22.11.1 *Test Equipment* — None.

22.11.2 *Procedure* — For each independent safety interlock circuit (such as door safety interlock), EMO, and safety sensor (e.g., exhaust sensor, low fluid level sensor), disconnect each safety interlock circuit one conductor at a time.

22.11.3 *Acceptable Results* — The following sections provide the acceptable results for the applicable safety circuits:

22.11.3.1 The opening of the safety circuit causes the equipment to be placed in a safe condition as if the safety device had been actuated.

22.11.3.2 Reconnecting the conductor should not cause the system to resume operation.

22.12 *Capacitor Stored Energy Discharge Test*

22.12.1 *Test Equipment* — Timer with accuracy of ± 1 seconds. DC voltmeter with sensitivity of 1.0 percent.

22.12.2 *Procedure* — Test each capacitor that stores a hazardous energy (20 Joules or more). Monitor the voltage across the capacitor terminals continuously. Disconnect the equipment from the supply. Record the voltage across the capacitor terminals after 10 seconds.

22.12.3 *Acceptable Results* — The capacitor is discharged to less than 20 Joules within 10 seconds of equipment disconnection from the supply.

NOTE 67: The following formula is provided to calculate the energy:

$J = 1/2\ CV^2$

where: J is the energy in joules

C is the capacitance in farads

V is the potential in volts

EXCEPTION: This criterion does not apply if a tool is necessary to remove a panel to reach the capacitor and the equipment is marked specifying the discharge time—5 minutes maximum—that is required for the capacitor to discharge to less than 20 Joules.

22.13 *Temperature Test*

22.13.1 *Test Equipment* — Timer with accuracy of ± 5 seconds. A thermometer with a full range of resolution and an accuracy of 0.1°C.

22.13.2 *Procedure* — The equipment is to be operated at the manufacturer's maximum design load for 8 hours or until thermal equilibrium is reached (whichever occurs first). Measure and record the ambient room temperature. Measure and record the temperatures of the various components and devices for comparison with Appendix 1, Table A1-11.

NOTE 68: Thermal equilibrium is attained when three successive readings taken at five minute intervals indicate that there is no temperature change of the part exceeding 1.0°C.

22.13.3 *Acceptable Results* — The ambient temperature should be subtracted from 40°C or the maximum ambient temperature specified in the manufacturer's documentation, whichever is greater. This difference should be added to all the measured temperatures and these results should not exceed the values listed in Appendix 1, Table A1-11.

22.14 *Strength of Electrical Enclosures Test*

22.14.1 *30N Steady Force Test* — This test applies to mechanical strength of enclosures.

22.14.1.1 *Test Equipment* — Force gauge.

22.14.1.2 *Procedure* — The enclosure walls and covers are to be subjected to a steady force of 30 N ± 3 N for a period of 5 seconds applied by means of a straight un-jointed version of a test finger to the part, on or within the complete equipment, or on a separate sub-assembly.

22.14.1.3 *Acceptable Results* — If the straight un-jointed version of the test finger penetrates the material or opening, it should not be possible to touch any hazardous energized parts inside the enclosure with the jointed or un-jointed test finger.

22.14.2 *250N Steady Force Test* — This test applies to deflection of electrical enclosure panels.

22.14.2.1 *Test Equipment* — Force gauge.

22.14.2.2 *Procedure* — The panel is to be subjected to a steady force of 250 N ± 10 N (55.55 lbs. ± 2.22 lbs.) for a period of 5 seconds, applied to the enclosure, fitted to the equipment, by means of a suitable test tool providing contact over a circular plane surface 30 mm in diameter.

22.14.2.3 *Acceptable Results* — If flexing of the enclosure panel occurs, it should not cause shorting or reduction of a clearance distance to less than that stipulated between the enclosure and hazardous energized parts inside.

22.15 *Finger Probe Test*

22.15.1 *Test Equipment* — IEC Finger Probe (see IEC 61010).

22.15.2 *Procedure* — The jointed test finger is applied without force in every possible position to all outer surfaces, including the bottom. Any enclosure panels that are not secured by a means that requires a tool to open are opened and the finger probe is applied.

22.15.3 *Acceptable Results* — If the finger probe cannot touch any conductive part that is energized with a hazardous voltage under normal operating conditions, then this is an acceptable result.

22.16 *Wire Flexing Test* — This test applies to wiring that runs from a fixed panel to a swing panel or door and is supplied with hazardous voltage or power.

22.16.1.1 *Procedure* — The swing panel or door is opened to its intended fully open position and then closed. This process is repeated 500 times. After this is done a dielectric test is performed in accordance with Section 22.6 and the wire is inspected for any signs of physical damage.

22.16.2 *Acceptable Results* — The wire passes the dielectric test and shows no visible signs of physical damage.

22.17 *Reporting Test Results* — include the following information on the test data form:

a) name, model, and serial number of the equipment,

b) date of test(s),

c) name(s)/signature(s) of tester(s),

d) complete test methods and conditions,

e) complete test results, and

f) complete test equipment information (type of test equipment, manufacturers' names, model numbers, serial numbers, and calibration information).

22.17.1 The general configuration and actual operating mode that was used for the test should be clearly documented. Where components are tested separately or only parts of the overall system are operational, this should be documented as a condition for the test results reported. This information may be on the test data form(s) or incorporated in the test report.

APPENDIX 1

NOTICE: The material in this appendix is an official part of SEMI S22 and was approved by full letter ballot procedures on September 3, 2003.

Table A1-1 Conductor Ampacity - Conductor Ampacity Table for Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2 or equivalent Insulation - COPPER, 0-2000 volts, 30 Deg C ambient temperature.

Standard AWG 30 – 4: 0 percent Derated 1-3 Conductors

Wire Size		*Cross Section Area*	*0% Derated 1 – 3 Current Carrying Conductors*				*Single Wire Bending Space*		*Protective Conductor Wire size*		*Protective Conductor Cross Section Area*
			Amps per Conductor[#1] Insulation Rating								
Metric	*AWG*	*Sq. mm*	*60ºC*	*75ºC*	*90ºC*	*105ºC*	*mm*	*Inches*	*Metric*	*AWG*	*Sq. mm*
	30	0.050	-	0.5	0.8	1	6.4	0.25		**30**	0.050
	28	0.079	-	0.8	1	2	6.4	0.25		**28**	0.079
	26	0.126	-	1	2	3	6.4	0.25		**26**	0.126
	24	0.201	2	2	3	4	6.4	0.25		**24**	0.201
	22	0.318	3	3	5	7	13	0.5		**22**	0.318
0.50		0.500	5	5	9	11	13	0.5	**0.50**		0.500
	20	0.509	5	5	9	11	13	0.5		**20**	0.509
0.75		0.75	6	6	12	16	13	0.5	**0.75**		0.75
	18	0.823	7	7	14	18	13	0.5		**18**	0.823
1.00		1.0	8	8	15	19	19	0.75	**1.00**		1.0
	16	1.31	10	10	18	22	20	0.75		**16**	1.31
1.50		1.5	11	11	20	24	19	0.75	**1.50**		1.5
	14	2.08	15	15	25	30	20	0.75		**14**	2.08
2.50		2.5	17	17	27	32	25	1.0	**2.50**		2.5
	12	3.31	20	20	30	35	26	1.0		**12**	3.31
4.00		4.0	24	24	34	39	25	1.0	**4.00**		4.0
	10	5.26	30	30	40	45	26	1.0		**10**	5.26
6.00		6.0	32	35	44	49	38	1.5	**6.00**		6.0
	8	8.37	40	50	55	60	39	1.5		**10**	5.26
10.00		10.0	45	55	62	68	51	2	**6.00**		6.0
	6	13.30	55	65	75	85	51	2		**10**	5.26
16.00		16.0	60	72	82	92	76	3	**10.00**		10.0
	4	21.15	70	85	95	105	76	3		**8**	8.37

[#1] Ampacity may be limited by terminal temperature rating.

Table A1-2 Conductor Ampacity - Conductor Ampacity Table for Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2 or equivalent Insulation - COPPER, 0-2000 volts, 30 Deg C ambient temperature.

