INTERNATIONAL
TECHNOLOGY ROADMAP
FOR
SEMICONDUCTORS
2006 UPDATE

YIELD ENHANCEMENT

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YIELD ENHANCEMENT

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—i*n 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.

Table 108 Definitions for the Different Interface Points UPDATED

	POS *Delivery Point of Gas/Chemical Supplier*	*POD* *Outlet of Central Facility System*	*POC* *Submain or VMB/VMP Take off Valve*	*POE* *Entry to Equipment or Sub Equipment*	*POU* *Entry to the Process Chamber*	*POP* *Contact with Wafer*
Interfaces	*SEMI Standards Focus Area*	*ITRS Factory Integration Facilities Group Focus Area*		*ITRS Factory Integration Equipment Group Focus Area*		*ITRS Front End Processes, Lithography, Interconnect TWG Focus Area*
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

Difficult Challenges ≥ 32 nm	*Summary of Issues*
Signal-to-noise ratio—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?
High throughput logic diagnosis capability—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
Detection of multiple killer defects—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
High aspect ratio inspection—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 ½× 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
Difficult Challenges < 32 nm	*Summary of Issues*
Process stability versus 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.	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)
Inline defect characterization and analysis—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
Wafer edge and bevel control and inspection—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
Rapid yield learning requires efficient data management and suitable test structures—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
Development of parametric sensitive yield models including new materials—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

	Product	*MPU*	*DRAM*
	Yield Ramp Phase	*Volume Production*	*Volume Production*
	$Y_{OVERALL}$	**75%**	**85%**
	Y_{RANDOM}	**83%**	**89.50%**
	$Y_{SYSTEMATIC}$	**90%**	**95%**
ADD	***Ymaterial***	**>99%**	**>99%**
ADD	***Chip Size***	**140 mm^2**	**88 mm^2**
	Cluster Parameter	**2**	**2**

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^2) [B]	**111**	**88**	**140**	**111**	**88**	**140**	**111**	**88**	**140**
	Overall Electrical D_0 (faults/m^2) at Critical Defect Size Or Greater [C]	**2210**	**2210**	**2210**	**2210**	**2210**	**2210**	**2210**	**2210**	**2210**
WAS	*Random D_0 (faults/m^2) [D]*	**1757**	**2214**	**1395**	**1757**	**2214**	**1395**	**1757**	**2214**	**1395**
IS	*Random D_0 (faults/m^2) [D]*	**1395**	**1395**	**1395**	**1395**	**1395**	**1395**	**1395**	**1395**	**1395**
	Number of Mask Levels [E]	**33**	**33**	**33**	**35**	**35**	**35**	**35**	**35**	**37**
WAS	*Random Faults/Mask*	**53**	**67**	**42**	**50**	**63**	**40**	**50**	**63**	**38**
IS	*Random Faults/Mask*	**42**	**42**	**42**	**40**	**40**	**40**	**40**	**40**	**38**
	MPU Random Particles per Wafer pass (PWP) Budget (defects/m^2) 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^2) [B]	**111**	**88**	**140**	**111**	**88**	**140**	**111**
	Overall Electrical D_0 (faults/m^2) at Critical Defect Size Or Greater [C]	**2210**	**2210**	**2210**	**2210**	**2210**	**2210**	**2210**
WAS	*Random D_0 (faults/m^2) [D]*	**1757**	**2214**	**1395**	**1757**	**2214**	**1395**	**1757**
IS	*Random D_0 (faults/m^2) [D]*	**1395**	**1395**	**1395**	**1395**	**1395**	**1395**	**1395**
	Number of Mask Levels [E]	**37**	**37**	**37**	**39**	**39**	**39**	**39**
WAS	*Random Faults/Mask*	**47**	**60**	**38**	**45**	**57**	**36**	**45**
IS	*Random Faults/Mask*	**38**	**38**	**38**	**36**	**36**	**36**	**36**
	MPU Random Particles per Wafer pass (PWP) Budget (defects/m^2) 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.

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)	**40**	**35**	**32.5**	**28.5**	**25**	**22.5**	**20**	**17.5**	**16**
	Chip Size (mm^2) [B]	**88**	**139**	**110**	**74**	**117**	**93**	**74**	**117**	**93**
	Cell Array Area (%) at Production [B]	**63%**	**63%**	**63%**	**56%**	**56%**	**56%**	**56%**	**56%**	**56%**
	Non-core Area (mm^2)	**32**	**51**	**41**	**32**	**51**	**41**	**32**	**51**	**41**
WAS	*Overall Electrical D_0 (faults/m^2) at critical defect size or greater [C]*	**5220**	**3288**	**4143**	**5219**	**3288**	**4143**	**5219**	**3288**	**4143**
IS	*Overall Electrical D_0 (faults/m^2) at critical defect size or greater [C]*	**5220**	**5220**	**5220**	**4389**	**4389**	**4389**	**4389**	**4389**	**4389**
WAS	*Random D_0 (faults/m^2) [D]*	**3517**	**2216**	**2791**	**3516**	**2215**	**2791**	**3516**	**2215**	**2791**
IS	*Random D_0 (faults/m^2) [D]*	**3517**	**3517**	**3517**	**2957**	**2957**	**2957**	**2957**	**2957**	**2957**
	Number of Mask Levels [E]	**24**	**24**	**24**	**24**	**24**	**26**	**26**	**26**	**26**
WAS	*Random Faults/Mask*	**147**	**92**	**116**	**147**	**92**	**107**	**135**	**85**	**107**
IS	*Random Faults/Mask*	**147**	**147**	**147**	**123**	**123**	**114**	**114**	**114**	**114**
	DRAM Random Particle per Wafer pass (PWP) Budget (defects/m^2) for Generic Tool Type Scaled to -40 nm Critical Defect Size or Greater									
WAS	CMP clean	**1808**	**872**	**872**	**872**	**445**	**419**	**417**	**201**	**201**
IS	CMP clean	**1808**	**1384**	**1194**	**772**	**594**	**444**	**351**	**269**	**225**
WAS	CMP insulator	**1400**	**675**	**675**	**675**	**344**	**324**	**323**	**156**	**156**
IS	CMP insulator	**1400**	**1072**	**924**	**598**	**460**	**344**	**272**	**208**	**174**
WAS	CMP metal	**2145**	**1035**	**1035**	**1035**	**528**	**497**	**495**	**239**	**239**
IS	CMP metal	**2145**	**1642**	**1416**	**916**	**705**	**527**	**416**	**319**	**266**
WAS	Coat/develop/bake	**559**	**270**	**270**	**270**	**138**	**130**	**129**	**62**	**62**
IS	Coat/develop/bake	**559**	**428**	**369**	**239**	**184**	**137**	**108**	**83**	**69**
WAS	CVD insulator	**1552**	**748**	**748**	**748**	**382**	**360**	**358**	**173**	**173**
IS	CVD insulator	**1552**	**1188**	**1025**	**663**	**510**	**381**	**301**	**231**	**193**
WAS	CVD oxide mask	**1905**	**919**	**919**	**919**	**469**	**441**	**439**	**212**	**212**
IS	CVD oxide mask	**1905**	**1459**	**1258**	**813**	**626**	**468**	**370**	**283**	**237**
WAS	Dielectric track	**784**	**378**	**378**	**378**	**193**	**182**	**181**	**87**	**87**
IS	Dielectric track	**784**	**600**	**518**	**335**	**258**	**193**	**152**	**116**	**97**
WAS	Furnace CVD	**1072**	**517**	**517**	**517**	**264**	**248**	**247**	**119**	**119**
IS	Furnace CVD	**1072**	**821**	**708**	**458**	**352**	**263**	**208**	**159**	**133**
WAS	Furnace fast ramp	**1009**	**487**	**487**	**487**	**248**	**234**	**233**	**112**	**112**
IS	Furnace fast ramp	**1009**	**773**	**666**	**431**	**331**	**248**	**196**	**150**	**125**
WAS	Furnace oxide/anneal	**808**	**390**	**390**	**390**	**199**	**187**	**186**	**90**	**90**
IS	Furnace oxide/anneal	**808**	**619**	**533**	**345**	**265**	**198**	**157**	**120**	**100**
WAS	Implant high current	**939**	**453**	**453**	**453**	**231**	**218**	**217**	**105**	**105**
IS	Implant high current	**939**	**719**	**620**	**401**	**308**	**231**	**182**	**140**	**117**
WAS	Implant low/medium current	**895**	**432**	**432**	**432**	**220**	**208**	**207**	**100**	**100**
IS	Implant low/medium current	**895**	**685**	**591**	**382**	**294**	**220**	**174**	**133**	**111**
WAS	Inspect PLY	**1225**	**591**	**591**	**591**	**301**	**284**	**283**	**136**	**136**
IS	Inspect PLY	**1225**	**938**	**809**	**523**	**402**	**301**	**238**	**182**	**152**
WAS	Inspect visual	**1264**	**610**	**610**	**610**	**311**	**293**	**292**	**141**	**141**
IS	Inspect visual	**1264**	**968**	**834**	**540**	**415**	**310**	**245**	**188**	**157**
WAS	Lithography cell	**1048**	**506**	**506**	**506**	**258**	**243**	**242**	**117**	**117**
IS	Lithography cell	**1048**	**802**	**692**	**447**	**344**	**257**	**203**	**156**	**130**
WAS	Lithography stepper	**697**	**336**	**336**	**336**	**171**	**162**	**161**	**78**	**78**
IS	Lithography stepper	**697**	**534**	**460**	**298**	**229**	**171**	**135**	**104**	**87**
WAS	Measure CD	**1047**	**505**	**505**	**505**	**258**	**243**	**242**	**117**	**117**

