]. Wafer out volume of yield learning from 30% to 70%: Assume 2/3 of total process steps are possible of yield detractors and need to fine tune the processes for sourcing systematic and random defects

[E]. Wafer out volume of yield learning from 70% to base line 85%: Assume 3/3 of total process steps are possible of yield detractors and need to fine tune the processes margin for sourcing systematic and random defects

## WAFER ENVIRONMENTAL CONTAMINATION CONTROL

Table 115a Technology Requirements for Wafer Environmental Contamination Control—Near-term Years  
UPDATED

Year of Production	2005	2006	2007	2008	2009	2010	2011	2012	2013
DRAM ½ Pitch (nm) (contacted)	80	70	65	57	50	45	40	36	32
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32
MPU Physical Gate Length (nm)	32	28	25	22	20	18	16	14	13
<i>Wafer Environment Control such as Cleanroom, SMIF POD, FOUN, etc....not necessarily the cleanroom itself but wafer environment.</i>									
WAS Critical particle size (nm) [A]	40	35	33	29	25	23	20	18	16
IS Critical particle size (nm) [1]	40	35	33	29	25	23	20	18	16
WAS Number of particles (/m <sup>3</sup> ) [A] [B]	ISO CL 2	ISO CL 2	ISO CL 2	ISO CL 2	ISO CL 2	ISO CL 1	ISO CL 1	ISO CL 1	ISO CL 1
IS Number of particles (/m <sup>3</sup> ) [1] [2]	ISO CL 2	ISO CL 2	ISO CL 2	ISO CL 2	ISO CL 2	ISO CL 1	ISO CL 1	ISO CL 1	ISO CL 1
<i>WAS Airborne Molecular Contaminants in Gas Phase (pptM) [C] [G] [M]</i>									
IS Airborne Molecular Contaminants in Gas Phase (pptM) [3, 7, 12,13,14,15,33]	-	-	-	-	-	-	-	-	-
<i>WAS Lithography (cleanroom ambient) [V]</i>									
IS Lithography (cleanroom ambient) [23]	-	-	-	-	-	-	-	-	-
WAS Total acids (as SO <sub>4</sub> ) including organic acids	5000	5000	5000	5000	5000	5000	5000	5000	5000
IS Total Inorganic Acids	5000	5000	5000	5000	5000	5000	5000	5000	5000
ADD Total Organic Acids [30]	-	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS Total bases (as NH <sub>3</sub> )	50000	50000	50000	50000	50000	50000	50000	50000	50000
IS Total bases	50000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
WAS Condensable organics (w/ GCMS retention times ≥ benzene, calibrated to hexadecane)	26000	26000	26000	26000	26000	26000	26000	26000	26000
IS Condensable organics (w/ GCMS retention times ≥ benzene, calibrated to hexadecane) [31]	26000	26000	26000	26000	26000	26000	26000	26000	26000
Refractory compounds (organics containing S, P, Si)	100	100	100	100	100	100	100	100	100
ADD SMC (surface molecular condensable) refractory compounds on wafers, ng/cm <sup>2</sup> /day [12]	-	2	2	2	2	2	2	2	2
<i>WAS Gate wafer environment (cleanroom/POD/FOUP ambient)</i>									
IS Gate/Furnace area wafer environment (cleanroom/POD/FOUP ambient)	-	-	-	-	-	-	-	-	-
WAS Total metals (as Cu) [H]	1	1	1	1	1	0.5	0.5	0.5	0.5
IS Total metals [8]	1	1	1	1	1	0.5	0.5	0.5	0.5
WAS Dopants [D] (front end of line only)	10	10	10	10	10	10	10	10	10
IS Dopants [4] (front end of line only)	10	10	10	10	10	10	10	10	10
WAS SMC (surface molecular condensable) organics on wafers, ng/cm <sup>2</sup> /week [M]*	2	2	2	2	2	0.5	0.5	0.5	0.5
IS SMC (surface molecular condensable) organics on wafers, ng/cm <sup>2</sup> /day [12]	2	2	2	2	2	0.5	0.5	0.5	0.5
<i>Salicidation Wafer Environment (Cleanroom/POD/FOUP ambient)</i>									
WAS Total acids (as SO <sub>4</sub> ) including organic acids	100	100	100	100	100	10	10	10	10
IS Total Inorganic Acids	100	100	100	100	100	10	10	10	10
ADD Total Organic Acids [30]	-	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
<i>Exposed Copper Wafer Environment (Cleanroom/POD/FOUP ambient)</i>									
WAS Total acids (as SO <sub>4</sub> ) including organic acids	500	500	500	500	500	500	500	500	500
IS Total Inorganic Acids	500	500	500	500	500	500	500	500	500
ADD Total Organic Acids [30]	-	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ADD Total other corrosive species [32]	-	1000	1000	1000	1000	1000	1000	1000	1000
<i>Exposed Aluminum Wafer Environment (Cleanroom/POD/FOUP ambient)</i>									
WAS Total acids (as SO <sub>4</sub> ) including organic acids	500	500	500	500	500	500	500	500	500
IS Total Inorganic Acids	500	500	500	500	500	500	500	500	500
ADD Total Organic Acids [30]	-	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS Total oxidizing species (as Cl <sub>2</sub> )	1000	1000	1000	1000	1000	500	500	500	500
IS Total other corrosive species [32]	1000	1000	1000	1000	1000	1000	1000	1000	1000
<i>Reticle Exposure (Cleanroom/POD/Box ambient)</i>									
WAS Total acids (as SO <sub>4</sub> ) including organic acids	500	500	500	500	500	TBD	TBD	TBD	TBD
IS Total Inorganic Acids	500	500	500	500	500	TBD	TBD	TBD	TBD
ADD Total Organic Acids [30]	-	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

## 18 Yield Enhancement

<i>Year of Production</i>		2005	2006	2007	2008	2009	2010	2011	2012	2013
	DRAM ½ Pitch (nm) (contacted)	80	70	65	57	50	45	40	36	32
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32
	MPU Physical Gate Length (nm)	32	28	25	22	20	18	16	14	13
WAS	Total bases (as NH <sub>3</sub> )	2500	2500	2500	2500	2500	TBD	TBD	TBD	TBD
IS	Total bases	2500	2500	2500	2500	2500	TBD	TBD	TBD	TBD
ADD	SMC (surface molecular condensable) organics on wafers, ng/cm <sup>2</sup> /week [12]	=	2	2	2	2	0.5	0.5	0.5	0.5
<i>General Wafer Environment (Cleanroom/POD/FOUP ambient, all areas unless specified below)</i>										
WAS	Total acids (as SO <sub>4</sub> ) including organic acids	1000	1000	1000	1000	1000	500	500	500	500
IS	Total Inorganic Acids	1000	1000	1000	1000	1000	500	500	500	500
ADD	Total Organic Acids [30]	-	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	Total bases (as NH <sub>3</sub> )	5000	5000	5000	5000	5000	2500	2500	2500	2500
IS	Total bases	5000	5000	5000	5000	5000	2500	2500	2500	2500
	Condensable organics (w/ GCMS retention times ≥ benzene, calibrated to hexadecane)	4000	3500	3000	3000	2500	2500	2500	2500	2500
WAS	Dopants [E] (front end of line only)	10	10	10	10	10	10	10	10	10
IS	Dopants [4] (front end of line only)	10	10	10	10	10	10	10	10	10
WAS	SMC (surface molecular condensable) organics on wafers, ng/cm <sup>2</sup> /day [M]*	2	2	2	2	2	0.5	0.5	0.5	0.5
IS	SMC (surface molecular condensable) organics on wafers, ng/cm <sup>2</sup> /day [12]	2	2	2	2	2	0.5	0.5	0.5	0.5
WAS	Front-end processes, bare Si, total dopants added to 24-hour witness wafer, atoms/cm <sup>2</sup> [D] [M]	2.00E+12	1.00E+12	1.00E+12	1.00E+12	1.00E+12	1.00E+12	1.00E+12	1.00E+12	1.00E+12
IS	Front-end processes, bare Si, total dopants added to 24-hour witness wafer, atoms/cm <sup>2</sup> [4] [13]	2.00E+12	1.00E+12	1.00E+12	1.00E+12	1.00E+12	1.00E+12	1.00E+12	1.00E+12	1.00E+12
WAS	Front-end processes, bare Si, total metals added to witness wafer, atoms/cm <sup>2</sup> [F] [M]	2.00E+10	2.00E+10	2.00E+10	2.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10
IS	Front-end processes, bare Si, total metals added to witness wafer, atoms/cm <sup>2</sup> [6] [14]	2.00E+10	2.00E+10	2.00E+10	2.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10
WAS	Process Critical Materials [G]									
IS	Process Critical Materials [5,7]									
WAS	Ultrapure Water [E] [L]									
IS	Ultrapure Water [29]									
	Resistivity at 25°C (MΩ·cm)	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2
WAS	Total oxidizable carbon (ppb) POE	<1	<1	<1	<1	<1	<1	<1	<1	<1
IS	Total oxidizable carbon (ppb) [22]	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Bacteria (CFU/liter)	<1	<1	<1	<1	<1	<1	<1	<1	<1
WAS	Total silica (ppb) as SiO <sub>2</sub> [P]	<0.5	<0.5	<0.5	<0.5	<0.5	<0.3	<0.3	<0.3	<0.3
IS	Total silica (ppb) as SiO <sub>2</sub> [18]	<0.5	<0.5	<0.5	<0.5	<0.5	<0.3	<0.3	<0.3	<0.3
WAS	Number of particles > critical size (/ml) [A] POE	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
IS	Number of particles > 0.05 μm (/ml) [26]	<0.2	<1	<0.9	<0.8	<0.4	<0.3	<0.3	<0.3	<0.2
WAS	Dissolved oxygen (ppb) (contaminant based) [N] POE	<10	<10	<10	<10	<10	<10	<10	<10	<10
IS	Dissolved oxygen (ppb) (contaminant based) [16] POE	<10	<10	<10	<10	<10	<10	<10	<10	<10
WAS	Dissolved nitrogen (ppm) [J]	8–12	8–12	8–18	8–18	8–18	8–18	8–18	8–18	8–18
IS	Dissolved nitrogen (ppm) [10]*	8–12	8–12	8–18	8–18	8–18	8–18	8–18	8–18	8–18
WAS	Critical metals (ppt, each) [F]	<1.0	<1.0	<1.0	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
IS	Critical metals (ppt, each) [6]	<1.0	<1.0	<1.0	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
WAS	Other critical ions (ppt each) [W]	<50	<50	<50	<50	<50	<50	<50	<50	<50
IS	Other critical ions (ppt each) [24]	<50	<50	<50	<50	<50	<50	<50	<50	<50
WAS	Temperature stability (K) POE	± 1	± 1	± 1	± 1	± 1	± 1	± 1	± 1	± 1
IS	Temperature stability (K) *	± 1	± 1	± 1	± 1	± 1	± 1	± 1	± 1	± 1
WAS	Temperature gradient in K/10 minutes [U] POE for immersion photolithography	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
IS	Temperature gradient in K/10 minutes [22] for immersion photolithography*	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WAS	Liquid Chemicals [F]									
IS	Liquid Chemicals									
WAS	49% HF: number of particles > critical size (/ml) [A] [K]	<10	<10	<10	<10	<10	<10	<10	<10	<10
IS	49% HF: number of particles/ml >0.065μm [1] [11]	<10	<10	<10	<10	<10	<10	<10	<10	<10
WAS	37% HCl: number of particles > critical size (/ml) [A] [K]	<10	<10	<10	<10	<10	<10	<10	<10	<10