Standard 25.00 Metric – 600 Kcmil: 0 percent Derated 1-3 Conductors

Wire Size		*Cross Section Area*	*0% Derated 1 – 3 Current Carrying Conductors*				*Single Wire Bending Space*		*Protective Conductor Wire size*		*Protective Conductor Cross Section Area*
			Amps per Conductor[#1] Insulation Rating								
Metric	*AWG*	*Sq. mm*	*60ºC*	*75ºC*	*90ºC*	*105ºC*	*mm*	*Inches*	*Metric*	*AWG*	*Sq. mm*
25.00		25.0	80	95	105	115	76	3	**10.00**		10.00
	3	26.67	85	100	110	120	76	3		**8**	8.37
	2	33.62	95	115	130	145	89	3.5		**6**	13.30
35.00		35.0	97	117	133	149	115	4.5	**16.00**		16.00
	1	42.41	110	130	150	170	115	4.5		**6**	13.30
50.00		50.0	120	144	164	180	140	5.5	**16.00**		16.00
	1/0	53.49	125	150	170	185	140	5.5		**6**	13.30
	2/0	67.43	145	175	195	205	152.4	6		**6**	13.30
70.00		70.0	148	179	199	210	165	6.5	**16.00**		16.00
	3/0	85.01	165	200	225	240	166	6.5		**6**	13.30
95.0		95.0	179	214	241	260	178	7	**16.00**		16.00
	4/0	107.2	195	230	260	285	178	7		**4**	21.15
120.0		120.0	208	246	280	308	216	8.5	**25.00**		25.00
	(250)	126.7	215	255	290	320	216	8.5		**4**	21.15
150.0		150.0	238	282	317	347	254	10	**25.00**		25.00
	(300)	152.0	240	285	320	350	254	10		**4**	21.15
	(350)	177.4	260	310	350	385	305	12		**3**	26.67
185.0		185.0	266	317	359	395	305	12	**35.00**		35.00
	(400)	202.7	280	335	380	420	331	13		**3**	26.67
240.0		240.0	309	367	416	456	331	13	**35.00**		35.00
	(500)	253.4	320	380	430	470	356	14		**3**	26.67
300.0		300.0	352	416	471	516	381	15	**35.00**		35.00
	(600)	304.0	355	420	475	520	381	15		**2**	33.62

[#1] Ampacity may be limited by terminal temperature rating.

Table A1-3 Derated Amps (Based on table for calculating Conductor Ampacity from Table A1-1&2) Conductor Ampacity - Conductor Ampacity Table for Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2 or equivalent Insulation - COPPER, 0-2000 volts

Ampacity based on 75 Deg C Chart for wire from .050 square mm cross section area (30 AWG) to .126 square mm cross section area (26 AWG) and ampacity based on 60°C chart for wire from .201 square mm cross section area (24 AWG) to 4.00 square mm cross section area, ampacity limit due to terminal temperature rating limitation.

90 deg/105 degree C Insulation & 30 deg C ambient temp, derating factor (%), and number of conductors.

Standard Wire Size		*Cross Section*	*90ºC 105ºC*	*90ºC 105ºC*	*90ºC 105ºC*	*90ºC 105ºC*	*90ºC 105ºC*	*90ºC 105ºC*	*90ºC 105ºC*	*Single Wire Bending Space*		*Protective Conductor Wire size*		*Protective Conductor Cross Section Area*
			–0%	*–20%*	*–30%*	*–50%*	*–55%*	*–60%*	*–65%*					
Metric	*AWG*	*Sq. mm*	*1–3*	*4–6*	*7–9*	*10–20*	*21–30*	*31–40*	*> 40*	*mm*	*inches*	*Metric*	*AWG*	*Sq. mm*
	30	0.050	0.5 0.5	0.5 0.5	0.5 0.5	0.25 0.5	0.25 0.25	0.25 0.25	0.25 0.25	6.4	0.25		**30**	0.050
	28	0.079	0.8 0.8	0.8 0.8	0.5 0.8	0.5 0.8	0.25 0.8	0.25 0.8	0.25 0.5	6.4	0.25		**28**	0.079
	26	0.126	1 1	1 1	1 1	1 1	1 1	1 1	0.5 1	6.4	0.25		**26**	0.126
	24	0.201	2 2	2 2	2 2	1 2	1 1	1 1	1 1	6.4	0.25		**24**	0.201
	22	0.318	3 3	3 3	3 3	2 3	2 3	2 2	1 2	13	0.5		**22**	0.318
0.50		0.500	5 5	5 5	3 3	2 3	2 3	2 2	1 2	13	0.5	**0.50**		0.500
	20	0.509	5 5	5 5	5 5	4 5	4 5	3 4	3 3	13	0.5		**20**	0.509
0.75		0.75	6 6	6 6	6 6	6 6	5 6	5 6	4 6	13	0.5	**0.75**		0.75
	18	0.823	7 7	7 7	7 7	7 7	6 7	6 7	5 6	13	0.5		**18**	0.823
1.00		1.00	8 8	8 8	8 8	8 8	7 8	6 8	5 7	19	0.75	**1.0**		1.0
	16	1.31	10 10	10 10	10 10	9 10	8 10	7 9	6 8	20	0.75		**16**	1.3
1.50		1.50	11 11	11 11	11 11	10 11	9 11	8 10	7 8	19	0.75	**1.5**		1.5
	14	2.08	15 15	15 15	15 15	13 15	11 14	10 12	9 11	20	0.75		**14**	2.08
2.50		2.50	17 17	17 17	17 17	13 16	12 14	11 13	9 11	25	1.0	**2.5**		2.5
	12	3.31	20 20	20 20	20 20	15 18	14 16	12 14	11 12	26	1.0		**12**	3.31
4.00		4.00	24 24	24 24	23 24	17 19	15 17	13 15	12 13	25	1.0	**4.0**		4.0

Table A1-4 (Based on table for calculating Conductor Ampacity from Table A1-1&2) Conductor Ampacity - Conductor Ampacity Table for Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2 or equivalent Insulation - COPPER, 0-2000 volts

Ampacity based on 60 Deg C Chart for wire from 5.26 square mm cross section area to 42.41 square mm cross section area (1 AWG) and ampacity based on 75°C chart for wire from 50.00 square mm cross section area to 70.00 square mm cross section area, ampacity limit due to terminal temperature rating limitation.

90 deg/105 degree C Insulation & 30 deg C ambient temp, derating factor (%), and number of conductors.

Standard Wire Size		*Cross Section*	*90ºC* *105ºC* *–0%*	*90ºC* *105ºC* *–20%*	*90ºC* *105ºC* *–30%*	*90ºC* *105ºC* *–50%*	*90ºC* *105ºC* *–55%*	*90ºC* *105ºC* *–60%*	*90ºC* *105ºC* *–65%*	*Single Wire Bending Space*		*Protective Conductor Wire size*		*Protective Conductor Cross Section Area*
Metric	*AWG*	*Sq. mm*	*1–3*	*4–6*	*7–9*	*10–20*	*21–30*	*31–40*	*> 40*	*mm*	*inches*	*Metric*	*AWG*	*Sq. mm*
	10	5.26	30 30	30 30	28 30	20 23	18 20	16 18	14 16	26	1.0		**10**	5.26
6.00		6.00	32 32	32 32	31 32	22 24	20 22	17 19	15 17	38	1.5	**6.00**		6.00
	8		40 40	40 40	39 40	28 30	25 27	22 24	19 21	39	1.5		**10**	5.26
10.00		10.00	45 45	45 45	43 45	31 34	28 31	25 27	22 24	51	2	**6.00**		6.00
	6		55 55	55 55	53 55	38 43	34 38	30 34	26 30	51	2		**8**	8.37
16.00		16.00	60 60	60 60	57 60	41 46	37 41	33 37	29 32	76	3	**10.00**		10.00
	4		70 70	70 70	67 70	48 53	43 47	38 42	33 37	77	3		**8**	8.367
25.00		25.00	80 80	80 80	74 80	53 58	47 52	42 46	37 40	76	3	**10.00**		10.00
	3	26.67	85 85	85 85	77 84	55 60	50 54	44 48	39 42	77	3		**8**	8.37
	2	33.62	95 95	95 95	91 95	65 73	59 65	52 58	46 51	89	3.5		**6**	13.30
35.00		35.00	97 97	97 97	93 97	67 74	60 67	53 60	47 52	114	4.5	**16.00**		16.00
	1	42.41	110 110	110 110	105 110	75 85	68 77	60 68	53 60	115	4.5		**6**	13.30
50.00		50.00	120 120	131 144	115 126	82 90	74 81	65 72	57 63	140	5.5	**16.00**		16.00
	1/0	53.49	150 150	136 148	119 130	85 93	77 83	68 74	60 65	140	5.5		**6**	13.30
	2/0	67.43	175 175	156 164	137 144	98 103	88 92	78 82	68 72	152.4	6		**6**	13.30
70.0		70.0	179 179	160 168	140 147	100 105	90 95	80 84	70 74	165	6.5	**16.00**		16.00