	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**	**802**	**691**	**447**	**344**	**257**	**203**	**156**	**130**
WAS	Measure film	**984**	**475**	**475**	**475**	**242**	**228**	**227**	**110**	**110**
IS	Measure film	**984**	**753**	**650**	**420**	**323**	**242**	**191**	**146**	**122**
WAS	Measure overlay	**958**	**462**	**462**	**462**	**236**	**222**	**221**	**107**	**107**
IS	Measure overlay	**958**	**733**	**632**	**409**	**315**	**235**	**186**	**142**	**119**
WAS	Metal CVD	**986**	**476**	**476**	**476**	**243**	**229**	**227**	**110**	**110**
IS	Metal CVD	**986**	**755**	**651**	**421**	**324**	**242**	**191**	**146**	**122**
WAS	Metal electroplate	**750**	**362**	**362**	**362**	**185**	**174**	**173**	**83**	**83**
IS	Metal electroplate	**750**	**574**	**495**	**320**	**246**	**184**	**146**	**111**	**93**
WAS	Metal etch	**1816**	**876**	**876**	**876**	**447**	**421**	**419**	**202**	**202**
IS	Metal etch	**1816**	**1390**	**1199**	**775**	**597**	**446**	**352**	**270**	**226**
WAS	Metal PVD	**1083**	**522**	**522**	**522**	**266**	**251**	**250**	**121**	**121**
IS	Metal PVD	**1083**	**829**	**715**	**462**	**356**	**266**	**210**	**161**	**135**
WAS	Plasma etch	**1923**	**928**	**928**	**928**	**473**	**446**	**444**	**214**	**214**
IS	Plasma etch	**1923**	**1472**	**1269**	**821**	**632**	**472**	**373**	**286**	**239**
WAS	Plasma strip	**1475**	**711**	**711**	**711**	**363**	**342**	**340**	**164**	**164**
IS	Plasma strip	**1475**	**1129**	**974**	**630**	**485**	**362**	**286**	**219**	**183**
WAS	RTP CVD	**964**	**465**	**465**	**465**	**237**	**223**	**222**	**107**	**107**
IS	RTP CVD	**964**	**738**	**636**	**412**	**317**	**237**	**187**	**143**	**120**
WAS	RTP oxide/anneal	**706**	**341**	**341**	**341**	**174**	**164**	**163**	**79**	**79**
IS	RTP oxide/anneal	**706**	**541**	**466**	**301**	**232**	**173**	**137**	**105**	**88**
WAS	Test	**138**	**66**	**66**	**66**	**34**	**32**	**32**	**15**	**15**
IS	Test	**138**	**106**	**91**	**59**	**45**	**34**	**27**	**21**	**17**
WAS	Vapor phase clean	**2042**	**985**	**985**	**985**	**502**	**473**	**471**	**227**	**227**
IS	Vapor phase clean	**2042**	**1563**	**1348**	**872**	**671**	**502**	**396**	**303**	**254**
WAS	Wafer handling	**58**	**28**	**28**	**28**	**14**	**13**	**13**	**6**	**6**
IS	Wafer handling	**58**	**44**	**38**	**25**	**19**	**14**	**11**	**9**	**7**
WAS	Wet bench	**1463**	**705**	**705**	**705**	**360**	**339**	**337**	**163**	**163**
IS	Wet bench	**1463**	**1120**	**966**	**625**	**481**	**359**	**284**	**217**	**182**