<i>Year of Production</i>		2005	2006	2007	2008	2009	2010	2011	2012	2013
	DRAM ½ Pitch (nm) (contacted)	80	70	65	57	50	45	40	36	32
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32
	MPU Physical Gate Length (nm)	32	28	25	22	20	18	16	14	13
IS	37% HCl: number of particles/ml >0.065um [1] [11]	<10	<10	<10	<10	<10	<10	<10	<10	<10
WAS	30% H <sub>2</sub> O <sub>2</sub> : number of particles > critical size (/ml) [A] [K]	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
IS	30% H <sub>2</sub> O <sub>2</sub> : number of particles/ml >0.065um [1] [11]	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
WAS	29% NH <sub>4</sub> OH: number of particles > critical size (/ml) [A] [K]	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
IS	29% NH <sub>4</sub> OH: number of particles/ml >0.065um [1] [11]	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
WAS	100% IPA: number of particles > critical size (/ml) [A] [K]	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
IS	100% IPA: number of particles/ml >0.065um [1] [11]	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
WAS	49% HF: Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Ag, Au, Pd, Pt, Ru) (ppt, each) [S]	150	150	150	150	150	150	150	150	150
IS	49% HF: Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Ag, Au, Pd, Pt, Ru) (ppt, each) [21]	150	150	150	150	150	150	150	150	150
WAS	49% HF: Cl (ppb, each)	10	10	10	10	10	10	10	10	10
IS	49% HF: Cl (ppt)	-	10000	10000	10000	10000	10000	10000	10000	10000
WAS	30% H <sub>2</sub> O <sub>2</sub> : Al, Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Ag, Au, Ba, Cd, Mg, Mn, Mo, Pb, Pd, Pt, Ru, Sn, Ti, V, W, Zn) (ppt, each) [S]	150	150	150	150	150	150	150	150	150
IS	30% H <sub>2</sub> O <sub>2</sub> : Al, Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Ag, Au, Ba, Cd, Mg, Mn, Mo, Pb, Pd, Pt, Ru, Sn, Ti, V, W, Zn) (ppt, each) [21]	150	150	150	150	150	150	150	150	150
ADD	30% H <sub>2</sub> O <sub>2</sub> : SiO <sub>2</sub> (ppt) [27]	-	5000	5000	5000	5000	5000	5000	5000	5000
WAS	30% H <sub>2</sub> O <sub>2</sub> : Br, F (ppt, each)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	30% H <sub>2</sub> O <sub>2</sub> : Br, F (ppt, each)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	29% NH <sub>4</sub> OH: Al, Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Au, Ba, Cd, Mg, Mn, Mo, Pb, Pd, Pt, Ru, Sn, Ti, V, W, Zn) (ppt, each) [S]	150	150	150	150	150	150	150	150	150
IS	29% NH <sub>4</sub> OH: Al, Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Au, Ba, Cd, Mg, Mn, Mo, Pb, Pd, Pt, Ru, Sn, Ti, V, W, Zn) (ppt, each) [21]	150	150	150	150	150	150	150	150	150
WAS	100% IPA: Na, K, Fe, Ni, Cu, Cr, Co, Ca (ppt, each)	150	150	150	150	150	150	150	150	150
IS	100% IPA: Na, K, Fe, Ni, Cu, Cr, Co, Ca (ppt, each) [28]	150	150	150	150	150	150	150	150	150
WAS	100% IPA: Cl, Br (ppt, each)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	100% IPA: Cl (ppt) [28]	-	100000	100000	100000	100000	100000	100000	100000	100000
ADD	100% IPA: Br (ppt) [28]	-	100000	100000	100000	100000	100000	100000	100000	100000
WAS	100% IPA: NH <sub>4</sub> (ppt, each)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	100% IPA: NH <sub>4</sub> (ppt, each)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ADD	100% IPA: F (ppt) [28]	-	100000	100000	100000	100000	100000	100000	100000	100000
WAS	49% HF: All other metals not listed in row above (ppt, each) [R]	500	500	500	500	500	500	500	500	500
IS	49% HF: All other metals not listed in row above (ppt, each) [20]	500	500	500	500	500	500	500	500	500
WAS	30% H <sub>2</sub> O <sub>2</sub> : All other metals not listed in row above (ppt, each) [R]	500	500	500	500	500	500	500	500	500
IS	30% H <sub>2</sub> O <sub>2</sub> : All other metals not listed in row above (ppt, each) [21]	500	500	500	500	500	500	500	500	500
WAS	29% NH <sub>4</sub> OH: all other metals not listed in row above (ppt, each) [R]	500	500	500	500	500	500	500	500	500
IS	29% NH <sub>4</sub> OH: all other metals not listed in row above (ppt, each) [21]	500	500	500	500	500	500	500	500	500
WAS	100% IPA: all other metals not listed in row above (ppt, each) [R]	500	500	500	500	500	500	500	500	500
IS	100% IPA: all other metals not listed in row above (ppt, each) [21]	500	500	500	500	500	500	500	500	500
WAS	49% HF: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	49% HF: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