Table A1-5 (Based on table for calculating Conductor Ampacity from Table A1-1&2) Conductor Ampacity - Conductor Ampacity Table for Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2 or equivalent Insulation - COPPER, 0-2000 volts

Ampacity based on 75 Deg C Chart , ampacity limit due to terminal temperature rating limitation.														
90 deg/105 degree C Insulation & 30 deg C ambient temp, derating factor (%), and number of conductors.														
Standard Wire Size		*Cross Section*	*90ºC 105ºC*	*90ºC 105ºC*	*90ºC 105ºC*	*90ºC 105ºC*	*90ºC 105ºC*	*90ºC 105ºC*	*90ºC 105ºC*	*Single Wire Bending Space*		*Protective Conductor Wire size*		*Protective Conductor Cross Section Area*
			–0%	*–20%*	*–30%*	*–50%*	*–55%*	*–60%*	*–65%*					
Metric	*AWG*	*Sq. mm*	*1–3*	*4–6*	*7–9*	*10–20*	*21–30*	*31–40*	*> 40*	*mm*	*inches*	*Metric*	*AWG*	*Sq. mm*
	3/0	85.01	200 200	180 192	158 168	113 120	101 108	90 96	79 84	166	6.5		**6**	13.30
95.0		95.0	214	193 208	169 182	120 130	108 117	96 104	84 91	178	7	**16.00**		
	4/0	107.2	230	208 228	182 200	130 143	117 128	104 114	91 100	178	7		**4**	21.15
120.0		120.0	246	224 246	196 215	140 154	126 138	112 123	98 107	216	8.5	**25.00**		
	Kcmil													
	250	126.7	255	232 255	203 224	145 160	131 144	116 128	102 112	216	8.5		**4**	21.15
150.0		150.0	282 282	253 277	222 242	158 173	142 156	126 138	111 121	254	10	**25.00**		
	300	152.0	285	256 280	224 245	160 175	144 158	128 140	112 123	254	10		**4**	21.15
	350	177.4	310	280 308	245 270	175 193	158 173	140 154	123 135	305	12		**3**	26.67
185.0			317 317	287 316	251 276	179 197	161 177	143 158	125 138	305	12	**35.00**		
	400	202.7	335	304 335	266 294	190 210	171 189	152 168	133 147	331	13		**3**	26.67
240.0			367 367	332 364	291 319	208 228	187 205	166 182	145 159	331	13	**35.00**		
	500	253.4	380	344 376	301 329	215 235	194 212	172 188	151 165	356	14		**3**	26.67
300.0			416 416	376 412	329 361	235 258	212 232	188 206	164 198	381	15	**35.00**		
	600	304.0	420	380 416	333 364	238 260	214 234	190 208	166 182	381	15		**2**	33.62

Table A1-6 Ambient Temperature Correction Factors for Tables A1-1 through A1-5

Ambient Temperature (Degrees C)	*60 degree C Insulation*	*75 degree C Insulation*	*90/105 degree C Insulation*
21–25	1.08	1.05	1.04
26–30	1.00	1.00	1.00
31–35	0.91	0.94	0.96
36–40	0.82	0.88	0.91
41–45	0.71	0.82	0.87
46–50	0.58	0.75	0.82
51–55	0.41	0.67	0.76
56–60	-	0.58	0.71
61–70	-	0.33	0.58
71–80	-	-	0.41

Table A1-7 Non-insulated Bus Bar Sizes

Thickness	*Thickness*	*Width*	*Width*	*Area*	*Area*	*Amperage*
mm	*Inches*	*mm*	*Inches*	*mm*^{2}	*Inches*^{2}	*A*
1.59	0.063	12.7	0.50	20.0	0.031	31
		19.1	0.75	30.3	0.047	47
		25.4	1.00	40.6	0.063	63
		38.1	1.50	60.6	0.094	94
		50.8	2.00	80.6	0.125	125
		76.2	3.00	121.3	0.188	188
3.18	0.125	12.7	0.50	40.6	0.063	63
		19.1	0.75	60.6	0.094	94
		25.4	1.00	80.6	0.125	125
		38.1	1.50	121.3	0.188	188
		50.8	2.00	161.3	0.250	250
		63.5	2.50	201.9	0.313	313
		76.2	3.00	241.9	0.375	375
		101.6	4.00	322.6	0.500	500
6.35	0.250	12.7	0.50	80.6	0.125	125
		19.1	0.75	121.3	0.188	188
		25.4	1.00	161.3	0.250	250
		38.1	1.50	241.9	0.375	375
		50.8	2.00	322.6	0.500	500
		63.5	2.50	403.2	0.625	625
		76.2	3.00	483.9	0.750	750
		88.9	3.50	564.5	0.875	875
		101.6	4.00	645.2	1.00	1000
		127.0	5.00	806.5	1.25	1250
		152.4	6.00	967.7	1.50	1500
9.53	0.375	12.7	0.50	121.3	0.188	188
		19.1	0.75	181.3	0.281	281
		25.4	1.00	241.9	0.375	375
		38.1	1.50	363.2	0.563	563
		50.8	2.00	483.9	0.750	750
		63.5	2.50	605.2	0.938	938
		76.2	3.00	725.8	1.125	1125
		88.9	3.50	847.1	1.313	1313
		101.6	4.00	967.7	1.500	1500
12.7	0.500	19.1	0.75	241.9	0.375	375
		25.4	1.00	322.6	0.500	500
		38.1	1.50	483.9	0.750	750
		50.8	2.00	645.2	1.00	1000
		76.2	3.00	967.7	1.50	1500
		101.6	4.00	1290.3	2.00	2000

[#1] Refer to Table A1-12 for creepage and clearance distances between non-insulated bus-bars.

Table A1-8 Indicator Lights and Illuminated Pushbuttons With Respect To The Safety Of Persons, Property And/Or The Environment

Color	*Meaning*	*Explanation*	*Action by Operator*	*Action by Other Persons* *#1*
Red	Danger	Dangerous Situation Or Imperative Order	Immediate Response To Deal With A Dangerous Situation	Escape Or Stop
Yellow	Caution/Warning	- Out Of Order - Faulty Situation - Permanent Or Temporary Risk (E.G. Accessibility To Hazardous Areas)	Intervention To Prevent A Dangerous Situation	Evacuation Or Restricted Access
Green	Safe	- Indication Of A Safe Situation - Safe to Proceed - Way Clear	No Specific Action Demanded	No Specific Action Demanded
Blue	Mandatory	- Indication Of A Need For Mandatory Action	Mandatory Action	Mandatory Action
White Gray	No Meaning Assigned	General Information	No Specific Action Demanded	No Specific Action Demanded

[#1] Other Persons - Persons who are in the vicinity of the plant or process, but who are not themselves operators.