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^2) [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^2)	**32**	**51**	**41**	**32**	**51**	**41**	**32**
WAS	*Overall Electrical D_0 (faults/m^2) at critical defect size or greater [C]*	**5219**	**3288**	**4143**	**5219**	**3288**	**4143**	**5219**
IS	*Overall Electrical D_0 (faults/m^2) at critical defect size or greater [C]*	**4389**	**4389**	**4389**	**4389**	**4389**	**4389**	**4389**
WAS	*Random D_0 (faults/m^2) [D]*	**3516**	**2215**	**2791**	**3516**	**2215**	**2791**	**3516**
IS	*Random D_0 (faults/m^2) [D]*	**2957**	**2957**	**2957**	**2957**	**2957**	**2957**	**2957**
	Number of Mask Levels [E]	**26**	**26**	**26**	**26**	**26**	**26**	**26**
WAS	*Random Faults/Mask*	**135**	**85**	**107**	**135**	**85**	**107**	**135**
IS	*Random Faults/Mask*	**114**	**114**	**114**	**114**	**114**	**114**	**114**
	DRAM Random Particle per Wafer pass (PWP) Budget (defects/m^2) for Generic Tool Type Scaled to -40 nm Critical Defect Size or Greater							
WAS	CMP clean	**201**	**103**	**100**	**100**	**53**	**53**	**51**
IS	CMP clean	**172**	**137**	**106**	**88**	**71**	**56**	**43**
WAS	CMP insulator	**156**	**79**	**78**	**78**	**41**	**41**	**40**
IS	CMP insulator	**133**	**106**	**82**	**68**	**55**	**43**	**33**
WAS	CMP metal	**239**	**122**	**119**	**119**	**63**	**63**	**61**
IS	CMP metal	**204**	**163**	**126**	**104**	**84**	**67**	**51**
WAS	Coat/develop/bake	**62**	**32**	**31**	**31**	**16**	**16**	**16**
IS	Coat/develop/bake	**53**	**42**	**33**	**27**	**22**	**17**	**13**
WAS	CVD insulator	**173**	**88**	**86**	**86**	**46**	**45**	**44**
IS	CVD insulator	**148**	**118**	**91**	**75**	**61**	**48**	**37**
WAS	CVD oxide mask	**212**	**108**	**106**	**106**	**56**	**56**	**54**
IS	CVD oxide mask	**181**	**144**	**112**	**92**	**75**	**59**	**45**
WAS	Dielectric track	**87**	**45**	**43**	**43**	**23**	**23**	**22**
IS	Dielectric track	**75**	**59**	**46**	**38**	**31**	**24**	**19**
WAS	Furnace CVD	**119**	**61**	**59**	**59**	**32**	**31**	**30**
IS	Furnace CVD	**102**	**81**	**63**	**52**	**42**	**33**	**25**
WAS	Furnace fast ramp	**112**	**57**	**56**	**56**	**30**	**30**	**29**
IS	Furnace fast ramp	**96**	**76**	**59**	**49**	**40**	**31**	**24**
WAS	Furnace oxide/anneal	**90**	**46**	**45**	**45**	**24**	**24**	**23**
IS	Furnace oxide/anneal	**77**	**61**	**47**	**39**	**32**	**25**	**19**
WAS	Implant high current	**105**	**53**	**52**	**52**	**28**	**28**	**27**
IS	Implant high current	**89**	**71**	**55**	**46**	**37**	**29**	**22**
WAS	Implant low/medium current	**100**	**51**	**50**	**50**	**26**	**26**	**25**
IS	Implant low/medium current	**85**	**68**	**53**	**43**	**35**	**28**	**21**
WAS	Inspect PLY	**136**	**70**	**68**	**68**	**36**	**36**	**35**
IS	Inspect PLY	**116**	**93**	**72**	**59**	**48**	**38**	**29**
WAS	Inspect visual	**141**	**72**	**70**	**70**	**37**	**37**	**36**
IS	Inspect visual	**120**	**96**	**74**	**61**	**50**	**39**	**30**
WAS	Lithography cell	**117**	**60**	**58**	**58**	**31**	**31**	**30**
IS	Lithography cell	**100**	**79**	**62**	**51**	**41**	**33**	**25**
WAS	Lithography stepper	**78**	**40**	**39**	**39**	**21**	**20**	**20**
IS	Lithography stepper	**66**	**53**	**41**	**34**	**27**	**22**	**17**
WAS	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*
IS	Measure CD	**100**	**79**	**61**	**51**	**41**	**33**	**25**
WAS	Measure film	**110**	**56**	**55**	**55**	**29**	**29**	**28**
IS	Measure film	**94**	**75**	**58**	**48**	**39**	**31**	**23**
WAS	Measure overlay	**107**	**54**	**53**	**53**	**28**	**28**	**27**
IS	Measure overlay	**91**	**73**	**56**	**46**	**38**	**30**	**23**
WAS	Metal CVD	**110**	**56**	**55**	**55**	**29**	**29**	**28**
IS	Metal CVD	**94**	**75**	**58**	**48**	**39**	**31**	**23**
WAS	Metal electroplate	**83**	**43**	**42**	**42**	**22**	**22**	**21**
IS	Metal electroplate	**71**	**57**	**44**	**36**	**29**	**23**	**18**
WAS	Metal etch	**202**	**103**	**101**	**101**	**53**	**53**	**51**
IS	Metal etch	**173**	**138**	**107**	**88**	**71**	**56**	**43**
WAS	Metal PVD	**121**	**61**	**60**	**60**	**32**	**32**	**31**
IS	Metal PVD	**103**	**82**	**64**	**53**	**43**	**34**	**26**
WAS	Plasma etch	**214**	**109**	**107**	**107**	**57**	**56**	**54**
IS	Plasma etch	**183**	**146**	**113**	**93**	**76**	**60**	**46**
WAS	Plasma strip	**164**	**84**	**82**	**82**	**43**	**43**	**42**
IS	Plasma strip	**140**	**112**	**87**	**72**	**58**	**46**	**35**
WAS	RTP CVD	**107**	**55**	**53**	**53**	**28**	**28**	**27**
IS	RTP CVD	**92**	**73**	**57**	**47**	**38**	**30**	**23**
WAS	RTP oxide/anneal	**79**	**40**	**39**	**39**	**21**	**21**	**20**
IS	RTP oxide/anneal	**67**	**54**	**41**	**34**	**28**	**22**	**17**
WAS	Test	**15**	**8**	**8**	**8**	**4**	**4**	**4**
IS	Test	**13**	**10**	**8**	**7**	**5**	**4**	**3**
WAS	Vapor phase clean	**227**	**116**	**113**	**113**	**60**	**60**	**58**
IS	Vapor phase clean	**194**	**155**	**120**	**99**	**80**	**63**	**49**
WAS	Wafer handling	**6**	**3**	**3**	**3**	**2**	**2**	**2**
IS	Wafer handling	**6**	**4**	**3**	**3**	**2**	**2**	**1**
WAS	Wet bench	**163**	**83**	**81**	**81**	**43**	**43**	**41**
IS	Wet bench	**139**	**111**	**86**	**71**	**57**	**45**	**35**

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.