20 Yield Enhancement

Year of Production		2005	2006	2007	2008	2009	2010	2011	2012	2013
	DRAM ½ Pitch (nm) (contacted)	80	70	65	57	50	45	40	36	32
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32
	MPU Physical Gate Length (nm)	32	28	25	22	20	18	16	14	13
WAS	29% NH4OH: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<del>29% NH4OH: total oxidizable carbon (ppb)</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>
WAS	37% HCl: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<del>37% HCl: total oxidizable carbon (ppb)</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>
	30% H2O2: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	100% IPA – Specific organic acids: formate, acetate, citrate, propionate, oxalate (ppt, each)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	IPA: High molecular weight organics (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	30%H2O2: resin byproducts (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	37% HCl: K, Ni, Cu, Cr, Co, (ppt)	1000	1000	1000	1000	1000	1000	1000	1000	1000
IS	37% HCl: K, Ni, Cu, Cr, Co, (ppt, each)	1000	1000	1000	1000	1000	1000	1000	1000	1000
WAS	96% H2SO4: K, Ni, Cu, Cr, Co, (ppt)	1000	1000	1000	1000	1000	1000	1000	1000	1000
IS	96% H2SO4: K, Ni, Cu, Cr, Co, (ppt, each)	1000	1000	1000	1000	1000	1000	1000	1000	1000
WAS	37% HCl: all other metals not listed in row above (ppt, each) [R]	10000	10000	10000	10000	10000	10000	10000	10000	10000
IS	37% HCl: all other metals not listed in row above (ppt, each) [20]	10000	10000	10000	10000	10000	10000	10000	10000	10000
WAS	96% H2SO4: all other metals not listed in row above (ppt, each) [R]	10000	10000	10000	10000	10000	10000	10000	10000	10000
IS	96% H2SO4: all other metals not listed in row above (ppt, each) [20]	10000	10000	10000	10000	10000	10000	10000	10000	10000
	BEOL solvents, strippers K, Li, Na, (ppt, each)	10000	10000	10000	10000	10000	10000	10000	10000	10000
WAS	Planar slurries: scratching particles (/ml > key particle size) [1] [O]	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<u>CMP slurries: scratching particles (/ml &gt; key particle size) [9] [17]</u>	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	Post-CMP clean chemicals: particles>critical size (/ml) [A] [K] [O]	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<u>Post-CMP clean chemicals: particles&gt;critical size (/ml) [1] [9] [17]</u>	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	Post-CMP clean chemicals: elements TBD (ppt, each) [O]	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<u>Post-CMP clean chemicals: elements TBD (ppt, each) [17]</u>	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	Plating chemicals: particles > critical size (/ml) [A] [K] [O]	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<u>Plating chemicals: particles &gt; critical size (/ml) [1] [9] [17]</u>	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Was	<b>ILD CVD Precursors (e.g., Trimethylsilane, Tetramethylsilane) [X]</b>									
IS	<u>ILD CVD Precursors (e.g., Trimethylsilane, Tetramethylsilane) [25]</u>	-	-	-	-	-	-	-	-	-
Was	Metals (ppb)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Is	<u>Metals except B, Au, Ag (ppb, each)</u>	-	<5	<5	<5	<5	<5	<5	<5	<5
ADD	<u>B, Au, Ag (ppb, each)</u>	-	<10	<10	<10	<10	<10	<10	<10	<10
Was	H2O and Other Oxygen Containing Impurities (ppmV)	<10	<10	<5	<5	<5	<5	<5	<5	<5
IS	<u>H2O (ppm)</u>	-	<1	<1	<1	<1	<1	<1	<1	<1
ADD	<u>CO, CO2 (ppm)</u>	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
ADD	<u>Non-methane hydrocarbons C2-C4 (ppm)</u>	-	<4	<4	<4	<4	<4	<4	<4	<4
ADD	<u>Nitrogen (ppm)</u>	-	<2	<2	<2	<2	<2	<2	<2	<2
ADD	<u>Ar+O2 (ppm)</u>	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
ADD	<u>Chloride (ppm)</u>	-	<1	<1	<1	<1	<1	<1	<1	<1
ADD	<u>ILD CVD Precursors (e.g., Trimethylaluminum) [25]</u>	-	-	-	-	-	-	-	-	-
ADD	<u>Metals each element (ppb)</u>	-	<150	<150	<150	<150	<150	<150	<150	<150
ADD	<u>O2 (ppm)</u>	-	<10	<10	<10	<10	<10	<10	<10	<10
ADD	<u>Silicon (ppm)</u>	-	<1	<1	<1	<1	<1	<1	<1	<1
ADD	<u>Hydrocarbons (ppm)</u>	-	<5	<5	<5	<5	<5	<5	<5	<5
	<b>Bulk Gases (Contaminants, ppbv)</b>									
	N2 (O2, H2, H2O, CO, CO2, THC)	<5	<5	<5	<5	<5	<1	<1	<1	<1
	O2 (N2, Ar)	<50	<50	<50	<50	<50	<25	<25	<25	<25

<i>Year of Production</i>		2005	2006	2007	2008	2009	2010	2011	2012	2013
	DRAM ½ Pitch (nm) (contacted)	80	70	65	57	50	45	40	36	32
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32
	MPU Physical Gate Length (nm)	32	28	25	22	20	18	16	14	13
	O <sub>2</sub> (H <sub>2</sub> , H <sub>2</sub> O, CO, CO <sub>2</sub> , THC)	<10	<10	<10	<10	<10	<5	<5	<5	<5
	Ar (N <sub>2</sub> , O <sub>2</sub> , H <sub>2</sub> , H <sub>2</sub> O, CO, CO <sub>2</sub> , THC)	<5	<5	<5	<5	<5	<1	<1	<1	<1
	H <sub>2</sub> (N <sub>2</sub> , Ar)	<50	<50	<50	<50	<50	<25	<25	<25	<25
	H <sub>2</sub> (O <sub>2</sub> , H <sub>2</sub> O, CO, CO <sub>2</sub> , THC)	<10	<10	<10	<10	<10	<5	<5	<5	<5
	He (N <sub>2</sub> , O <sub>2</sub> , H <sub>2</sub> , H <sub>2</sub> O, CO, CO <sub>2</sub> , THC)	<10	<10	<10	<10	<10	<5	<5	<5	<5
WAS	CO <sub>2</sub> (CO, H <sub>2</sub> O, O <sub>2</sub> , THC)	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
IS	CO <sub>2</sub> (N <sub>2</sub> , CO, H <sub>2</sub> O, O <sub>2</sub> , THC)	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
<b>Lithography Purge Gases</b>										
WAS	Critical clean dry air (H <sub>2</sub> O)	<2500	<2500	<2500	<2500	<2500	<2500	<2500	<2500	<2500
IS	Critical clean dry air (H <sub>2</sub> O)	:	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
ADD	Critical clean dry air (H <sub>2</sub> , CO)	:	<2000	<2000	<2000	<2000	<2000	<2000	<2000	<2000
WAS	Critical clean dry air (organics (molecular weight > benzene) normalized to hexadecane equivalent) (ppb)	<22	<22	<22	<22	<22	<22	<22	<22	<22
IS	Critical clean dry air (organics (molecular weight > benzene) normalized to hexadecane equivalent) (ppb)	:	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2
	Critical clean dry air (total base as NH <sub>3</sub> ) (ppb)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	Critical clean dry air (NH <sub>3</sub> (as NH <sub>3</sub> )) (ppb)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Critical clean dry air (total acid including SO <sub>2</sub> (as SO <sub>4</sub> )) (ppb)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Critical clean dry air (SO <sub>4</sub> (as SO <sub>4</sub> )) (ppb)	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
ADD	Critical clean dry air (Each refractory compound (Organics containing S, P, Si))	:	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Lithography nitrogen tool/maintenance purging gas supply (H <sub>2</sub> O, O <sub>2</sub> , CO <sub>2</sub> ) (ppb)	<500	<500	<500	<500	<500	<500	<500	<500	<500
	Lithography nitrogen tool/maintenance purging gas supply (CO) (ppb)	<2000	<2000	<2000	<2000	<2000	<2000	<2000	<2000	<2000
	Lithography nitrogen tool/maintenance purging gas supply (H <sub>2</sub> ) (ppb)	<2000	<2000	<2000	<2000	<2000	<2000	<2000	<2000	<2000
WAS	Lithography nitrogen tool/maintenance purging gas supply (organics (molecular weight > benzene) normalized to hexadecane equivalent) (ppbV)	<22	<22	<22	<22	<22	<22	<22	<22	<22
IS	Lithography nitrogen tool/maintenance purging gas supply (organics (molecular weight > benzene) normalized to hexadecane equivalent) (ppb)	:	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2
	Lithography nitrogen tool/maintenance purging gas supply (total base (as NH <sub>3</sub> )) (ppb)	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
	Lithography nitrogen tool/maintenance purging gas supply (total acid (as SO <sub>4</sub> ) including SO <sub>2</sub> ) (ppb)	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
WAS	Lithography nitrogen tool/maintenance purging gas supply (refractory compounds (organics containing S, P, Si, etc.) normalized to hexadecane equivalent) (ppbw)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
IS	Lithography nitrogen tool/maintenance purging gas supply (refractory compounds (organics containing S, P, Si, etc.) normalized to hexadecane equivalent) (ppb)	:	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Lithography helium tool/maintenance purging gas supply (H <sub>2</sub> O) (ppb)	<3500	<3500	<3500	<3500	<3500	<3500	<3500	<3500	<3500
WAS	Lithography helium tool/maintenance purging gas supply (O <sub>2</sub> , CO <sub>2</sub> ) (ppb)	<500	<500	<500	<500	<500	<500	<500	<500	<500
IS	Lithography helium tool/maintenance purging gas supply (O <sub>2</sub> , CO <sub>2</sub> ) (ppb)	:	<4000	<4000	<4000	<4000	<4000	<4000	<4000	<4000
WAS	Lithography helium tool/maintenance purging gas supply (CO, H <sub>2</sub> ) (ppb)	<2000	<2000	<2000	<2000	<2000	<2000	<2000	<2000	<2000
IS	Lithography helium tool/maintenance purging gas supply (CO, H <sub>2</sub> ) (ppb)	:	<10000	<10000	<10000	<10000	<10000	<10000	<10000	<10000
WAS	Lithography helium tool/maintenance purging gas supply (organics(molecular weight > benzene) normalized to hexadecane equivalent) (ppb)	<22	<22	<22	<22	<22	<22	<22	<22	<22