Table A1-9 Indicator Lights and Illuminated Pushbuttons With Respect To The Condition Of The Process

Color	*Meaning*	*Explanation*	*Action by Operator*	*Examples of Application*
Red	Emergency	Dangerous Condition	Immediate Action To Deal With A Dangerous Condition, E.G. By - Operating Emergency Off (EMO) - Opening Safety Valve - Starting Cooling Pump	- Pressure/Temperature Of Main Fluid Systems Out Of Safe Limits - Voltage Drop - Breakdown Of Main Unit -Stopping Of Essential Machines, Service Systems -Deep-Freezer Temperature Too High
Yellow	Abnormal	- Abnormal Condition - Impending Critical Condition	Monitoring And/Or Intervention (e.g., By Reestablishing The Intended Function)	- Pressure/Temperature Different From Normal Level - Tripping Of A Protecting Command - Position Change Of A Valve - Deep-Freezer On Super Freezing
Green	Normal	Normal Condition	Optional	- Authorization To Proceed - Indication Of Normal Working Limits
Blue	Mandatory	- Indication Of Condition That Requires Action	Mandatory Action	Indication To The Operator To Input Information
White Gray	No Meaning Assigned	Not Safety Indicators	Surveillance	General Information (e.g., Confirmation Of A Command, Indication Of Measured Values)

Table A1-10 Indicator Lights and Illuminated Pushbuttons With Respect To The State Of Equipment

Color	*Meaning*	*Explanation*	*Action by Operator*	*Examples of Application*
Red	Emergency	Fault Condition	Immediate Action To Deal With A Dangerous Condition, E.G. By - Operating Emergency Off (EMO) - Opening Safety Valve - Starting Cooling Pump	- Pressure/Temperature Of Auxiliary Systems Out Of Safe Limits - Stopping Of Necessary Service Systems - Over-Traveling Of A Stop Position On A Hoist
Yellow	Abnormal	Abnormal Condition	Monitoring And/Or Intervention (e.g. By Reestablishing The Intended Function)	- Conveyor Overloaded - Over-Traveling Of A Limit Switch - Position Change Of A Valve Or Conveyor Belt
Green	Normal	Normal Condition	Optional	- Authorization To Proceed - Indication Of Normal Working Limits
Blue	Mandatory	Mandatory Significance	Mandatory Action	Indication Of A Need To Enter: - Preset Values - Other Mode Of Control
White Gray	No Meaning Assigned	---	---	Status Indication, E.G. - Switch Open/Close - Valve Open/Close - Motor Stopped/Running

Table A1-11 Maximum Temperature Limit

Parts of the Equipment	*Temperature Limit (°C)*
Knife switch blade and contact jaws	55
Fuse and fuse clip	110
Insulated conductors	#1
Field wiring terminals	--
Equipment marked for 60° C or 60/75 °C supply wires	75
Equipment marked for 75 °C supply wires	90
Buses and connecting straps or bars	125
Capacitors	#2
Power switching semiconductors	#3
Printed wiring boards	#4
Motors and Transformers	#5

#1 The temperature as marked on the conductor or otherwise the rated temperature designated by the conductor manufacturer.

#2 The temperature marked on the capacitor or otherwise the rated temperature designated by the conductor manufacturer.

#3 The case temperature for the applied power dissipation recommended by the semiconductor manufacturer.

#4 The operating temperature of the board as specified by the board manufacturer.

#5 The rated temperature of the motor or transformer as specified by the manufacturer, if provided. When not provided, use appropriate standards such as IEC 61010-1 for guidance.

Table A1-12 Creepage and Clearance in Class 1000 or Less Cleanroom

		Basic/Supplementary (mm)			*Double/Reinforced (mm)*		
Installation Category	*Working Voltage*	*Clearance*	*Creepage*	*Test Voltage, Vrms*	*Clearance*	*Creepage*	*Test Voltage, Vrms[3]*
Category 1	50	0.1	0.18	230	0.10	0.35	400
	100	0.1	0.25	350	0.12	0.50	510
	150	0.1	0.30	490	0.40	0.60	740
	300	0.5	0.70	820	1.60	1.60	140-0
	600	1.5	1.70	1350	3.30	3.40	2300
	1000	3.0	3.20	2200	6.50	6.50	3700
Category 2	50	0.1	0.18	350	0.12	0.35	510
	100	0.1	0.25	490	0.40	0.50	740
	150	0.5	0.50	820	1.60	1.60	1400
	300	1.5	1.50	1350	3.30	3.30	2300
	600	3.0	3.00	2200	6.50	6.50	3700
	1000	5.5	5.50	3250	11.50	11.50	5550
Category 3	50	0.1	0.18	490	0.4	0.4	740
	100	0.5	0.50	820	1.6	1.6	1400
	150	1.5	1.50	1350	3.3	3.3	2300
	300	3.0	3.00	2200	6.5	6.5	3700
	600	5.5	5.50	3250	11.5	11.5	5550
	1000	8.0	8.00	4350	16.0	16.0	7400

[#1] Specified creepage distances less than 0.70 mm may be reduced on uncoated printed wiring boards according to the following table.

[#2] Cleanroom Class 1000 or less is pollution degree 1, however the pollution degree in a particular area in a given piece of equipment may exceed pollution degree 1, even if the equipment is installed in a cleanroom class 1000 or less.

Equipment Creepage Distance, mm	***PWB Creepage Distance***			
	Basic or Supplementary Insulation	*Double or Reinforced*		
		Category 1	*Category 2*	*Category 3*
0.18	0.1	No reduction		No reduction
0.25	0.1			
0.30	0.2			
0.35		0.10	0.12	
0.50	0.5	0.20	0.40	
0.60		0.45		

[#3] If necessary to test using DC voltage, increase specified test voltage by 42 percent.

Table A1-13 Creepage and Clearance in greater than Class 1000 Cleanroom

		Basic or Supplementary Insulation						*Double or Reinforced Insulation*					
			Creepage Distance						*Creepage Distance*				
Installation Category	*Working Voltage*	*Clearance Distance*	*CTI > 600*	*CTI > 400*	*CTI > 100*	*Printed Wiring Board CTI > 175*	*Test Voltage, rms*[1]	*Clearance Distance*	*CTI > 600*	*CTI > 400*	*CTI > 100*	*Printed Wiring Board CTI > 175*	*Test Voltage, rms*[1]
Category 1	50	0.2	0.6	0.85	1.2	0.20	230	0.2	1.2	1.7	2.4	0.4	400
	100	0.2	0.7	1.00	1.4	0.20	350	0.2	1.4	2.0	2.8	0.4	510
	150	0.2	0.8	1.10	1.6	0.35	490	0.4	1.6	2.2	3.2	0.7	740
	300	0.5	1.5	2.10	3.0	1.40	820	1.6	3.0	4.2	6.0	2.8	1400
	600	1.5	3.0	4.30	6.0	3.00	1350	3.3	6.0	8.5	12.0	6.0	2300
	1000	3.0	5.0	7.00	7.0	5.00	2200	6.5	10.0	14.0	20.0	10.0	3700
Category 2	50	0.2	0.6	0.85	1.2	0.2	350	0.2	1.2	1.7	2.4	0.4	510
	100	0.2	0.7	1.00	1.4	0.2	490	0.2	1.4	2.0	2.8	0.4	740
	150	0.5	0.8	1.10	1.6	0.5	820	1.6	1.6	2.2	3.2	1.6	1950
	300	1.5	1.5	2.10	3.0	1.5	1350	3.3	3.3	4.2	6.0	3.3	3250
	600	3.0	3.0	4.30	6.0	3.0	2200	6.5	6.5	8.5	12.0	6.5	5250
	1000	5.5	5.5	7.00	10.0	5.5	3250	11.5	11.5	14.0	24.0	11.5	7850
Category 3	50	0.2	0.6	0.85	1.2	0.2	490	0.4	1.2	1.7	2.4	0.4	740
	100	0.5	0.7	1.00	1.4	0.5	820	1.6	1.6	2.0	2.8	1.6	1950
	150	1.5	1.5	1.50	1.6	1.5	1350	3.3	3.3	3.3	3.3	3.3	3250
	300	3.0	3.0	3.00	3.0	3.0	2200	6.5	6.5	6.5	6.5	6.5	5250
	600	5.5	5.5	5.50	6.0	5.5	3250	11.5	11.5	11.5	12.0	11.5	7850
	1000	8.0	8.0	8.00	10.0	8.0	4350	16.0	16.0	16.0	20.0	16.0	10450

[#1] If necessary to test using DC voltage, increase specified test voltage by 42 percent.