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*	
	*Patterned Wafer Inspection, PSL Spheres * at 90% Capture, Equivalent Sensitivity (nm) [A, B]*										
WAS	Process R&D at 300 cm^2/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^2/hr (0,4 "300 mm wafer"/hr)	**40**	**35**	**32.5**	**28.5**	**25**	**22.5**	**20**	**17.5**	**16**	*0.5 × DR*
ADD	**Process R&D at 300 cm2/hr with 50 % Capture rate**	**-**	**21**	**19.5**	**17.1**	**15**	**13.5**	**12**	**10.5**	**9.6**	*0.3 x DR*
WAS	Yield ramp at 1200 cm^2/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^2/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^2/hr (10 "200 mm wafer"/hr)	**◆ 80**	**70**	**65**	**57**	**50**	**45**	**40**	**35**	**32**	*1.0 × DR*
IS	Volume production at 3000 cm^2/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	**Defect coordinate precision [µm] note**	**-**	**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 ($/cm^2)	**0.078**	**0.078**	**0.078**	**0.078**	**0.078**	**0.078**	**0.08**	**0.078**	**0.078**	
	*High Aspect Ratio Feature Inspection: Defects other than Residue, Equivalent Sensitivity in PSL Diameter (nm) at 90% Capture Rate *[D, E]*										
	Sensitivity without speed requirement	**80**	**70**	**65**	**57**	**50**	**45**	**40**	**35**	**32**	*1.0 × DR*
WAS	Process verification at 300 cm^2/hr (1 "200 mm wafer"/hr)	**◆ 80**	**70**	**65**	**57**	**50**	**45**	**40**	**35**	**32**	*1.0 × DR*
IS	Process verification at 300 cm^2/hr (0,4 "300 mm wafer"/hr)	**◆ 80**	**◆70**	**65**	**57**	**50**	**45**	**40**	**35**	**32**	*1.0 × DR*
ADD	**Process verification at 300 cm2/hr at 50% capture rate**	**-**	**42**	**39**	**34.2**	**30**	**27**	**24**	**21**	**19.2**	*0.6 x DR*
WAS	Volume manufacturing at 1200 cm^2/hr (4 "200 mm wafer"/hr)	**◆ 80**	**70**	**65**	**57**	**50**	**45**	**40**	**35**	**32**	*1.0 × DR*
IS	Volume manufacturing at 1200 cm^2/hr (1,7 "300 mm wafer"/hr)	**◆ 80**	**◆70**	**65**	**57**	**50**	**45**	**40**	**35**	**32**	*1.0 × DR*
	CoO HARI ($/cm^2)	**0.388**	**0.388**	**0.388**	**0.388**	**0.388**	**0.388**	**0.388**	**0.388**	**0.388**	
	Unpatterned, PSL Spheres at 90% Capture, Equivalent Sensitivity (nm) [F, G]										
WAS	Metal film	**64**	**56**	**52**	**45.6**	**40.0**	**36.0**	**32.0**	**28.0**	**25.6**	*0.8 x DR*
IS	Poly Si and metal films	**64**	**84**	**78**	**68.4**	**60**	**54**	**48**	**42**	**38.4**	*1,2 x DR*
WAS	Bare silicon and non-metal film	**40**	**35**	**32.5**	**28.5**	**25**	**22.5**	**20**	**17.5**	**16**	*0,5 x 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*	
	*Patterned Wafer Inspection, PSL Spheres * at 90% Capture, Equivalent Sensitivity (nm) [A, B]*										
IS	Bare silicon ~~and non-metal film~~	**40**	**35**	**32.5**	**28.5**	**25**	**22.5**	**20**	**17.5**	**16**	*0,5 x DR*
ADD	**Other smooth film**	**-**	**56**	**52**	**45.6**	**40**	**36**	**32**	**28**	**25.6**	*0,8 x DR*
ADD	**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^2)	**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**	
	Defect Review (Patterned Wafer)										
	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*
WAS	Speed at ADR without ADC	**960**	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**	
IS	Speed at ADR wo ADC **(defects/hrs)**	**960**	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**	
	*Automatic Defect Classification at Defect Review Platform * [K]*										
WAS	Redetection: minimum defect size (nm)	**32**	**28**	**26**	**22.8**	**20**	**18**	**16**	**14**	**12.8**	*0.4 × DR*
IS	Redetection: minimum defect size (nm)	**32**	**28**	**26**	**22.8**	**20**	**18**	**16**	**14**	**12.8**	*0.4 × DR*
WAS	Number of defect types [L]	**◆10**	**10**	**10**	**15**	**15**	**15**	**15**	**15**	**20**	
IS	Number of defect types [L]	**◆10**	**◆10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	
WAS	Speed (defects/hours) w ADC	**◆720**	**720**	**720**	**720**	**720**	**720**	**720**	**720**	**720**	
IS	Speed (defects/hours) w ADC	**◆720**	**720**	**720**	**720**	**720**	**720**	**720**	**720**	**720**	
WAS	Speed w/elemental (defects/hours)	**◆360**	**360**	**360**	**360**	**360**	**360**	**360**	**360**	**360**	
IS	Speed w/elemental (defects/hours)	**◆360**	**◆360**	**360**	**360**	**360**	**360**	**360**	**360**	**360**	
WAS	Number of defect types (inline ADC) [M]	**◆10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	
IS	Number of defect types (inline ADC) [M]	**◆10**	**◆10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	
	Wafer inspection on multilayer product wafer of top and bottom bevel, APEX and 3 mm wafer edge exclusion *PSL spheres at 90% capture rate, Equivalent sensitivity (nm) [N, O]*										
WAS	Sensitivity [nm] without speed requirement at 50% capture rate	**◆400**	**350**	**325**	**285**	**250**	**225**	**200**	**175**	**160**	*5 × DR*
IS	Sensitivity [nm] without speed requirement at 50% capture rate	**◆400**	**◆350**	**325**	**285**	**250**	**225**	**200**	**175**	**160**	*5 × DR*
WAS	Sensitivity [nm] at 100 wafer/hrs	**◆2000**	**1750**	**1625**	**1425**	**1250**	**1125**	**1000**	**875**	**800**	*25 × DR*
IS	Sensitivity [nm] at 100 wafer/hrs	**◆2000**	**◆1750**	**1625**	**1425**	**1250**	**1125**	**1000**	**875**	**800**	*25 × DR*
	Defect classes, ADC [P]	**3**	**5**	**5**	**5**	**10**	**10**	**10**	**10**	**10**	
WAS	Tool matching (% variation tool-to-tool)	**◆10 %**	**10%**	**10%**	**10%**	**5%**	**5%**	**5%**	**5%**	**5%**	
IS	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*