## 22 Yield Enhancement

<i>Year of Production</i>		2005	2006	2007	2008	2009	2010	2011	2012	2013
<i>DRAM ½ Pitch (nm) (contacted)</i>		80	70	65	57	50	45	40	36	32
<i>MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)</i>		90	78	68	59	52	45	40	36	32
<i>MPU Physical Gate Length (nm)</i>		32	28	25	22	20	18	16	14	13
<b>IS</b>	Lithography helium tool/maintenance purging gas supply (organics(molecular weight > benzene) normalized to hexadecane equivalent) (ppb)	:	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2
	Lithography helium tool/maintenance purging gas supply (total base (as NH <sub>3</sub> )) (ppb)	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
	Lithography helium tool/maintenance purging gas supply (total acid including SO <sub>2</sub> (as SO <sub>4</sub> )) (ppb)	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
<b>WAS</b>	Lithography helium tool/maintenance purging gas supply (refractory compounds (organics containing S, P, Si, etc.) normalized to hexadecane equivalent) (ppbw)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
<b>IS</b>	Lithography helium tool/maintenance purging gas supply (refractory compounds (organics containing S, P, Si, etc.) normalized to hexadecane equivalent) (ppb)	:	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<b>WAS</b>	Number of particles > critical size (/M <sup>3</sup> ) [A]	<100	<100	<100	<100	<100	<100	<100	<100	<100
<b>IS</b>	Number of particles > critical size (/M3) [1]	<100	<100	<100	<100	<100	<100	<100	<100	<100
<b>Specialty Gases</b>										
<i>Etchants (Corrosive, e.g., BCl<sub>3</sub>, Cl<sub>2</sub>)</i>										
	O <sub>2</sub> , H <sub>2</sub> O (ppbv)	<1000	<500	<500	<500	<100	100	100	100	100
<b>WAS</b>	Critical specified metals/total metals (ppbw) [Q]	<10/1000	<10/1000	<10/1000	<1/TBD	<1/TBD	<1/TBD	<1/TBD	<1/TBD	<1/TBD
<b>IS</b>	Critical specified metals/total metals (ppbw) [19]	<10/1000	<10/1000	<10/1000	<1/1000	<1/1000	<1/1000	<1/1000	<1/1000	<1/1000
<i>Etchants (Non-corrosive, e.g., C<sub>2</sub>F<sub>6</sub>, NF<sub>3</sub>)</i>										
	O <sub>2</sub> , H <sub>2</sub> O (ppb)	<1000	<1000	<1000	<1000	<1000	100	100	100	100
<i>Deposition (e.g., SiH<sub>4</sub>, NH<sub>3</sub>, (CH<sub>3</sub>)<sub>3</sub>SiH)</i>										
	O <sub>2</sub> , H <sub>2</sub> O (ppb)	<1000	<1000	<1000	<1000	<1000	100	100	100	100
<b>WAS</b>	Critical specified metals/total metals (ppbw) [Q]	<10/1000	<10/1000	<10/1000	<1/TBD	<1/TBD	<1/TBD	<1/TBD	<1/TBD	<1/TBD
<b>IS</b>	Critical specified metals/total metals (ppbw) [19]	<10/1000	<10/1000	<10/1000	<1/1000	<1/1000	<1/1000	<1/1000	<1/1000	<1/1000
<i>Dopants (e.g., AsH<sub>3</sub>, PH<sub>3</sub>, GeH<sub>4</sub>)</i>										
	O <sub>2</sub> , H <sub>2</sub> O (ppb)	<1000	<500	<500	<500	<100	100	100	100	100
<i>Inerts for purging</i>										
	O <sub>2</sub> , H <sub>2</sub> O (ppb)	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
	He, H <sub>2</sub> cylinder carrier/purge gases (N <sub>2</sub> , H <sub>2</sub> O, ppb)	<100	<100	<100	<100	<100	<100	<100	<100	<100

Manufacturable solutions exist, and are being optimized

Manufacturable solutions are known

Interim solutions are known

Manufacturable solutions are NOT known

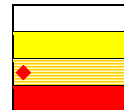


Table 115b Technology Requirements for Wafer Environmental Contamination Control—Long-term Years  
**UPDATED**

<i>Year of Production</i>		2014	2015	2016	2017	2018	2019	2020
DRAM ½ Pitch (nm) (contacted)		28	25	22	20	18	16	14
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)		28	25	22	20	18	16	14
MPU Physical Gate Length (nm)		11	10	9	8	7	6	6
<i>Wafer Environment Control such as Cleanroom, SMIF POD, FOUP, etc....not necessarily the cleanroom itself but wafer environment.</i>								
WAS	Critical particle size (nm) [A]	14	13	11	10	9		
IS	Critical particle size (nm) [1]	14	13	11	10	9		
WAS	Number of particles (/m <sup>3</sup> ) [A] [B]	ISO CL1	ISO CL1	ISO CL1	ISO CL1	ISO CL1	ISO CL1	ISO CL1
IS	Number of particles (/m <sup>3</sup> ) [1] [2]	ISO CL1	ISO CL1	ISO CL1	ISO CL1	ISO CL1	ISO CL1	ISO CL1
WAS	<i>Airborne Molecular Contaminants in Gas Phase (pptM) [C] [G] [M]</i>							
IS	<i>Airborne Molecular Contaminants in Gas Phase (pptM) [3, 7, 12,13,14,15,33]</i>	-	-	-	-	-	-	-
WAS	Lithography (cleanroom ambient) [V]							
IS	Lithography (cleanroom ambient) [23]							
WAS	Total acids (as SO <sub>4</sub> ) including organic acids	5000	5000	5000	5000	5000	5000	5000
IS	Total Inorganic Acids	5000	5000	5000	5000	5000	5000	5000
ADD	Total Organic Acids [30]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	Total bases (as NH <sub>3</sub> )	50000	50000	50000	50000	50000	50000	50000
IS	Total bases	50,000	50,000	50,000	50,000	50,000	50,000	50,000
WAS	Condensable organics (w/ GCMS retention times ≥ benzene, calibrated to hexadecane)	26000	26000	26000	26000	26000	26000	26000
IS	Condensable organics (w/ GCMS retention times ≥ benzene, calibrated to hexadecane) [31]	26000	26000	26000	26000	26000	26000	26000
	Refractory compounds (organics containing S, P, Si)	100	100	100	100	100	100	100
ADD	SMC (surface molecular condensable) refractory compounds on wafers, ng/cm <sup>2</sup> /day [12]	2	2	2	2	2	2	2
WAS	<i>Gate wafer environment (cleanroom/POD/FOUP ambient)</i>							
IS	<i>Gate/Furnace area wafer environment (cleanroom/POD/FOUP ambient)</i>	-	-	-	-	-	-	-
WAS	Total metals (as Cu) [H]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
IS	Total metals [8]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
WAS	Dopants [D] (front end of line only)	10	10	10	10	10	10	10
IS	Dopants [4] (front end of line only)	10	10	10	10	10	10	10
WAS	SMC (surface molecular condensable) organics on wafers, ng/cm <sup>2</sup> /week [M]*	0.5	0.5	0.5	0.5	0.5	0.5	0.5
IS	SMC (surface molecular condensable) organics on wafers, ng/cm <sup>2</sup> /day [12]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	<i>Salicidation Wafer Environment (Cleanroom/POD/FOUP ambient)</i>							
WAS	Total acids (as SO <sub>4</sub> ) including organic acids	10	10	10	10	10	10	10
IS	Total Inorganic Acids	10	10	10	10	10	10	10
ADD	Total Organic Acids [30]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	<i>Exposed Copper Wafer Environment (Cleanroom/POD/FOUP ambient)</i>							
WAS	Total acids (as SO <sub>4</sub> ) including organic acids	500	500	500	500	500	500	500
IS	Total Inorganic Acids	500	500	500	500	500	500	500
ADD	Total Organic Acids [30]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ADD	Total other corrosive species [32]	1000	1000	1000	1000	1000	1000	1000
	<i>Exposed Aluminum Wafer Environment (Cleanroom/POD/FOUP ambient)</i>							
WAS	Total acids (as SO <sub>4</sub> ) including organic acids	500	500	500	500	500	500	500
IS	Total Inorganic Acids	500	500	500	500	500	500	500
ADD	Total Organic Acids [30]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	Total oxidizing species (as Cl <sub>2</sub> )	500	500	500	500	500	500	500
IS	Total other corrosive species [32]	1000	1000	1000	1000	1000	1000	1000
	<i>Reticle Exposure (Cleanroom/POD/Box ambient)</i>							
WAS	Total acids (as SO <sub>4</sub> ) including organic acids	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	Total Inorganic Acids	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ADD	Total Organic Acids [30]	TBD	TBD	TBD	TBD	TBD	TBD	TBD