[#2] Cleanroom Class greater than 1000 is pollution degree 2, however the pollution degree in a particular area in a given piece of equipment may exceed pollution degree 2, even if the equipment is installed in a cleanroom greater than 1000.

Table A1-14 Over Currrent Protection For Transformers without Thermal Protection

Transformer Primary Rating	*Transformer Secondary Rating*	*Maximum Primary Protection Percent Of Rating (See Note 1)*	*Maximum Secondary Protection Percent Of Rating* [#1]
Any Rating	9 amperes or more	250	125
Any Rating	Less than 9 amperes	250	167
9A or more	Any Rating	125	Not Required
Less than 9A and more than 2A	Any Rating	167	Not Required
2A or less	Any Rating	300	Not Required

[#1] Where the rating does not match a standard overcurrent device rating, the next standard size is permitted.

Table A1-15 Over Current Protection For Transformers with Thermal Protection

Transformer Impedance	*Maximum Primary Protection Percent Of Rating (See Note 1)*	*Maximum Secondary Protection Percent Of Rating* #1
6 percent or Less	600	125
More than 6 percent and Less Than 10 percent	400	125

#1 Where the rating does not match a standard overcurrent device rating, the next standard size is permitted.

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DELAYED REVISION SECTION 1 (Effective July 1, 2006) MODIFICATION TO SEMI S22

NOTICE: This Delayed Revision Section contains material that has been balloted and approved by the SEMI Environmental Health and Safety Committee, but is not immediately effective. The provisions of this material are not an authoritative part of the document until their effective date. The main body of SEMI S22-1103a remains the authoritative version. Some or all of the provisions of revisions not yet in effect may be optionally applied prior to the effective date, providing they do not conflict with portions of the authoritative version other than those that are to be revised or replaced as part of the deferred revision, and are labeled accordingly.

NOTICE: Unless otherwise noted, all material to be added shall be underlined, and all material to be deleted shall be ~~struck through~~.

D1-1 Revisions to Section 13 (Safety Circuits) — OPTIONAL Before Effective Date

D1-1.1 Make the following changes to ¶13.7.3 and ¶13.7.3.1:

13.7.3 *Safety Interlock Design* — Electromechanical devices and components are preferred~~.~~——, but solid state devices and ~~non-programmable~~ solid state components may be used provided that the safety interlock system or relevant parts of the system are evaluated for suitability for use in accordance with appropriate standard(s). The evaluation for suitability should take into consideration abnormal conditions such as overvoltage, undervoltage, power supply interruption, transient overvoltage, ramp voltage, electromagnetic susceptibility, electrostatic discharge, thermal cycling, humidity, dust, vibration, jarring, or interfacing to a network.

EXCEPTION: Where the severity of a reasonably foreseeable mishap is deemed to be minor per SEMI S10, a software-based safety interlock may be considered suitable.

13.7.3.1 FECS may be used in conjunction with electromechanical or solid state devices and components provided the programmable safety control system conforms to an appropriate standard for electronic safety systems. Components of the FECS should be tested and certified according to the requirements of the standard used. Examples of recognized electronic safety systems standards include IEC 61508, ISO 13849-1, (EN 954-1), ANSI/ISA SP84.01, DIN/V/VDE-0801.

~~EXCEPTION: Where the severity of a reasonably foreseeable mishap is deemed to be minor per SEMI S10, a software-based safety interlock may be considered suitable.~~

DELAYED REVISION SECTION 2 (Effective July 1, 2006) MODIFICATION TO SEMI S22

NOTICE: This Delayed Revision Section contains material that has been balloted and approved by the SEMI Environmental Health and Safety Committee, but is not immediately effective. The provisions of this material are not an authoritative part of the document until their effective date. The main body of SEMI S22-1103a remains the authoritative version. Some or all of the provisions of revisions not yet in effect may be optionally applied prior to the effective date, providing they do not conflict with portions of the authoritative version other than those that are to be revised or replaced as part of the deferred revision, and are labeled accordingly.

NOTICE: Unless otherwise noted, all material to be added shall be underlined, and all material to be deleted shall be ~~struck through~~.

D2-1 Revisions to Section 13 (Safety Circuit) — OPTIONAL Before Effective Date

D2-1.1 Modify “e” of 13.3.4:

e) the EMO actuator should be ~~non-lockable and~~ self-latching.

SEMI S23-0705
GUIDE FOR CONSERVATION OF ENERGY, UTILITIES AND MATERIALS USED BY SEMICONDUCTOR MANUFACTURING EQUIPMENT

This guide was technically approved by the global Environmental Health and Safety Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on May 20, 2005. It was available at www.semi.org in June 2005 and on CD-ROM in July 2005. Originally published March 2005.

1 Purpose

1.1 This guide addresses concepts related to energy, utilities and materials conservation on semiconductor manufacturing equipment.

1.2 This guide addresses measurements related to energy, utilities and materials usage on semiconductor manufacturing equipment.

1.3 This guide also addresses continuous improvement planning for energy, utilities and materials usage on semiconductor manufacturing equipment in order to promote energy, utilities and materials conservation.

1.4 This guide is a series of options and instructions intended to increase awareness of the reader to available techniques in the area of energy, utilities and materials conservation. A particular course of action is suggested for utilities and materials use measurement and conversion of use measurements into equivalent energy.

NOTE 1: Because this SEMI standard is a Guide, all criteria using "should" may be considered optional.

2 Scope

2.1 This guide is intended to be a tool that can be used to analyze energy, utilities and materials conservation on semiconductor manufacturing equipment.

2.2 This guide describes methods for reporting energy, utilities and material use rate, and the consumption reduction in semiconductor manufacturing equipment.

2.3 This guide also suggests use of energy equivalent values in order to facilitate quantification of overall energy consumption and conservation related to SME as well as easy planning of energy conservation.

2.4 This guide focuses only on the use stage of equipment life cycle and addresses a limited set of utilities and materials to be considered.

2.5 Additionally, this guide describes setting targets for, verifying and improving utilities and materials use rate and energy conservation.

2.6 This guide contains the following sections:

- Purpose
- Scope
- Limitations
- Referenced Standards
- Terminology
- General Concepts
- Life Cycle Assessment (LCA) of Energy Usage
- Baseline Process(es)
- Utilities and Materials Use rate Measurement

- Conversion Factors for Equivalent Energy[1]
- Target Setting and Improvement
- Monitoring and Reporting
- Related Documents

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 This guide is not intended to supersede the applicable codes and regulations of the region where the equipment is used.

3.2 This guide is not intended to provide definite targets for utilities and materials usage or energy conservation.

3.3 The information suggested in this guide may be provided by the equipment supplier to the user if that is the agreement between those parties.

4 Referenced Standards and Documents

4.1 *SEMI Standards*

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

SEMI E6 — Guide for Semiconductor Equipment Installation Documentation

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

5 Terminology

5.1 *Abbreviations & Acronyms*

5.1.1 *DIW* — De-ionized Water

5.1.2 *ISMT* — International SEMATECH

5.1.3 *LCA* — Life Cycle Assessment

5.1.4 *UPW* — Ultra Pure Water

5.2 *Definitions*

5.2.1 Definitions defined in SEMI S2 and SEMI E6 is incorporated herein by reference unless a term is otherwise specified below.

5.2.2 *baseline* — for the purposes of this document, “baseline” refers to operating conditions, including process chemistry, for which the equipment was designed and manufactured, (refer to SEMI S2).

5.2.3 *energy impact* — positive and negative effects on the amount of energy required to produce or provide an item or material, or to execute a process or step.

5.2.4 *environmental impact* — positive and negative effects to the earth environment from a variety of sources including people and their activities, and the operation of semiconductor manufacturing equipment and facilities

5.2.5 *exhaust* — airflow moving from semiconductor manufacturing equipment to a location outside of a fab or laboratory area.