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*	
	*Patterned Wafer Inspection, PSL Spheres * at 90% Capture, Equivalent Sensitivity (nm) [A, B]*								
WAS	Process R&D at 300 cm^2/hr (1 “200 mm wafer”/hr)	**14**	**12.5**	**11**	**10**	**9**	**8**	**7**	*0.5 × DR*
IS	Process R&D at 300 cm^2/hr (0,4 “300 mm wafer”/hr)	**14**	**12.5**	**11**	**10**	**9**	**8**	**7**	*0.5 × DR*
ADD	**Process R&D at 300 cm2/hr with 50 % Capture rate**	**8.4**	**7.5**	**6.6**	**6**	**5.4**	**4.8**	**4.2**	*0.3 x DR*
WAS	Yield ramp at 1200 cm^2/hr (4 “200 mm wafer”/hr)	**22.4**	**20**	**17.6**	**16**	**14.4**	**12.8**	**11**	*0.8 × DR*
IS	Yield ramp at 1200 cm^2/hr (1,7 “300 mm wafer”/hr)	**22.4**	**20**	**17.6**	**16**	**14.4**	**12.8**	**11**	*0.8 × DR*
WAS	Volume production at 3000 cm^2/hr (10 “200 mm wafer”/hr)	**28**	**25**	**22**	**20**	**18**	**16**	**14**	*1.0 × DR*
IS	Volume production at 3000 cm^2/hr (4,3 “300 mm wafer”/hr)	**28**	**25**	**22**	**20**	**18**	**16**	**14**	*1.0 × DR*
WAS	Tool matching (% variation tool to tool) [C]	**2**	**2**	**2**	**2**	**2**	**2**	**2**	
IS	Tool matching (% variation tool to tool) [C]	**5**	**5**	**5**	**5**	**5**	**5**	**5**	
ADD	**Defect coordinate precision [µm] note**	**0.98**	**0.875**	**0.77**	**0.7**	**0.63**	**0.56**	**0.49**	*35x DR*
	Wafer edge exclusion (mm)	**2**	**2**	**2**	**2**	**2**	**2**	**2**	
	Cost of ownership ($/$cm^2$)	**0.078**	**0.078**	**0.078**	**0.078**	**0.078**	**0.078**	**0.078**	
	*High Aspect Ratio Feature Inspection: Defects other than Residue, Equivalent Sensitivity in PSL Diameter (nm) at 90% Capture Rate *[D, E]*								
	Sensitivity without speed requirement	**28**	**25**	**22**	**20**	**18**	**16**	**14**	*1.0 × DR*
WAS	Process verification at 300 cm^2/hr (1 “200 mm wafer”/hr)	**28**	**25**	**22**	**20**	**18**	**16**	**14**	*1.0 × DR*
IS	Process verification at 300 cm^2/hr (0,4 “300 mm wafer”/hr)	**28**	**25**	**22**	**20**	**18**	**16**	**14**	*1.0 × DR*
ADD	**Process verification at 300 cm2/hr at 50% capture rate**	**16.8**	**15**	**13.2**	**12**	**10.8**	**9.6**	**8.4**	*0.6 x DR*
WAS	Volume manufacturing at 1200 cm^2/hr (4 “200 mm wafer”/hr)	**28**	**25**	**22**	**20**	**18**	**16**	**14**	*1.0 × DR*
IS	Volume manufacturing at 1200 cm^2/hr (1,7 “300 mm wafer”/hr)	**28**	**25**	**22**	**20**	**18**	**16**	**14**	*1.0 × DR*
	CoO HARI ($/$cm^2$)	**0.388**	**0.388**	**0.388**	**0.388**	**0.388**	**0.388**	**0.388**	
	Unpatterned, PSL Spheres at 90% Capture, Equivalent Sensitivity (nm) [F, G]								
WAS	Metal film	**22.4**	**20.0**	**17.6**	**16.0**	**14.4**	**12.8**	**11.0**	*0.8 x DR*
IS	Poly Si and metal films	**33.6**	**30**	**26.4**	**24**	**21.6**	**19.2**	**16.8**	*1,2 x DR*
WAS	Bare silicon and non-metal film	**14**	**12.5**	**11**	**10**	**9**	**8**	**7**	*0,5 x DR*
IS	Bare silicon ~~and non-metal film~~	**14**	**12.5**	**11**	**10**	**9**	**8**	**7**	*0,5 x DR*
ADD	**Other smooth film**	**22.4**	**20**	**17.6**	**16**	**14.4**	**12.8**	**11.2**	*0,8 x DR*
ADD	**Throughput at sensitivity for all layers [wfr/hrs]**	**100**	**100**	**110**	**110**	**120**	**120**	**130**	-
	Wafer backside (defect size, nm) [H]	**140**	**125**	**110**	**100**	**90**	**80**	**70**	*5.0 x DR*

	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*	
	CoO ($/cm^2)	**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**	
	Defect Review (Patterned Wafer)								
	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*
WAS	Speed at ADR without ADC	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**	
IS	Speed at ADR wo ADC **(defects/hrs)**	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**	
	*Automatic Defect Classification at Defect Review Platform * [K]*								
WAS	Redetection: minimum defect size (nm)	**11.2**	**10**	**8.8**	**8**	**7.2**	**6.4**	**5.6**	*0.4 × DR*
IS	Redetection: minimum defect size (nm)	**11.2**	**10**	**8.8**	**8**	**7.2**	**6.4**	**5.6**	*0.4 × DR*
WAS	Number of defect types [L]	**20**	**20**	**25**	**25**	**25**	**25**	**25**	
IS	Number of defect types [L]	**10**	**10**	**10**	**10**	**10**	**10**	**10**	
WAS	Speed (defects/hours) w ADC	**720**	**720**	**720**	**720**	**720**	**720**	**720**	
IS	Speed (defects/hours) w ADC	**720**	**720**	**720**	**720**	**720**	**720**	**720**	
WAS	Speed w/elemental (defects/hours)	**360**	**360**	**360**	**360**	**360**	**360**	**360**	
IS	Speed w/elemental (defects/hours)	**360**	**360**	**360**	**360**	**360**	**360**	**360**	
WAS	Number of defect types (inline ADC) [M]	**10**	**10**	**10**	**10**	**10**	**10**	**10**	
IS	Number of defect types (inline ADC) [M]	**10**	**10**	**10**	**10**	**10**	**10**	**10**	
	Wafer inspection on multilayer product wafer of top and bottom bevel, APEX and 3 mm wafer edge exclusion								
	PSL spheres at 90% capture rate, Equivalent sensitivity (nm) [N, O]								
	Sensitivity [nm] without speed requirement at 50% capture rate	**140**	**125**	**110**	**100**	**90**	**80**	**70**	*5 × DR*
	Sensitivity [nm] at 100 wafer/hrs	**700**	**625**	**550**	**500**	**450**	**400**	**350**	*25 × 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	🟥

Notes for Tables 113a and b:

[A] Patterned wafer scan speed is required to be at least 300 cm^2 /hour for process R&D mode, 1,200 cm^2 /hour for yield ramp mode, and, at least, 3,000 cm^2 /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 cm^2 /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 Ration 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× 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× 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 × 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**
Process R&D at 300 mm wafer/hr, sampling rate at 100% [A]									
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**
Yield ramp from 30% to 70% at 300 mm wafer/hr, sampling rate at 50% [A]									
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**
Yield ramp from 70% to base line (85%) at 300 mm wafer/hr, sampling rate at 20% [A]									
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	🟥