24 Yield Enhancement

<i>Year of Production</i>		2014	2015	2016	2017	2018	2019	2020
	DRAM ½ Pitch (nm) (contacted)	28	25	22	20	18	16	14
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	28	25	22	20	18	16	14
	MPU Physical Gate Length (nm)	11	10	9	8	7	6	6
WAS	Total bases (as NH <sub>3</sub> )	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	Total bases	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ADD	SMC (surface molecular condensable) organics on wafers, ng/cm <sup>2</sup> /week [12]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
<i>General Wafer Environment (Cleanroom/POD/FOUP ambient, all areas unless specified below)</i>								
WAS	Total acids (as SO <sub>4</sub> ) including organic acids	500	500	500	500	500	500	500
IS	Total Inorganic Acids	500	500	500	500	500	500	500
ADD	Total Organic Acids [30]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	Total bases (as NH <sub>3</sub> )	2500	2500	2500	2500	2500	2500	2500
IS	Total bases	2500	2500	2500	2500	2500	2500	2500
	Condensable organics (w/ GCMS retention times ≥ benzene, calibrated to hexadecane)	2500	2500	2500	2500	2500	2500	2500
WAS	Dopants [E] (front end of line only)	10	10	10	10	10	10	10
IS	Dopants [4] (front end of line only)	10	10	10	10	10	10	10
WAS	SMC (surface molecular condensable) organics on wafers, ng/cm <sup>2</sup> /day [M]*	0.5	0.5	0.5	0.5	0.5	0.5	0.5
IS	SMC (surface molecular condensable) organics on wafers, ng/cm <sup>2</sup> /day [12]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
WAS	Front-end processes, bare Si, total dopants added to 24-hour witness wafer, atoms/cm <sup>2</sup> [D] [M]	1.00E+1 2	1.00E+1 2	1.00E+1 2	1.00E+1 2	1.00E+1 2	1.00E+1 2	1.00E+1 2
IS	Front-end processes, bare Si, total dopants added to 24-hour witness wafer, atoms/cm <sup>2</sup> [4] [13]	1.00E+1 2	1.00E+1 2	1.00E+1 2	1.00E+1 2	1.00E+1 2	1.00E+1 2	1.00E+1 2
WAS	Front-end processes, bare Si, total metals added to witness wafer, atoms/cm <sup>2</sup> [F] [M]	1.00E+1 0	1.00E+1 0	1.00E+1 0	1.00E+1 0	1.00E+1 0	1.00E+1 0	1.00E+1 0
IS	Front-end processes, bare Si, total metals added to witness wafer, atoms/cm <sup>2</sup> [6] [14]	1.00E+1 0	1.00E+1 0	1.00E+1 0	1.00E+1 0	1.00E+1 0	1.00E+1 0	1.00E+1 0
WAS	<i>Process Critical Materials [G]</i>							
IS	<i>Process Critical Materials [5,7]</i>							
WAS	<i>Ultrapure Water [E] [L]</i>							
IS	<i>Ultrapure Water [29]</i>							
	Resistivity at 25°C (MΩ-cm)	18.2	18.2	18.2	18.2	18.2	18.2	18.2
WAS	Total oxidizable carbon (ppb) POE	<1	<1	<1	<1	<1	<1	<1
IS	Total oxidizable carbon (ppb) [22]	<1	<1	<1	<1	<1	<1	<1
	Bacteria (CFU/liter)	<1	<1	<1	<1	<1	<1	<1
WAS	Total silica (ppb) as SiO <sub>2</sub> [P]	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
IS	Total silica (ppb) as SiO <sub>2</sub> [18]	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
WAS	Number of particles > critical size (/ml) [A] POE	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
IS	Number of particles > 0.05 μm (/ml) [26]	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
WAS	Dissolved oxygen (ppb) (contaminant based) [N] POE	<10	<10	<10	<10	<10	<10	<10
IS	Dissolved oxygen (ppb) (contaminant based) [16] POE	<10	<10	<10	<10	<10	<10	<10
WAS	Dissolved nitrogen (ppm) [J]	8-18	8-18	8-18	8-18	8-18	8-18	8-18
IS	Dissolved nitrogen (ppm) [10]*	8-18	8-18	8-18	8-18	8-18	8-18	8-18
WAS	Critical metals (ppt, each) [F]	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
IS	Critical metals (ppt, each) [6]	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
WAS	Other critical ions (ppt each) [W]	<50	<50	<50	<50	<50	<50	<50
IS	Other critical ions (ppt each) [24]	<50	<50	<50	<50	<50	<50	<50
WAS	Temperature stability (K) POE	± 1	± 1	± 1	± 1	± 1	± 1	± 1
IS	Temperature stability (K) *	± 1	± 1	± 1	± 1	± 1	± 1	± 1
WAS	Temperature gradient in K/10 minutes [U] POE for immersion photolithography	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
IS	Temperature gradient in K/10 minutes [22] for immersion photolithography*	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WAS	<i>Liquid Chemicals [F]</i>							
IS	<i>Liquid Chemicals</i>							
WAS	49% HF: number of particles > critical size (/ml) [A] [K]	<10	<10	<10	<10	<10	<10	<10
IS	49% HF: number of particles/ml >0.065μm [1] [11]	<10	<10	<10	<10	<10	<10	<10
WAS	37% HCl: number of particles > critical size (/ml) [A] [K]	<10	<10	<10	<10	<10	<10	<10
IS	37% HCl: number of particles/ml >0.065μm [1] [11]	<10	<10	<10	<10	<10	<10	<10

<i>Year of Production</i>		2014	2015	2016	2017	2018	2019	2020
	DRAM ½ Pitch (nm) (contacted)	28	25	22	20	18	16	14
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	28	25	22	20	18	16	14
	MPU Physical Gate Length (nm)	11	10	9	8	7	6	6
WAS	30% H <sub>2</sub> O <sub>2</sub> : number of particles > critical size (/ml) [A] [K]	<1000	<1000	<1000	<1000	<1000	<1000	<1000
IS	30% H <sub>2</sub> O <sub>2</sub> : number of particles/ml >0.065um [1] [11]	<1000	<1000	<1000	<1000	<1000	<1000	<1000
WAS	29% NH <sub>4</sub> OH: number of particles > critical size (/ml) [A] [K]	<1000	<1000	<1000	<1000	<1000	<1000	<1000
IS	29% NH <sub>4</sub> OH: number of particles/ml >0.065um [1] [11]	<1000	<1000	<1000	<1000	<1000	<1000	<1000
WAS	100% IPA: number of particles > critical size (/ml) [A] [K]	<1000	<1000	<1000	<1000	<1000	<1000	<1000
IS	100% IPA: number of particles/ml >0.065um [1] [11]	<1000	<1000	<1000	<1000	<1000	<1000	<1000
WAS	49% HF: Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Ag, Au, Pd, Pt, Ru) (ppt, each) [S]	150	150	150	150	150	150	150
IS	49% HF: Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Ag, Au, Pd, Pt, Ru) (ppt, each) [21]	150	150	150	150	150	150	150
WAS	49% HF: Cl (ppb, each)	10	10	10	10	10	10	10
IS	49% HF: Cl (ppt)	10000	10000	10000	10000	10000	10000	10000
WAS	30% H <sub>2</sub> O <sub>2</sub> : Al, Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Ag, Au, Ba, Cd, Mg, Mn, Mo, Pb, Pd, Pt, Ru, Sn, Ti, V, W, Zn) (ppt, each) [S]	150	150	150	150	150	150	150
IS	30% H <sub>2</sub> O <sub>2</sub> : Al, Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Ag, Au, Ba, Cd, Mg, Mn, Mo, Pb, Pd, Pt, Ru, Sn, Ti, V, W, Zn) (ppt, each) [21]	150	150	150	150	150	150	150
ADD	30% H <sub>2</sub> O <sub>2</sub> : SiO <sub>2</sub> (ppt) [27]	5000	5000	5000	5000	5000	5000	5000
WAS	30% H <sub>2</sub> O <sub>2</sub> : Br, F (ppt, each)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<del>30% H<sub>2</sub>O<sub>2</sub>: Br, F (ppt, each)</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>
WAS	29% NH <sub>4</sub> OH: Al, Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Au, Ba, Cd, Mg, Mn, Mo, Pb, Pd, Pt, Ru, Sn, Ti, V, W, Zn) (ppt, each) [S]	150	150	150	150	150	150	150
IS	29% NH <sub>4</sub> OH: Al, Na, K, Fe, Ni, Cu, Cr, Co, Ca, (Au, Ba, Cd, Mg, Mn, Mo, Pb, Pd, Pt, Ru, Sn, Ti, V, W, Zn) (ppt, each) [21]	150	150	150	150	150	150	150
WAS	100% IPA: Na, K, Fe, Ni, Cu, Cr, Co, Ca (ppt, each)	150	150	150	150	150	150	150
IS	100% IPA: Na, K, Fe, Ni, Cu, Cr, Co, Ca (ppt, each) [28]	150	150	150	150	150	150	150
WAS	100% IPA: Cl, Br (ppt, each)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	100% IPA: Cl (ppt) [28]	100000	100000	100000	100000	100000	100000	100000
ADD	100% IPA: Br (ppt) [28]	100000	100000	100000	100000	100000	100000	100000
WAS	100% IPA: NH <sub>4</sub> (ppt, each)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<del>100% IPA: NH<sub>4</sub> (ppt, each)</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>
ADD	100% IPA: F (ppt) [28]	100000	100000	100000	100000	100000	100000	100000
WAS	49% HF: All other metals not listed in row above (ppt, each) [R]	500	500	500	500	500	500	500
IS	49% HF: All other metals not listed in row above (ppt, each) [20]	500	500	500	500	500	500	500
WAS	30% H <sub>2</sub> O <sub>2</sub> : All other metals not listed in row above (ppt, each) [R]	500	500	500	500	500	500	500
IS	30% H <sub>2</sub> O <sub>2</sub> : All other metals not listed in row above (ppt, each) [21]	500	500	500	500	500	500	500
WAS	29% NH <sub>4</sub> OH: all other metals not listed in row above (ppt, each) [R]	500	500	500	500	500	500	500
IS	29% NH <sub>4</sub> OH: all other metals not listed in row above (ppt, each) [21]	500	500	500	500	500	500	500
WAS	100% IPA: all other metals not listed in row above (ppt, each) [R]	500	500	500	500	500	500	500
IS	100% IPA: all other metals not listed in row above (ppt, each) [21]	500	500	500	500	500	500	500
WAS	49% HF: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<del>49% HF: total oxidizable carbon (ppb)</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>
WAS	29% NH <sub>4</sub> OH: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<del>29% NH<sub>4</sub>OH: total oxidizable carbon (ppb)</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>
WAS	37% HCl: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	<del>37% HCl: total oxidizable carbon (ppb)</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>	<del>TBD</del>