1 Conversion Factors for Equivalent Energy shown in Table-2 except N2 are quoted from the SEAJ document “SEAJ-E-002E — Guideline for Energy Quantification on Semiconductor Manufacturing Equipment and Utilities”

5.2.6 *heal load* — the sum of all heat energy transferred by conduction, convection, and radiation outside the envelop of the equipment.

5.2.7 *idle* — the condition where the equipment is energized and readied for processing (all systems ready and temperatures controlled) but is not actually performing any active function such as materials movement or processing, (refer to SEMI E6).

5.2.8 *Life Cycle Assessment* — a methodology used to evaluate the environmental impact of semiconductor manufacturing equipment throughout its life cycle, including raw material procurement, manufacturing, transportation, use and disposal.

5.2.9 *process mode* — The condition where the equipment is energized and performing its intended function on target materials (such as implanting wafers, pumping gas, or inspecting photo-masks).

5.2.10 *roadmap* — a sequence for the incremental introduction or improvement of technology over time with month or year milestones and supporting information.

6 General Concepts

6.1 Energy is used to produce the various utilities and materials that go into the manufacturing, packaging, shipping, installing, use, decommissioning and disposing of a piece of semiconductor manufacturing equipment. Reducing the energy used in any of these life cycles will improve the environmental impact of the semiconductor manufacturing equipment.

NOTE 2: This guide focuses on only the use of the equipment life cycle stage.

6.2 Given the state of the industry with regard to energy conservation information and measurements, the use stage of the equipment life cycle appears to be the most effective stage to analyze for energy conservation opportunities. The energy used in the use stage is the best derived from the use rate of utilities and materials provided for the stage.

6.3 Various methods have been proposed for converting the use rate of specific utilities and materials into equivalent energy values. The energy used to produce any particular utility or material varies from location to location and from time to time. While any single set of energy conversion factors cannot be valid world wide, some parties find value in the conversion exercise, particularly in identifying a utility or material that has a greater energy impact than others.

6.4 The equipment suppliers should investigate the utilities and materials use rate of the equipment and identify and implement design or process changes that lessen the energy impact of the equipment. The expense of implementing these changes can be balanced against the potential energy impact improvement when developing an energy conservation plan.

NOTE 3: Changes in use rate can also affect the users cost of ownership for the equipment. This can also be considered in the cost-benefit analysis.

6.5 An equipment user can consider supplier-reported utilities and materials use rates, energy equivalent values, and planned improvements when making the purchasing decisions.

6.6 The use rate of utilities and materials for a piece of equipment depends on the particular control parameters used to achieve the desired effect on a wafer (i.e. it depends on the process recipe) as well as the particular hardware used in the equipment and the conditions under which the measurements are taken. It is important to record this and other particular information when use rate measurements are conducted.

6.7 Based on the above considerations, the equipment supplier should set targets for energy, utilities and materials conservation, and consider continuous improvement plans for energy, utilities and materials usage on semiconductor manufacturing equipment.

NOTE 4: The supplier may apply the concepts of this guide to the equipment model or models of their choice.

6.8 The characterization and quantification of energy, utilities and materials consumption should be based on a supplier baseline process.

7 Life Cycle Assessment (LCA) of Energy Usage

7.1 Analyzing energy use during various stages in the life cycle of semiconductor manufacturing equipment can yield valuable information for promoting energy conservation.

7.2 There are many ways the equipment life cycle can be conceptually divided into different stages.

7.3 This guide focuses only on the use (or use) stage of equipment life cycle.

7.4 Other life cycle stages may include

- raw materials procurement,
- manufacturing,
- packaging,
- transportation (shipment),
- decommissioning, and
- disposal.

7.5 The use stage can be further divided into processing, idling, maintenance and service. This guide only addresses processing and idling.

7.6 Using the model methods of this guide, the equipment supplier may also analyze maintenance and service.

NOTE 5: The SEAJ standard "SEAJ-E-003E — Guideline for conducting an LCA of Semiconductor Manufacturing Equipment – Energy Saving Perspective " may be referenced for an example of a more complete life cycle analysis.

8 Baseline Process(es)

8.1 The measurement, conservation monitoring, improvement, and reporting methods should be based on one or several supplier baseline process(es). The equipment supplier is encouraged to consider baseline process(es) which also meet the needs of the users.

8.2 Considering the range of use a supplier intends for the equipment, several baseline processes may be used when utilities and materials use rate measurements are conducted.

8.3 The use rate and energy impact of any particular baseline process recipe can vary depending on the equipment optional hardware that is installed, whether the optional hardware is participating in the process or not (it may consume utilities and materials even when idle). Therefore, when baseline process(es) are designed, the particular hardware configuration can be a significant parameter and should be considered.

NOTE 6: In the course of analysis, the supplier may discover that for two or more recipes which have the same desired effect, one recipe is more energy efficient than another.

NOTE 7: For users to make effective cost of ownership or energy impact comparisons between equipment, it is useful to have supplier data derived from the same baseline process (i.e. achieving the same desired effect on a substrate or other material). It is recommended that suppliers discuss this with the users and gather data that will facilitate effective comparisons.

9 Utilities and Materials Use rate Measurement

9.1 A first step in determining the energy impact of a particular piece of equipment during any life cycle stage is to measure the use rate of utilities and materials in that stage.

9.2 Table 1 contains the recommended minimum set of utility and material parameters to measure while the equipment is performing its intended material processing function (according to a particular recipe) and while it is idling.

NOTE 8: Related Information 1 contains additional use rate information that may be useful.

NOTE 9: Many different chemicals may be used in the processing step. Process chemicals are not included in Table 1 because equivalent energy conversion factors are generally not available for them. The equipment supplier may, however, wish to measure and record their use rate anyway.

9.3 The units used in Table 1 are those used in SEMI E6, "Guide for Semiconductor Equipment Installation Documentation" which contains criteria for documenting all utility requirements for every connection point on a piece of equipment. If the measurement equipment used to gather data does not report values in the indicated units, appropriate conversion factors should be used.

9.4 For the processing measurements, the average value of each parameter over the course of several processing cycles should be recorded as well as the length of the cycle.

9.5 For the idling measurements, the average value of each parameter over a period of idling should be recorded as well as the length of the period.

NOTE 10: See Related Information 1 for additional recommendations.

Table 1

Utility or Material	*Basic Use rate Metrics and Units*	*Related SEMI E6 Sections (0303 Version)*
Exhaust	Pressure (Pa) Flow (m^3/hr) Inlet Temp (°C) Outlet Temp (°C)	§18
Vacuum	Pressure (Pa) Flow (m^3/hr)	§17
Dry Air Nitrogen (N2)	Pressure (Pa) Flow (m^3/hr)	§16
Cooling Water	Supply Pressure (KPa) Return Pressure (KPa) Flow (m^3/hr) Inlet Temp (°C) Outlet Temp (°C)	§13
Ultra Pure Water (UPW)	Purity Requirements Inlet Temp (°C) Flow (m^3/hr)	§13
Electricity	Real Power (Watts)	§12

[#1] "Ultra Pure Water" is sometimes known as "De-Ionized Water".

[#2] "Real Power" is sometimes known as "True Power".

10 Conversion Factors for Equivalent Energy

10.1 Conversion factors can be used to convert the utility and material use rate data gathered for a particular baseline process recipe into equivalent energy consumption data.

10.2 The actual electrical energy required to provide a particular utility or material will, of course, vary among the locations where the equipment will be installed. Therefore, the output of the conversion calculation will not be correct for any particular location. However, if a reasonable set of conversion factors are used, the output of the conversion can be used to identify those utilities and materials which, generally speaking, have a higher environmental impact.

NOTE 11: The use of a standard set of conversion factors also allows comparison of results from tests of various equipment.

10.3 It is recommended that equivalent energy be reported on a per year basis.

10.4 In Table 1, the use rate metrics have a per-hour basis. Therefore, the number of hours the equipment spends processing and idling must be estimated to calculate per-year data.

10.5 Table 2 contains a recommended set of conversion factors.

NOTE 12: Related Information 1 contains additional conversion factor information that may be useful.