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**
Process R&D at 300 mm wafer/hr, sampling rate at 100% [A]							
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**
Yield ramp from 30% to 70% at 300 mm wafer/hr, sampling rate at 50% [A]							
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**
Yield ramp from 70% to base line (85%) at 300 mm wafer/hr, sampling rate at 20% [A]							
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*
	Wafer Environment Control such as Cleanroom, SMIF POD, FOUP, etc….not necessarily the cleanroom itself but wafer environment.									
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^3) [A] [B]	**ISO CL 2**	**ISO CL 2**	**ISO CL 2**	**ISO CL 2**	**ISO CL 2**	**ISO CL1**	**ISO CL1**	**ISO CL1**	**ISO CL1**
IS	Number of particles (/m^3) [1] [2]	**ISO CL 2**	**ISO CL 2**	**ISO CL 2**	**ISO CL 2**	**ISO CL 2**	**ISO CL1**	**ISO CL1**	**ISO CL1**	**ISO CL1**
WAS	***Airborne Molecular Contaminants in Gas Phase (pptM)) [C] [G] [M]***									
IS	***Airborne Molecular Contaminants in Gas Phase (pptM)) [3, 7, 12,13,14,15,33]***	-	-	-	-	-	-	-	-	-
WAS	Lithography (cleanroom ambient) [V]									
IS	Lithography (cleanroom ambient) [23]	-	-	-	-	-	-	-	-	-
WAS	Total acids (as SO_4) 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_3)	**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/cm2/day [12]	**-**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
WAS	***Gate wafer environment (cleanroom/POD/FOUP ambient)***									
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^2/week [M]*	**2**	**2**	**2**	**2**	**2**	**0.5**	**0.5**	**0.5**	**0.5**
IS	SMC (surface molecular condensable) organics on wafers, ng/cm2/day [12]	**2**	**2**	**2**	**2**	**2**	**0.5**	**0.5**	**0.5**	**0.5**
	Salicidation Wafer Environment (Cleanroom/POD/FOUP ambient)									
WAS	Total acids (as SO_4) 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**
	Exposed Copper Wafer Environment (Cleanroom/POD/FOUP ambient)									
WAS	Total acids (as SO_4) 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**
	Exposed Aluminum Wafer Environment (Cleanroom/POD/FOUP ambient)									
WAS	Total acids (as SO_4) 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_2)	**1000**	**1000**	**1000**	**1000**	**1000**	**500**	**500**	**500**	**500**
IS	Total other corrosive species [32]	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**
	Reticle Exposure (Cleanroom/POD/Box ambient)									
WAS	Total acids (as SO_4) 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**

	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	Total bases (as NH_3)	**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/cm2/week [12]	**-**	**2**	**2**	**2**	**2**	**0.5**	**0.5**	**0.5**	**0.5**
	General Wafer Environment (Cleanroom/POD/FOUP ambient, all areas unless specified below)									
WAS	Total acids (as SO_4) 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_3)	**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^2/day [M]*	**2**	**2**	**2**	**2**	**2**	**0.5**	**0.5**	**0.5**	**0.5**
IS	SMC (surface molecular condensable) organics on wafers, ng/cm2/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_2 [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/cm2 [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_2 [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/cm2 [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 (MOhm-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_2 [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_2 [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 >0.065um [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**

	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*
IS	37% HCl: number of particles/ml >0.065um [1] [11]	**<10**	**<10**	**<10**	**<10**	**<10**	**<10**	**<10**	**<10**	**<10**
WAS	30% H_2O_2: number of particles > critical size (/ml) [A] [K]	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
IS	30% H2O2: number of particles/ml >0.065um [1] [11]	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
WAS	29% NH_4OH: number of particles > critical size (/ml) [A] [K]	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
IS	29% NH4OH: 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_2O_2: 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_2O_2: 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% H2O2: SiO2 (ppt) [27]	**-**	**5000**	**5000**	**5000**	**5000**	**5000**	**5000**	**5000**	**5000**
WAS	30% H_2O_2: Br, F (ppt, each)	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**
IS	~~30% H_2O_2: Br, F (ppt, each)~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~
WAS	29% NH_4OH: 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% NH4OH: 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_4 (ppt, each)	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**
IS	~~100% IPA: NH_4 (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_2O_2: All other metals not listed in row above (ppt, each) [R]	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**
IS	30% H2O2: All other metals not listed in row above (ppt, each) [21]	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**
WAS	29% NH_4OH: all other metals not listed in row above (ppt, each) [R]	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**
IS	29% NH4OH: 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**~~

	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% NH_4OH: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	~~29% NH4OH: total oxidizable carbon (ppb)~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~
WAS	37% HCl: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	~~37% HCl: total oxidizable carbon (ppb)~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~	~~TBD~~
	30% H_2O_2: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	100% IPA – Specific organic acids: formate, acetate, citrate, proprionate, 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%H_2O_2: 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% H_2SO_4: 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% H_2SO_4: 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) [I] [O]	TBD	TBD	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	TBD	TBD
WAS	Post-CMP clean chemicals: particles>critical size (/ml) [A] [K] [O]	TBD	TBD	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	TBD	TBD
WAS	Post-CMP clean chemicals: elements TBD (ppt, each) [O]	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IS	Post-CMP clean chemicals: elements TBD (ppt, each) [17]	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	Plating chemicals: particles > critical size (/ml) [1] [9] [17]	TBD	TBD	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	<1	<1
Is	Metals except B, Au, Ag (ppb, each)	-	<5	<5	<5	<5	<5	<5	<5	<5
ADD	B, Au, Ag (ppb, each)	-	<10	<10	<10	<10	<10	<10	<10	<10
Was	H_2O and Other Oxygen Containing Impurities (ppmV)	<10	<10	<5	<5	<5	<5	<5	<5	<5
IS	H2O (ppm)	-	<1	<1	<1	<1	<1	<1	<1	<1
ADD	CO, CO2 (ppm)	-	< 0.5	< 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	< 4
ADD	Nitrogen (ppm)	-	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
ADD	Ar+O2 (ppm)	-	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
ADD	Chloride (ppm)	-	<1	<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	<150
ADD	O2 (ppm)	-	<10	<10	<10	<10	<10	<10	<10	<10
ADD	Silicon (ppm)	-	<1	<1	<1	<1	<1	<1	<1	<1
ADD	Hydrocarbons (ppm)	-	<5	<5	<5	<5	<5	<5	<5	<5
	Bulk Gases (Contaminants, ppbv)									
	N_2 (O_2, H_2, H_2O, CO, CO_2, THC)	<5	<5	<5	<5	<5	<1	<1	<1	<1
	O_2 (N_2, Ar)	<50	<50	<50	<50	<50	<25	<25	<25	<25