26 Yield Enhancement

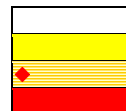
<i>Year of Production</i>		2014	2015	2016	2017	2018	2019	2020
	DRAM ½ Pitch (nm) (contacted)	28	25	22	20	18	16	14
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	28	25	22	20	18	16	14
	MPU Physical Gate Length (nm)	11	10	9	8	7	6	6
	30% H <sub>2</sub> O <sub>2</sub> : total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	100% IPA – Specific organic acids: formate, acetate, citrate, propionate, oxalate (ppt, each)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	IPA: High molecular weight organics (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	30%H <sub>2</sub> O <sub>2</sub> : resin byproducts (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	37% HCl: K, Ni, Cu, Cr, Co, (ppt)	1000	1000	1000	1000	1000	1000	1000
IS	37% HCl: K, Ni, Cu, Cr, Co, (ppt, each)	1000	1000	1000	1000	1000	1000	1000
WAS	96% H <sub>2</sub> SO <sub>4</sub> : K, Ni, Cu, Cr, Co, (ppt)	1000	1000	1000	1000	1000	1000	1000
IS	96% H <sub>2</sub> SO <sub>4</sub> : K, Ni, Cu, Cr, Co, (ppt, each)	1000	1000	1000	1000	1000	1000	1000
WAS	37% HCl: all other metals not listed in row above (ppt, each) [R]	10000	10000	10000	10000	10000	10000	10000
IS	37% HCl: all other metals not listed in row above (ppt, each) [20]	10000	10000	10000	10000	10000	10000	10000
WAS	96% H <sub>2</sub> SO <sub>4</sub> : all other metals not listed in row above (ppt, each) [R]	10000	10000	10000	10000	10000	10000	10000
IS	96% H <sub>2</sub> SO <sub>4</sub> : all other metals not listed in row above (ppt, each) [20]	10000	10000	10000	10000	10000	10000	10000
WAS	BEOL solvents, strippers K, Li, Na, (ppt, each)	10000	10000	10000	10000	10000	10000	10000
	Planar slurries: scratching particles (/ml > key particle size) [1] [O]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	CMP slurries: scratching particles (/ml > key particle size) [9] [17]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	Post-CMP clean chemicals: particles>critical size (/ml) [A] [K] [O]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	Post-CMP clean chemicals: particles>critical size (/ml) [1] [9] [17]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	Post-CMP clean chemicals: elements TBD (ppt, each) [O]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	Post-CMP clean chemicals: elements TBD (ppt, each) [17]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WAS	Plating chemicals: particles > critical size (/ml) [A] [K] [O]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	Plating chemicals: particles > critical size (/ml) [1] [9] [17]	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Was	ILD CVD Precursors (e.g., Trimethylsilane, Tetramethylsilane) [X]							
IS	ILD CVD Precursors (e.g., Trimethylsilane, Tetramethylsilane) [25]	-	-	-	-	-	-	-
Was	Metals (ppb)	<1	<1	<1	<1	<1	<1	<1
IS	Metals except B, Au, Ag (ppb, each)	<5	<5	<5	<5	<5	<5	<5
ADD	B, Au, Ag (ppb, each)	<10	<10	<10	<10	<10	<10	<10
Was	H <sub>2</sub> O and Other Oxygen Containing Impurities (ppmV)	<5	<5	<5	<5	<5	<5	<5
IS	H <sub>2</sub> O (ppm)	<1	<1	<1	<1	<1	<1	<1
ADD	CO, CO <sub>2</sub> (ppm)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
ADD	Non-methane hydrocarbons C2-C4 (ppm)	<4	<4	<4	<4	<4	<4	<4
ADD	Nitrogen (ppm)	<2	<2	<2	<2	<2	<2	<2
ADD	Ar+O <sub>2</sub> (ppm)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
ADD	Chloride (ppm)	<1	<1	<1	<1	<1	<1	<1
ADD	ILD CVD Precursors (e.g., Trimethylaluminum) [25]	-	-	-	-	-	-	-
ADD	Metals each element (ppb)	<150	<150	<150	<150	<150	<150	<150
ADD	O <sub>2</sub> (ppm)	<10	<10	<10	<10	<10	<10	<10
ADD	Silicon (ppm)	<1	<1	<1	<1	<1	<1	<1
ADD	Hydrocarbons (ppm)	<5	<5	<5	<5	<5	<5	<5
	<b>Bulk Gases (Contaminants, ppbv)</b>							
	N <sub>2</sub> (O <sub>2</sub> , H <sub>2</sub> , H <sub>2</sub> O, CO, CO <sub>2</sub> , THC)	<1	<1	<1	<1	<1	<1	<1
	O <sub>2</sub> (N <sub>2</sub> , Ar)	<25	<25	<25	<25	<25	<25	<25
	O <sub>2</sub> (H <sub>2</sub> , H <sub>2</sub> O, CO, CO <sub>2</sub> , THC)	<5	<5	<5	<5	<5	<5	<5
	Ar (N <sub>2</sub> , O <sub>2</sub> , H <sub>2</sub> , H <sub>2</sub> O, CO, CO <sub>2</sub> , THC)	<1	<1	<1	<1	<1	<1	<1
	H <sub>2</sub> (N <sub>2</sub> , Ar)	<25	<25	<25	<25	<25	<25	<25
	H <sub>2</sub> (O <sub>2</sub> , H <sub>2</sub> O, CO, CO <sub>2</sub> , THC)	<5	<5	<5	<5	<5	<5	<5

<i>Year of Production</i>		2014	2015	2016	2017	2018	2019	2020
	DRAM ½ Pitch (nm) (contacted)	28	25	22	20	18	16	14
	MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	28	25	22	20	18	16	14
	MPU Physical Gate Length (nm)	11	10	9	8	7	6	6
	He (N <sub>2</sub> , O <sub>2</sub> , H <sub>2</sub> , H <sub>2</sub> O, CO, CO <sub>2</sub> , THC)	<5	<5	<5	<5	<5	<5	<5
WAS	CO <sub>2</sub> (CO, H <sub>2</sub> O, O <sub>2</sub> , THC)	<1000	<1000	<1000	<1000	<1000	<1000	<1000
IS	CO <sub>2</sub> (N <sub>2</sub> , CO, H <sub>2</sub> O, O <sub>2</sub> , THC)	<1000	<1000	<1000	<1000	<1000	<1000	<1000
<b>Lithography Purge Gases</b>								
WAS	Critical clean dry air (H <sub>2</sub> O)	<2500	<2500	<2500	<2500	<2500	<2500	<2500
IS	Critical clean dry air (H <sub>2</sub> O)	<1000	<1000	<1000	<1000	<1000	<1000	<1000
ADD	Critical clean dry air (H <sub>2</sub> , CO)	<2000	<2000	<2000	<2000	<2000	<2000	<2000
WAS	Critical clean dry air (organics (molecular weight > benzene) normalized to hexadecane equivalent) (ppb)	<22	<22	<22	<22	<22	<22	<22
IS	Critical clean dry air (organics (molecular weight > benzene) normalized to hexadecane equivalent) (ppb)	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2
	Critical clean dry air (total base as NH <sub>3</sub> ) (ppb)	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	Critical clean dry air (NH <sub>3</sub> (as NH <sub>3</sub> )) (ppb)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Critical clean dry air (total acid including SO <sub>2</sub> (as SO <sub>4</sub> )) (ppb)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Critical clean dry air (SO <sub>4</sub> (as SO <sub>4</sub> )) (ppb)	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
ADD	Critical clean dry air (Each refractory compound (Organics containing S, P, Si)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Lithography nitrogen tool/maintenance purging gas supply (H <sub>2</sub> O, O <sub>2</sub> , CO <sub>2</sub> ) (ppb)	<500	<500	<500	<500	<500	<500	<500
	Lithography nitrogen tool/maintenance purging gas supply (CO) (ppb)	<2000	<2000	<2000	<2000	<2000	<2000	<2000
	Lithography nitrogen tool/maintenance purging gas supply (H <sub>2</sub> ) (ppb)	<2000	<2000	<2000	<2000	<2000	<2000	<2000
WAS	Lithography nitrogen tool/maintenance purging gas supply (organics (molecular weight > benzene) normalized to hexadecane equivalent) (ppbV)	<22	<22	<22	<22	<22	<22	<22
IS	Lithography nitrogen tool/maintenance purging gas supply (organics (molecular weight > benzene) normalized to hexadecane equivalent) (ppb)	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2
	Lithography nitrogen tool/maintenance purging gas supply (total base (as NH <sub>3</sub> )) (ppb)	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
	Lithography nitrogen tool/maintenance purging gas supply (total acid (as SO <sub>4</sub> ) including SO <sub>2</sub> ) (ppb)	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
WAS	Lithography nitrogen tool/maintenance purging gas supply (refractory compounds (organics containing S, P, Si, etc.) normalized to hexadecane equivalent) (ppbw)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
IS	Lithography nitrogen tool/maintenance purging gas supply (refractory compounds (organics containing S, P, Si, etc.) normalized to hexadecane equivalent) (ppb)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Lithography helium tool/maintenance purging gas supply (H <sub>2</sub> O) (ppb)	<3500	<3500	<3500	<3500	<3500	<3500	<3500
WAS	Lithography helium tool/maintenance purging gas supply (O <sub>2</sub> , CO <sub>2</sub> ) (ppb)	<500	<500	<500	<500	<500	<500	<500
IS	Lithography helium tool/maintenance purging gas supply (O <sub>2</sub> , CO <sub>2</sub> ) (ppb)	<4000	<4000	<4000	<4000	<4000	<4000	<4000
WAS	Lithography helium tool/maintenance purging gas supply (CO, H <sub>2</sub> ) (ppb)	<2000	<2000	<2000	<2000	<2000	<2000	<2000
IS	Lithography helium tool/maintenance purging gas supply (CO, H <sub>2</sub> ) (ppb)	<10000	<10000	<10000	<10000	<10000	<10000	<10000
WAS	Lithography helium tool/maintenance purging gas supply (organics(molecular weight > benzene) normalized to hexadecane equivalent) (ppb)	<22	<22	<22	<22	<22	<22	<22
IS	Lithography helium tool/maintenance purging gas supply (organics(molecular weight > benzene) normalized to hexadecane equivalent) (ppb)	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2	<3.2
	Lithography helium tool/maintenance purging gas supply (total base (as NH <sub>3</sub> )) (ppb)	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
	Lithography helium tool/maintenance purging gas supply (total acid including SO <sub>2</sub> (as SO <sub>4</sub> )) (ppb)	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025