10.6 The output units of all conversions are estimated kWh (kilowatt hours). This can be understood as the energy impact of the particular utility or material used.

NOTE 13: See Related Information 1 for example calculations.

10.7 The equipment supplier may also use an alternate set of conversion factors.

NOTE 14: If alternate conversion factors are used, it is recommended that the factors be documented in the report of the results.

10.8 A conversion factor is better if it accurately represents the actual electrical energy required to create and distribute a particular utility or material at the equipment's end use location.

10.9 Determining reasonable energy conversion factors for most process chemicals has not yet entered the state of the art. Therefore, conversion factors are not recommended for them.

NOTE 15: See Related Information 1 for additional information.

Table 2 Recommended Energy Conversion Factors

Utility or Material		*Energy Conversion Factor*	*Basis of Conversion Factor (other units)*
Exhaust		$\frac{0.004\text{ kWh}}{\text{m}^3}$	Exhaust pressure: 2kPa (200 mm Aq; 8 in H_2O)
Vacuum		$\frac{0.075\text{ kWh}}{\text{m}^3}$	Vacuum pressure: 58.8E + 2 Pa (600 mm Aq)
Dry Air		$\frac{0.147\text{ kWh}}{\text{m}^3}$	Supply pressure: 4.9E + 5 Pa (71 psi; 5 kg/cm^2)
Cooling Water (20–25°C)		$\frac{1.78\text{ kWh}}{\text{m}^3}$	Water cooled by refrigeration process Supply pressure: 4.9E + 5 Pa (71 psi; 5 kg/cm^2)
Cooling Water (32–37°C)		$\frac{0.250\text{ kWh}}{\text{m}^3}$	Water cooled by open cooling tower Supply pressure: 4.9E + 5 Pa (71 psi; 5 kg/cm^2)
UPW / DIW (under pressure)		$\frac{10.2\text{ kWh}}{\text{m}^3}$	Supply pressure: 19.6E + 4 Pa (28.4 psi; 2 kg/cm^2)
UPW / DIW (ambient pressure)		$\frac{10.0\text{ kWh}}{\text{m}^3}$	Power for distilling.
Heat Load	Removal via Air	$\frac{3.24 \times 10^{-4}\text{ kWh}}{\text{m}^3\ °\text{C}}$	Specific Heat and Density of Air.
	Removal via Water	$\frac{1.16\text{ kWh}}{\text{m}^3\ °\text{C}}$	Specific Heat and Density of Water.
	Burden	$\frac{0.382\text{ kWh}}{\text{kWh}}$	Refrigeration (air conditioning) efficiency.
N_2 (Volume calculated at one atmosphere pressure and 20 °C.)		$\frac{0.250\text{ kWh}}{\text{m}^3}$	Supply pressure: 7.93E + 5 Pa (115 psi; 8.1 kg/cm^2)
Electricity		$1 \times (V_{RMS} \times I_{RMS}) \times$ measurement period = kWh	This is electrical energy supplied. This is not the same as energy used to generate the electricity.

[#1] Source except N_2: SEAJ-E-002E — Guideline for Energy Quantification on Semiconductor Manufacturing Equipment and Utilities.

#2 Source for N_2: ISMT (presented by Walter Worth at 10th International Semiconductor Environment, Safety and Health Conference).

#3 The Heat Load conversion factor expresses the amount of energy required to remove (i.e. refrigerate) 1 kWh of radiant energy from the equipment environment.

#4 The units for gas pressure of "kg/cm^2" are technically incorrect (because kg is a unit of mass, not force), but they are customary in some regions. The "kg" may be understood as "kilograms force". One kilogram force is equal to 9.81 Newtons. Therefore, 1 kg_f/cm^2 is equal to $9.81 N/cm^2$ = 98.1E + 3 Pa.

11 Target Setting and Improvement

11.1 Using the use rate data and the equivalent energy conversion outcomes from baseline process recipes as a measure of success, the equipment supplier should set target energy conservation, and utilities and materials use rate levels for the equipment and develop timelines for achieving them. The equipment supplier should also present a clear justification for each target.

11.2 The equipment supplier should discuss energy conservation improvement plans and utilities and materials use rate improvement plans with the users before implementing them so that the cost-benefit balance and its related assumptions can be more fully understood by all both parties.

11.3 Energy consumption reduction, and utilities and materials use rate reduction should be achieved through various means such as equipment design changes or recipe changes.

11.4 A more energy efficient method for the production of a particular utility or material can also significantly change the equipment's energy impact. The equipment supplier may wish to recommend to the users that utilities or materials be provided in a particular manner or from a particular source to achieve the best energy impact.

11.5 Equipment suppliers can also work with end users to understand the impact of their utility needs on the operating efficiency of end user utilities. Examples of these include decreasing the Room Heat Burden by means of increased cooling water heat transfer, decreased exhaust pressure drops, decreased cooling water heat exchanger pressure drops, etc. All of these changes, while not necessarily decreasing the utility use rate, may have a significant environmental impact.

11.6 There is a certain expense of time and materials for making a change to equipment. However, there may also be a benefit in reducing utility and material use rate. It is recommended that the cost/benefit balance be carefully analyzed before undertaking an equipment change.

11.7 The following are a few ideas for reducing equipment energy consumption that may be feasible. There are certainly many more.

- Use the highest available voltage for the region of operation as the primary feed voltage (e.g., 300V Japan, 380V China, 480V USA and Taiwan, 240V or 400V Europe).
- Use warmer cooling water.
- Increase cooling water heat exchanger mean temperature difference.
- Decrease exhaust and cooling water pressure drops.
- Reduce bulk gas minimum supply pressures.
- Use less pure processing chemicals.
- Use clean dry air for pneumatic controls instead of nitrogen.
- Use control systems to activate exhaust only when needed.

11.8 The equipment suppliers should prepare an improvement roadmap which should focus on the use rate of one or several specific utilities or materials, or they should focus on the related equivalent energy impact, or both.

11.9 The following data should be considered to be included in an improvement roadmap.

- The type of equipment (model, options, configuration).
- The utilities and materials that are targeted for improvement.
- The baseline recipe(s) that will be used to demonstrate progress.

- The use rate data that is measured at various times.
- The one or several sets of conversion factors used to estimate equivalent energy consumption.
- The target date by which the improvement (by specific utility/material or overall) will be achieved.
- Information describing why a target seems achievable and, generally speaking, how it will be achieved.
- A cost/benefit analysis on the equipment upgrade.

12 Monitoring and Reporting

12.1 *Monitoring*

12.1.1 The equipment supplier should review the improvement status periodically and update the roadmap to monitor the conservation progress. A period of once every two years is recommended.

12.1.2 If the review indicates that targets have not (or will not) be achieved, it is useful to document the reasons as part of the roadmap data and to re-adjust the target dates and achievement strategy based on the most recent information.

12.2 *Reporting*

12.2.1 The equipment supplier should report to the users energy data, utilities and material use rate data and related improvement roadmaps for the equipment.

12.2.2 The reports should contain the roadmap data addressed in ¶11.9 at a minimum.

12.2.3 The equipment suppliers should also consider including data that the users would like to have included in the report.

NOTE 16: The equipment supplier should be careful not to include in the reports any information that is identified as confidential to any party involved unless appropriate non-disclosure agreements are in place. Specific recipes, desired effects to the substrate, methods of achieving energy conservation and forecasted results are examples of information that may be, or may contain parts that are, confidential.

13 Related Documents

13.1 *ISMT Documents*[2]

ISMT — Utilities Consumption Characterization Protocols for Semiconductor Tools, TT #00043939A-ENG

ISMT — Environmental, Safety and Health (ESH) Metrics for Semiconductor Manufacturing Equipment (SME), TT #02034261A-TR

13.2 *SEAJ Documents*[3]

SEAJ-E-002E — Guideline for Energy Quantification on Semiconductor Manufacturing Equipment and Utilities

SEAJ-EP-003E — Guideline for conducting an LCA of Semiconductor Manufacturing Equipment – Energy Saving Perspective

SEAJ-E-001E — Power Measurement Protocol for Semiconductor Equipment

2 International SEMATECH, 2706 Montopolis Drive, Austin, TX, website http://www.sematech.org

3 Semiconductor Equipment Association of Japan, 7-10 Shinjuku 1-chome Shinjuku-ku, Tokyo, 160-0022, Japan, Phone 81.3.3353.7589, Fax 81.3.3353.7970, website http://www.seaj.or.jp

RELATED INFORMATION 1
ADDITIONAL USE RATE MEASUREMENT AND CONVERSION FACTOR INFORMATION

NOTICE: This related information is not an official part of SEMI S23 and was derived from the Japanese Environmental, Health, & Safety committee. This related information was approved for publication by full letter ballot on May 20, 2005.