	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*
	O_2 (H_2, H_2O, CO, CO_2, THC)	**<10**	**<10**	**<10**	**<10**	**<10**	**<5**	**<5**	**<5**	**<5**
	Ar (N_2, O_2, H_2, H_2O, CO, CO_2, THC)	**<5**	**<5**	**<5**	**<5**	**<5**	**<1**	**<1**	**<1**	**<1**
	H_2 (N_2, Ar)	**<50**	**<50**	**<50**	**<50**	**<50**	**<25**	**<25**	**<25**	**<25**
	H_2 (O_2, H_2O, CO, CO_2, THC)	**<10**	**<10**	**<10**	**<10**	**<10**	**<5**	**<5**	**<5**	**<5**
	He (N_2, O_2, H_2, H_2O, CO, CO_2, THC)	**<10**	**<10**	**<10**	**<10**	**<10**	**<5**	**<5**	**<5**	**<5**
WAS	CO_2 (CO, H_2O, O_2, THC)	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
IS	CO2 (N2, CO, H2O, O2, THC)	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
	Lithography Purge Gases									
WAS	Critical clean dry air (H_2O)	**<2500**	**<2500**	**<2500**	**<2500**	**<2500**	**<2500**	**<2500**	**<2500**	**<2500**
IS	Critical clean dry air (H2O)	**-**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
ADD	Critical clean dry air (H2, 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_3) (ppb)	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**
	Critical clean dry air (NH_3 (as NH_3)) (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_2 (as SO_4)) (ppb)	**< 0.1**	**< 0.1**	**< 0.1**	**< 0.1**	**< 0.1**	**< 0.1**	**< 0.1**	**< 0.1**	**< 0.1**
	Critical clean dry air (SO_4 (as SO_4)) (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 (0rganics 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_2O, O_2, CO_2) (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_2) (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_3)) (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_4) including SO_2) (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_2O) (ppb)	**<3500**	**<3500**	**<3500**	**<3500**	**<3500**	**<3500**	**<3500**	**<3500**	**<3500**
WAS	Lithography helium tool/maintenance purging gas supply (O_2, CO_2) (ppb)	**<500**	**<500**	**<500**	**<500**	**<500**	**<500**	**<500**	**<500**	**<500**
IS	Lithography helium tool/maintenance purging gas supply (O_2, CO_2) (ppb)	**-**	**<4000**	**<4000**	**<4000**	**<4000**	**<4000**	**<4000**	**<4000**	**<4000**
WAS	Lithography helium tool/maintenance purging gas supply (CO, H_2) (ppb)	**<2000**	**<2000**	**<2000**	**<2000**	**<2000**	**<2000**	**<2000**	**<2000**	**<2000**
IS	Lithography helium tool/maintenance purging gas supply (CO, H_2) (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**

	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*
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**	**<3.2**
	Lithography helium tool/maintenance purging gas supply (total base (as NH_3)) (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_2 (as SO_4)) (ppb)	**< 0.025**	**< 0.025**	**< 0.025**	**< 0.025**	**< 0.025**	**< 0.025**	**< 0.025**	**< 0.025**	**< 0.025**
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**	**<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**	**<0.1**
WAS	Number of particles > critical size (/M^3) [A]	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**
IS	Number of particles > critical size (/M3) [1]	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**
	Specialty Gases									
	***Etchants (Corrosive, e.g., BCl_3,** Cl_2)*									
	O_2, H_2O (ppbv)	**<1000**	**<500**	**<500**	**<500**	**<100**	**100**	**100**	**100**	**100**
WAS	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**
IS	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**
	***Etchants (Non-corrosive, e.g., C_2F_6,** NF_3)*									
	O_2, H_2O (ppb)	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**100**	**100**	**100**	**100**
	***Deposition (e.g., SiH_4,** NH_3, $(CH_3)_3SiH$)*									
	O_2, H_2O (ppb)	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**100**	**100**	**100**	**100**
WAS	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**
IS	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**
	***Dopants (e.g., AsH_3,** PH_3, GeH_4)*									
	O_2, H_2O (ppb)	**<1000**	**<500**	**<500**	**<500**	**<100**	**100**	**100**	**100**	**100**
	Inerts for purging									
	O_2, H_2O (ppb)	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
	He, H_2 cylinder carrier/purge gases (N_2, H_2O, 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

	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 Environment Control such as Cleanroom, SMIF POD, FOUP, etc….not necessarily the cleanroom itself but wafer environment.							
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^3) [A] [B]	**ISO CL1**	**ISO CL1**	**ISO CL1**	**ISO CL1**	**ISO CL1**	**ISO CL1**	**ISO CL1**
IS	Number of particles (/m^3) [1] [2]	**ISO CL1**	**ISO CL1**	**ISO CL1**	**ISO CL1**	**ISO CL1**	**ISO CL1**	**ISO CL1**
WAS	***Airborne Molecular Contaminants in Gas Phase (pptM)) [C] [G] [M]***							
IS	***Airborne Molecular Contaminants in Gas Phase (pptM)) [3, 7, 12,13,14,15,33]***	-	-	-	-	-	-	-
WAS	Lithography (cleanroom ambient) [V]							
IS	Lithography (cleanroom ambient) [23]	-	-	-	-	-	-	-
WAS	Total acids (as SO_4) 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_3)	**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/cm2/day [12]	**2**	**2**	**2**	**2**	**2**	**2**	**2**
WAS	***Gate wafer environment (cleanroom/POD/FOUP ambient)***							
IS	***Gate/Furnace area wafer environment (cleanroom/POD/FOUP ambient)***	-	-	-	-	-	-	-
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^2/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/cm2/day [12]	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
	Salicidation Wafer Environment (Cleanroom/POD/FOUP ambient)							
WAS	Total acids (as SO_4) 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**
	Exposed Copper Wafer Environment (Cleanroom/POD/FOUP ambient)							
WAS	Total acids (as SO_4) 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**
	Exposed Aluminum Wafer Environment (Cleanroom/POD/FOUP ambient)							
WAS	Total acids (as SO_4) 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_2)	**500**	**500**	**500**	**500**	**500**	**500**	**500**
IS	Total other corrosive species [32]	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**
	Reticle Exposure (Cleanroom/POD/Box ambient)							
WAS	Total acids (as SO_4) 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**

	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*
WAS	Total bases (as NH_3)	**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/cm2/week [12]	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
	General Wafer Environment (Cleanroom/POD/FOUP ambient, all areas unless specified below)							
WAS	Total acids (as SO_4) 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_3)	**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^2/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/cm2/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$_2$ [D] [M]	**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/cm2 [4] [13]	**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$_2$ [F] [M]	**1.00E+10**	**1.00E+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/cm2 [6] [14]	**1.00E+10**	**1.00E+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 (MOhm-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_2 [P]	**<0.3**	**<0.3**	**<0.3**	**<0.3**	**<0.3**	**<0.3**	**<0.3**
IS	Total silica (ppb) as SiO_2 [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	***Liquid Chemicals [F]***							
IS	***Liquid Chemicals***							
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 >0.065um [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 >0.065um [1] [11]	**<10**	**<10**	**<10**	**<10**	**<10**	**<10**	**<10**