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Year of Production		2014	2015	2016	2017	2018	2019	2020
	DRAM 1/2 Pitch (nm) (contacted)	28	25	22	20	18	16	14
	MPU/ASIC Metal 1 (M1) 1/2 Pitch (nm)(contacted)	28	25	22	20	18	16	14
	MPU Physical Gate Length (nm)	11	10	9	8	7	6	6
WAS	Lithography helium tool/maintenance purging gas supply (refractory compounds (organics containing S, P, Si, etc.) normalized to hexadecane equivalent) (ppbw)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
IS	Lithography helium tool/maintenance purging gas supply (refractory compounds (organics containing S, P, Si, etc.) normalized to hexadecane equivalent) (ppb)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WAS	Number of particles > critical size (/M <sup>3</sup> ) [A]	<100	<100	<100	<100	<100	<100	<100
IS	Number of particles > critical size (/M <sup>3</sup> ) [1]	<100	<100	<100	<100	<100	<100	<100
<b>Specialty Gases</b>								
<b>Etchants (Corrosive, e.g., BCl<sub>3</sub>, Cl<sub>2</sub>)</b>								
	O <sub>2</sub> , H <sub>2</sub> O (ppbv)	100	100	100	100	100	100	100
WAS	Critical specified metals/total metals (ppbw) [Q]	<1/TBD	<1/TBD	<1/TBD	<1/TBD	<1/TBD	<1/TBD	<1/TBD
IS	Critical specified metals/total metals (ppbw) [19]	<1/1000	<1/1000	<1/1000	<1/1000	<1/1000	<1/1000	<1/1000
<b>Etchants (Non-corrosive, e.g., C<sub>2</sub>F<sub>6</sub>, NF<sub>3</sub>)</b>								
	O <sub>2</sub> , H <sub>2</sub> O (ppb)	100	100	100	100	100	100	100
<b>Deposition (e.g., SiH<sub>4</sub>, NH<sub>3</sub>, (CH<sub>3</sub>)<sub>3</sub>SiH)</b>								
	O <sub>2</sub> , H <sub>2</sub> O (ppb)	100	100	100	100	100	100	100
WAS	Critical specified metals/total metals (ppbw) [Q]	<1/TBD	<1/TBD	<1/TBD	<1/TBD	<1/TBD	<1/TBD	<1/TBD
IS	Critical specified metals/total metals (ppbw) [19]	<1/1000	<1/1000	<1/1000	<1/1000	<1/1000	<1/1000	<1/1000
<b>Dopants (e.g., AsH<sub>3</sub>, PH<sub>3</sub>, GeH<sub>4</sub>)</b>								
	O <sub>2</sub> , H <sub>2</sub> O (ppb)	100	100	100	100	100	100	100
<b>Inerts for purging</b>								
	O <sub>2</sub> , H <sub>2</sub> O (ppb)	<1000	<1000	<1000	<1000	<1000	<1000	<1000
	He, H <sub>2</sub> cylinder carrier/purge gases (N <sub>2</sub> , H <sub>2</sub> O, ppb)	<100	<100	<100	<100	<100	<100	<100

Manufacturable solutions exist, and are being optimized  
 Manufacturable solutions are known  
 Interim solutions are known  
 Manufacturable solutions are NOT known



Notes for Tables 115a and b:ADDED	CR/AMC	UPW	BG/SG	PC/CVD
1 Critical particle size is based on 1/2 design rule. All defect densities are "normalized" to critical particle size. Critical particle size does not necessarily mean "killer" particles. Because of instrumentation limitations, particle densities at the critical dimension for nodes < 90 nm will need to be estimated from measured densities of larger particles and an assumed particle size distribution or determined empirically and extrapolated. The particle size distribution will depend on the fluid (e.g. water, clean room air, gases), f(x)=K*1/X^n (where n=2.2 for air/gases, n varies significantly for liquids from 1 to 4, empirical determination is recommended) [2,3]	o		o	o
2 Airborne particle requirements are based on ISO 14644-1 at "at rest".[4]	o			
3 Ion/species indicated is basis for calculation. Exposure time is 60 minutes with starting surface concentration of zero. Basis for lithography projections is defined by lithography tool suppliers. Mmetals and organics scale as defined in the surface preparation roadmap for metallics and organics. Values listed in table are based on experience, however, all airborne molecular contaminants can be calculated as S=E*(N*V/4); where S is the arrival rate (molecules/second/cm <sup>2</sup> ), E is the sticking coefficient (between 0 and 1), N is the concentration in air (molecules/cm <sup>3</sup> ); and V is the average thermal velocity (cm/second). The following sticking coefficients have been proposed; SO <sub>4</sub> = 1x10 <sup>-5</sup> , NH <sub>3</sub> = 1x10 <sup>-6</sup> , Cu = 2x10 <sup>-5</sup> . The sticking coefficients for organics vary greatly with molecular structure and are also dependent on surface termination.	o			
4 Includes P, B, As, Sb	o			
5 Contaminant targets apply up to POE (point-of-entry). POE is defined as the entry point to the equipment or subequipment, see also the text. Benchmark data has been collected both at Point of Delivery (POD) or Point of Entry (POE), which typically show only minor differences.	o	o	o	o

Notes for Tables 115a and b: <b>ADDED</b>	CR/AMC	UPW	BG/SG	PC/CVD
6 Critical metals and ions may include: Al, As, Ba, Ca, Co, Cu, Cr, Fe, K, Li, Mg, Mn, Na, Ni, Pb, Sn, Ti, Zn. Three different case studies were reviewed where the levels of Ca, Fe, and Ni in the UPW resulted in levels of problem densities (atoms/sq cm) on the wafer. These were reduced to acceptable levels by reducing the level of these elements in the UPW to levels well below 10 ppt. In only one case does the data exist that showed success by obtaining values below 0.5 ppt. These results drive the 1.0 ~ 0.5 ppt values.		o		
7 Units on all contaminants in WECC Table are often given as ppb (or ppm or ppt, we use ppb here solely for demonstration purposes). The reader should be aware that these units of parts per billion (ppb) may be ppb by mass, volume, or molar ratios. Where not designated, the following guidelines apply: Chemicals and UPW are typically ppb by mass, gases and clean room are typically ppb by volume. In the case of the fluid acting as an ideal gas, ppb by volume is equal to ppb molar. The notable exception to the above is metals in gases that are ppb by mass. Some parameters in the tables may be considered process variables rather than contaminants in the classical meaning. They are marked by an asterisk. The limits are sometimes fluent.	o	o	o	o
8 Detection of metals at the levels indicated will be dependent on sampling time and flow rate. Sticking Coefficients vary widely for metals. It is generally believed that Cu has a sticking coefficient 10x of other metals, and therefore the guideline for Cu could be lower.				o
9 Key particle size for scratching particles depends on mean particle size of slurry. Target level will be specific to slurry and wafer geometry sensitivity.				o
10 The Dissolved Nitrogen range is solely for the physical process needs of megasonics cleaning. Processes without megasonics cleaning can ignore the line item. The concentration is process specific and needs to be determined by the end user. Factors to consider include UPW temperature, partial pressure in the gas phase and megasonic energy input at the tool. Other gases, such as oxygen and hydrogen, may be used with different optimum levels. Process enhancements through chemistry associated with the other gases or other chemicals are outside of the scope of this chapter.		o		
11 As of the current year's update the finest sensitivity liquid particle sensor for chemicals is 0.065 $\mu\text{m}$ . Values obtained by these particle counters are not directly comparable to the roadmap values and need to be normalized to critical particle size values in the roadmap using the equation and methods of Footnote A above. Interim solution to higher sensitivity particle counter is to collect data over longer time period to provide greater precision in the data near the threshold sensitivity of the counter.				o
Most benchmark data has been collected at Point of Delivery (POD) or Point of Entry (POE) and is the basis for parameters in Table 115.	o	o	o	o
12 SMC Organics: Single wafer shall be oxidized to make organic-free, then wafer shall be exposed for 24 hours and top side analyzed by TD-GC-MS with 400°C thermal desorption, and quantitation based on hexadecane external standard. TIC response factor per SEMI MF 1982-1103 (formerly ASTM 1982-99).[1] Limits determined by above method are a guideline for many organics. Note higher limits can be used for process wafers oxidized or cleaned prior to subsequent process step. Processes such as gate oxide formation, or polysilicon deposition, may be more sensitive to organics, especially high boilers such as DOP. Silicon nitride nucleation may also be more sensitive than above for some processes. Please note dopants requirement is covered in earlier section. Contamination levels are time based, and samples should be exposed for a weeks time for better sensitivity; ng/cm <sup>2</sup> /week. Total contamination level on reticles that cause problems also vary with energy exposure. These guidelines subject to change with new data currently being generated.	o			
13 SMC Dopants: Single wafer is first stripped with HF to yield dopant-free surface and then exposed for 24 hours. Topside of wafer is analyzed by methods known to give reliable recovery of boron. This is a guideline for dopants based on sampling in operating running fabs. Lower specifications may be required for key FEPs, especially for smaller geometries, lower thermal budgets, and for lightly-doped devices. If wafers are stripped with HF or BOE immediately prior to next thermal process, then steps may become less sensitive to surface molecular dopants, and higher limits apply. Note that BEPs tend to be orders of magnitude less sensitive to dopants than FEPs.				

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	<i>Notes for Tables 115a and b:ADDED</i>	CR/AMC	UPW	BG/SG	PC/CVD
14	<i>SMC Metals: Single wafer known to meet the ITRS FEP spec of 1E10 atoms/cm<sup>2</sup>, from the Starting Materials table, is exposed to a clean environment for 24 hours. Subsequent analysis of top surface by VPD-ICP-MS or VPD-GFAA. Lower specifications may be required for key FEPs, especially for smaller geometries. If wafers are cleaned prior to the next thermal process, then air exposure during earlier steps may be less of an issue. Note that majority of environmental metallic contaminants are particles, not molecular. If total particles on wafers are kept in spec than majority of metals, most metals from the environment should be within specifications. Back-end processes (BEPs) tend to be less sensitive to metals that FEPs provided not particles. Specs of twice the incoming wafer specs are readily achievable and readily measurable in case of wafers exposed for 24 hours.</i>				
15	<i>SMC General: A 24-hour exposure will accentuate the contamination per wafer as wafers are often exposed too much shorter times in actual processing. The above SMC (surface molecular contamination) limits are preliminary, and no single value applies to all process steps or types of organics, dopants or metals. The SMC limits can vary substantially from process to process, and local air purification or purges may be needed to control contaminant levels.</i>				
16	<i>Dissolved oxygen (DO) has an effect on pre-gate oxide cleaning and the etch rate of non H-passivated SiO<sub>2</sub> and copper structures. The level in the Table is that of the most stringent. It is expected that slightly higher levels within the same order of magnitude would not have any significant effect on manufacturing processes. If the water for a specific processes need to remain at low oxygen concentrations lower levels of dissolved oxygen could provide somewhat larger process time windows before critical concentration levels are reached. It is known that some fabs consider DO a process variable and operate at DO levels 3 orders of magnitude higher than stated in the Table. Corrosion rates as a function of DO are not a linear relationship for all materials, specifically copper etch rates are near a maximum at 300 ppb DO.</i>		o		
17	<i>Uncertain at this time what target levels might be set given the variety of chemistries used in the industry and unknown sensitivity of the wafer to particles or ionic contamination in the chemical. This parameter is identified as a potentially critical one that should be considered and work is ongoing to define the correct levels.</i>				o
18	<i>Total Silica in UPW is a source of wafer water spots. Silica dissolved from the wafer surface, and later deposited back, is also a significant source for water spotting. The values in the Table are based on concentrations found in typical fabricators manufacturing 90nm geometry devices. As device geometries shrink lower silica concentration requirements are expected. Research is needed to develop a clear correlation between UPW concentrations and water spots. Boron and Reactive Silica have been removed from the Table as UPW operational parameters, values of 50ppt and 300ppt respectively. These two species remain valuable indicators of ion exchange resin removal capacity as they are the first two anions to leak from a mixed bed. They have been removed from the Table as they are not process critical at typical UPW system concentrations.</i>		o		
19	<i>The list of critical metals (e.g., Al, Ca, Cu, Fe, Mg, Ni, K, Si, Na) varies from process to process depending on the impact on electrical parameters such as gate oxide integrity or minority carrier lifetime as well as mobility of the metal in the substrate. The metals listed in note [G] for liquid process chemicals are of concern but the issues around metals in specialty gases are primarily around the potential for corrosion to add metal particles to the gas flow (e.g., Fe, Ni Co, P). The potential for volatile species containing metals must be considered for each specialty gas but are generally not present in the bulk gases.</i>			o	
20	<i>The following is a complete list of metal ions of concern in certain liquid chemicals: Ag, Al, As, Au, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Pd, Pt, Ru, Sb, Sn, Sr, Ti, V, W, Zn.</i>				o
21	<i>Elements listed that are not in parentheses may cause high or some risk to device quality and may often be present in process chemicals. Elements listed that are in parentheses may cause high risk to device quality but are not typically present in process chemicals.</i>				o

Notes for Tables 115a and b: <b>ADDED</b>	CR/AMC	UPW	BG/SG	PC/CVD
22 <i>Immersion photolithography tool manufacturers have asked for TOC levels ranging from less than 0.5 to less than 1.0 ppb in UPW. Some manufacturers are supplying ancillary UPW processing equipment to achieve these targets. The concern is hazing of tool lenses. At this time no data has been presented to support the source of haze generating organics to be the UPW. Other sources of organics are the photoresists and topping chemistries. This temperature stability requirement is for immersion photolithography tools, using UPW as an immersion fluid, and based upon utility requirements projected by some tool manufacturers in 2005. It represents the maximum rate of change of the temperature of the cold UPW supplied to the tool in order for the tool to maintain process required temperature stability.</i>		o		
23 <i>The photolithography AMC guidelines are for tools with ArF lasers only, and are based on inputs from the photolithography tool supplier. All photolithography tools should have chemical filters on the makeup air to the internals of the tools. These filters have a finite lifetime, which is dependent on the contaminant loading. Providing a chemically cleaner environment will extend the life of these filters.</i>	o			
24 <i>Other critical ions may include inorganic ions such as Fluoride, Chloride, Nitrate, Nitrite, Phosphate, Bromide, Sulfate as well as ammonium. However no reference was currently found that these ions in typical concentrations found in ultrapure water up to 50 ppt have any impact on the process. Also for organic anions such as acetate, formate, propionate, citrate, and oxalate no harmful levels have been established up to now.</i>		o		
25 <i>The variety of CVD and ALD precursors is continuously increasing as well as their applications. The contaminant types and levels vary widely due to the different chemical behavior. An overview about typical precursors is therefore given in attachment Precursor table.</i>				o
26 <i>Particle values for 2006 are based upon 2005 UPW benchmark studies of leading fabs manufacturing/developing 45nm to 130nm products measuring particles with optical lasers and Scanning Electron Microscopy (SEM). The values are dependent on the methods used for measurement. Values are based on the most widely used method of measurement namely, optical laser monitoring from various instrument manufacturers. Current optical laser technology is limited to particles &gt;0.05 um, and incapable of detecting particles at critical size based on 1/2 design rule. Although a correlation between wafer surface counts and UPW particles has not been established a conservative position has been agreed upon which supports the Front End Process ITRS Roadmap for wafer surface counts. It is believed that particle chemical composition plays an increasing role with regard to the contamination effect.</i>		o		
27 <i>It needs to be considered that the total H2O2 anion concentration will impact the life time of the solution. Also the fluoride in the ppm range of the total chemical mixture can etch the wafer.</i>				o
28 <i>Concentrations higher than 100 ppb could cause corrosion especially in back end of line processes.</i>				o
29 <i>The ultrapure water parameters provided in this table are applicable for the most critical process unless otherwise identified by additional footnotes.</i>		o		
30 <i>Typical Organic Acids found in cleanroom environments that may be of concern include Acetate, Citrate, Formate, Glycolate, Lactate, Oxalate, and Propionate. Others may also be of concern. These acids can be a significant load on acid removal filters.</i>	o			
31 <i>Ideally, continuous monitoring using online instrumentation would be preferred when practical since this can give both long term averages and catch excursions. When online monitoring is not available, an average grab sample for at least 4 hours, and not more than 24 hours is recommended, to get an average, increase sensitivity of the analysis, and avoid short term transient effects</i>	o			
32 <i>Other corrosive species include contaminants such as chlorine. Humidity is also of major concern, as it exacerbates corrosion. The humidity should be kept as low as possible in corrosive environments.</i>	o			
33 <i>Calculations for expressing ng/L into ppt are: [(ng/(L of Air)) * (22.4 L of Air)/mol Air / MW(ng/nmol)) * *1000picomol/nmol] = picomol/mol of Air = ppt molar and/or ppt volume.</i>	o			

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### ADDED References for Table 115a&b Notes

- 1) SEMI MF1982-1103 (previously ASTM F 1982-99e1), „Standard Test Methods for Analyzing Organic Contaminants on Silicon Wafer Surfaces by Thermal Desorption Gas Chromatography, „SEMI.
- 2) Cooper, D. W., “Comparing Three Environmental Particle Size Distributions,” *Journal of the IES*, Jan/Feb 1001, 21-24
- 3) Pui, D. Y. H. and Liu, B.Y.H., “Advances in Instrumentation for Atmospheric Aerosol Measurement,” *TSI Journal of Particle Instrumentation*, Vol 4. (2) Jul-Dec 1989, 3-2.
- 4) ISO 14644-1 *Cleanrooms and Associated Controlled Environments-Part 1: Classification of Air Cleanliness.*