	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*
WAS	30% H_2O_2: number of particles > critical size (/ml) [A] [K]	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
IS	30% H2O2: number of particles/ml >0.065um [1] [11]	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
WAS	29% NH_4OH: number of particles > critical size (/ml) [A] [K]	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
IS	29% NH4OH: 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_2O_2: 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_2O_2: 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% H2O2: SiO2 (ppt) [27]	**5000**	**5000**	**5000**	**5000**	**5000**	**5000**	**5000**
WAS	30% H_2O_2: Br, F (ppt, each)	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**
~~**IS**~~	~~30% H_2O_2: Br, F (ppt, each)~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~
WAS	29% NH_4OH: 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% NH4OH: 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_4 (ppt, each)	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**
~~**IS**~~	~~100% IPA: NH_4 (ppt, each)~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~
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_2O_2: All other metals not listed in row above (ppt, each) [R]	**500**	**500**	**500**	**500**	**500**	**500**	**500**
IS	30% H2O2: All other metals not listed in row above (ppt, each) [21]	**500**	**500**	**500**	**500**	**500**	**500**	**500**
WAS	29% NH_4OH: all other metals not listed in row above (ppt, each) [R]	**500**	**500**	**500**	**500**	**500**	**500**	**500**
IS	29% NH4OH: 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**~~	~~49% HF: total oxidizable carbon (ppb)~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~
WAS	29% NH_4OH: total oxidizable carbon (ppb)	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**
~~**IS**~~	~~29% NH4OH: total oxidizable carbon (ppb)~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~
WAS	37% HCl: total oxidizable carbon (ppb)	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**
~~**IS**~~	~~37% HCl: total oxidizable carbon (ppb)~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~	~~**TBD**~~

	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*
	30% H_2O_2: total oxidizable carbon (ppb)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	100% IPA – Specific organic acids: formate, acetate, citrate, proprionate, 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_2O_2: 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_2SO_4: K, Ni, Cu, Cr, Co, (ppt)	1000	1000	1000	1000	1000	1000	1000
IS	96% H2SO4: 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_2SO_4: all other metals not listed in row above (ppt, each) [R]	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
	BEOL solvents, strippers K, Li, Na, (ppt, each)	10000	10000	10000	10000	10000	10000	10000
WAS	Planar slurries: scratching particles (/ml > key particle size) [I] [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_2O and Other Oxygen Containing Impurities (ppmV)	<5	<5	<5	<5	<5	<5	<5
IS	H2O (ppm)	<1	<1	<1	<1	<1	<1	<1
ADD	CO, CO2 (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+O2 (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	O2 (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
	Bulk Gases (Contaminants, ppbv)							
	N_2 (O_2, H_2, H_2O, CO, CO_2, THC)	<1	<1	<1	<1	<1	<1	<1
	O_2 (N_2, Ar)	<25	<25	<25	<25	<25	<25	<25
	O_2 (H_2, H_2O, CO, CO_2, THC)	<5	<5	<5	<5	<5	<5	<5
	Ar (N_2, O_2, H_2, H_2O, CO, CO_2, THC)	<1	<1	<1	<1	<1	<1	<1
	H_2 (N_2, Ar)	<25	<25	<25	<25	<25	<25	<25
	H_2 (O_2, H_2O, CO, CO_2, THC)	<5	<5	<5	<5	<5	<5	<5

	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*
	He (N_2, O_2, H_2, H_2O, CO, CO_2, THC)	<5	<5	<5	<5	<5	<5	<5
WAS	CO_2 (CO, H_2O, O_2, THC)	<1000	<1000	<1000	<1000	<1000	<1000	<1000
IS	CO2 (N2, CO, H2O, O2, THC)	<1000	<1000	<1000	<1000	<1000	<1000	<1000
	Lithography Purge Gases							
WAS	Critical clean dry air (H_2O)	<2500	<2500	<2500	<2500	<2500	<2500	<2500
IS	Critical clean dry air (H2O)	<1000	<1000	<1000	<1000	<1000	<1000	<1000
ADD	Critical clean dry air (H2, 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_3) (ppb)	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	Critical clean dry air (NH_3 (as NH_3)) (ppb)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Critical clean dry air (total acid including SO_2 (as SO_4)) (ppb)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Critical clean dry air (SO_4 (as SO_4)) (ppb)	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
ADD	Critical clean dry air (Each refractory compound (0rganics 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_2O, O_2, CO_2) (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_2) (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_3)) (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_4) including SO_2) (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_2O) (ppb)	<3500	<3500	<3500	<3500	<3500	<3500	<3500
WAS	Lithography helium tool/maintenance purging gas supply (O_2, CO_2) (ppb)	<500	<500	<500	<500	<500	<500	<500
IS	Lithography helium tool/maintenance purging gas supply (O_2, CO_2) (ppb)	<4000	<4000	<4000	<4000	<4000	<4000	<4000
WAS	Lithography helium tool/maintenance purging gas supply (CO, H_2) (ppb)	<2000	<2000	<2000	<2000	<2000	<2000	<2000
IS	Lithography helium tool/maintenance purging gas supply (CO, H_2) (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_3)) (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_2 (as SO_4)) (ppb)	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025

	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*
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^3) [A]	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**
IS	Number of particles > critical size (/M3) [1]	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**	**<100**
	Specialty Gases							
	***Etchants (Corrosive, e.g., BCl_3,** Cl_2)*							
	O_2, H_2O (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**
	***Etchants (Non-corrosive, e.g., C_2F_6,** NF_3)*							
	O_2, H_2O (ppb)	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	***Deposition (e.g., SiH_4,** NH_3, $(CH_3)_3SiH$)*							
	O_2, H_2O (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**
	***Dopants (e.g., AsH_3,** PH_3, GeH_4)*							
	O_2, H_2O (ppb)	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	Inerts for purging							
	O_2, H_2O (ppb)	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**	**<1000**
	He, H_2 cylinder carrier/purge gases (N_2, H_2O, 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 ½ 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^2), E is the sticking coefficient (between 0 and 1), N is the concentration in air (molecules/cm^3); and V is the average thermal velocity (cm/second). The following sticking coefficients have been proposed; SO4 = $1x10^{-5}$, NH3 = $1x10^{-6}$, Cu = $2x10^{-5}$. 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:***ADDED**	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 asterix. 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 µm. 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/cm2/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 than 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.*				

	*Notes for Tables 115a and b:***ADDED**	CR/AMC	UPW	BG/SG	PC/CVD
14	*SMC Metals: Single wafer known to meet the ITRS FEP spec of 1E10 atoms/cm^2, 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.*				
15	*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.*				
16	*Dissolved oxygen (DO) has an effect on pre-gate oxide cleaning and the etch rate of non H-passivated SiO2 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.*		o		
17	*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.*				o
18	*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.*		o		
19	*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.*			o	
20	*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.*				o
21	*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.*				o

	Notes for Tables 115a and b: ***ADDED***	CR/AMC	UPW	BG/SG	PC/CVD
22	*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.*		o		
23	*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.*	o			
24	*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.*		o		
25	*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.*				o
26	*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 >0.05 um, and incapable of detecting particles at critical size based on ½ 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.*		o		
27	*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.*				o
28	*Concentrations higher than 100 ppb could cause corrosion especially in back end of line processes.*				o
29	*The ultrapure water parameters provided in this table are applicable for the most critical process unless otherwise identified by additional footnotes.*		o		
30	*Typical Organic Acids found in cleanroom envieronments that may be of concern include Acetate, Citrate, Formate, Glycolate, Lactate, Oxalate, and Proprionate. Others may also be of concern. These acids can be a significant load on acid removal filters.*	o			
31	*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*	o			
32	*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.*	o			
33	*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.*	o			

ADDED *References for Table 115a&b Notes*

1) SEMI MF1982-1103 (previously ASTMF 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 Aerosal 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.