NOTE: This RI is a summary of SEAJ document “SEAJ-E-002E — Guideline for Energy Quantification on Semiconductor Manufacturing Equipment and Utilities” and was approved to be published as related information of this document as written.

R1-1 Other Use rate Measurements and Data

R1-1.1 Equipment recipes describe how the various controls of the equipment should be set in order to achieve a desired effect on the substrate or other material being treated by the equipment. Because equipment control elements are different from equipment to equipment, the parameters of a recipe will also be different even if the desired effect on the substrate or other material is the same.

R1-1.2 Within this guide, “baseline recipe” should be understood as the collection of recipe parameters intended to produce a specific desired effect. Therefore, the desired effect can be the same from equipment to equipment even though the parameters of the recipes may be different.

R1-1.3 For processing measurements, the average value of each parameter over the course of the processing cycle should be noted. If the equipment processes substrates, a 10 substrate average should be recorded. If the equipment processes a material other than substrates (e.g. a vacuum pump), the average over a 30 minute processing period should be recorded.

R1-1.4 For idle measurements, the average value of each parameter over a period of 30 minutes should be recorded

R1-1.5 A supplier may need to measure additional metrics for other purposes (e.g. to support other metrics-gathering requirements and criteria relevant to supplier-user agreements). Adding those metrics to the energy conservation utility and material use rate measurement effort may be beneficial.

R1-1.6 Semiconductor manufacturing equipment typically processes wafers or other substrates. It is useful to characterize utility and material use rate during processing in terms of per-wafer amounts needed to achieve the desired effect of the recipe.

R1-1.7 By providing an equipment throughput metric (i.e., substrates per hour) with supporting throughput calculation information, the per hour processing metrics can be converted, approximately, into “per wafer” metrics. With further calculations based on the useful area of the wafers processed, the utilities and materials used per cm^2 during processing can be estimated.

R1-1.8 The data described in Table R1-1 should be recorded in addition to the use rate data of Table 1 in the main body of this guide. The goal is to record enough information to document the measurement event thoroughly so that it can be reproduced at a later time, perhaps, for example, to analyze the effect of equipment changes.

R1-1.9 Some of the data (e.g. wafer size) in Table R1-1 may not be applicable to the equipment under consideration.

Table R1-1 Recommended Additional Data to Record for the Measurement Event

Data Title	*Description*
Date	When the measurements were taken.
Equipment Under Test (EUT)	The equipment from which the measurements taken. Provide information such as general description, model number, and serial number.
EUT Configuration	The configuration of the equipment during the measurements, such as sub-systems that were or were not used and optional hardware that was installed.

Data Title	*Description*
Test Location	Where the measurement testing was done such as the particular test laboratory or manufacturing location.
Principal Test Personnel	The principal personnel involved in developing the test plan and conducting the testing.
Test Recipe	The recipe used when conducting the test
Test Throughput (per hour)	How many substrates or other material quantity was processed per hour during the test.
Throughput Calculation Method	How is throughput determined?
Wafer Size	What size wafer is processed by the equipment.
Test Duration	How long the equipment was operating for gathering the test data.
Test Setup	How the several pieces of test equipment were connected to the EUT.
Test Equipment and relevant Calibration Information for measuring; Exhaust Vacuum Dry Air Nitrogen Process Gas (at or above atmospheric pressure) Process Gas (below atmospheric pressure) Process Solids Process Liquids Cooling Water Ultra Pure Water Electricity Heat Load	The test equipment that was used to measure the use rate of each utility or material and its relevant calibration information such as when the test equipment was last calibrated and when it should be calibrated again.

R1-2 Equivalent Energy Conversion Factors

R1-2.1 *General*

R1-2.1.1 The conversion factors given in Table 2 of this guide are based on the following factory model;

- Clean room area: 4,400 m^2,
- Class 1: 20%,
- Class 1000: 80%,
- Wafer Size: 200 mm, and
- Wafer Start per month: 10,000.

R1-2.1.1.1 While the conversion factors derived from this model will not be exactly correct for other facilities, they can at least be used as a starting point for identifying the relative differences in energy impact among the utilities and materials listed in Table 1 of the guide.

R1-2.1.2 The conversion calculations of this guide can be used to express the estimated total equivalent energy that the equipment will consume in one year of use. The use rate measurements (units per hour) can be multiplied by the number of hours per year the equipment is estimated to be in the processing or idle state. This yields a total volume or mass of a utility or material consumed per year which is then multiplied by the energy conversion factor.

R1-2.1.3 Table R1-2 contains a calculation model and an example calculation.

R1-2.1.4 The heat load calculation follows a model that is different than the other items. It is shown in Table R1-3.

R1-2.2 *Estimated Hours per Year*

R1-2.2.1 It is recommended that the hours per year the equipment spends processing and idling be estimated as 6,132 and 2,190 respectively. This assumes 8,760 hours per year of opportunity. And, it assumes the equipment will be shut down (i.e. not consuming) for 5% of the 8,760 hours. To provide reporting commonality within the semiconductor industry, it is strongly recommended that alternate values not be used.

NOTE 1: The number of hours per year a piece of equipment spends processing or idling are not solely related to the equipment's "availability" (described in SEMI E10). The number also depends on the processing demands of the end user, which may be less than the equipment's availability.

R1-2.3 *Conversion Factor Basis*

R1-2.3.1 A key basis for some conversion factors is the condition(s) under which the conversion factor was developed. For example, the conversion factor for water supplied at 25°C might be different from the conversion factor for water supplied at room temperature because in addition to the energy used to distribute the water, energy is used to refrigerate the water.

R1-2.3.2 Table 2 of the guide includes some of the basis conditions for the recommended conversion factors. Where the actual conditions of the utility or material supply are different from these basis conditions, the conversion factor is less valid. There is no recommended method for adjusting the factor in response to these differences in all cases.

R1-2.4 *Alternate Conversion Factors*

R1-2.4.1 An equipment end user may have developed a set of conversion factors that they prefer for their business model. It is recommended that these also be considered.

R1-2.4.2 An alternate set of conversion factors for different equipment use regions may be useful for analyzing the impact of differing utility and material production efficiencies in those regions.

R1-2.4.3 A spreadsheet program can be used to show several different sets of conversion factors and the related conversion outcomes for a given set of utility and materials use rate data.

R1-2.4.4 The development of meaningful conversion factors requires a certain amount of data gathering and analysis. It is recommended that if alternate conversion factors are used, the supporting data and analysis be prepared and made available to interested parties for review.

R1-2.5 *Process Chemical Conversion Factors*

R1-2.5.1 It is likely that any process chemical conversion factor (i.e. the energy consumed to produce one cubic meter process chemical) is much greater than any other conversion factor listed in Table 3.

R1-2.5.2 A very rough analysis based on data from other industries, indicates, for example, that simple chemicals such as K20 or ethanol have energy equivalents much greater than 1000 kWh/m3.

R1-2.6 *Heat Load Calculation*

R1-2.6.1 The provided heat load calculation is based on the idea that all electrical energy supplied to the equipment becomes heat input which is transferred by one of three heat transfer modes.

R1-2.6.2 If there are other sources of heat within the equipment, such as chemical reactions, that are significant, they should also be considered part of the heat input.

R1-2.6.3 The heat energy is typically transferred by radiation and convection into the environment surrounding the equipment and remaining heat energy is transferred by convection to the process exhaust and conduction to the process cooling water. Theoretically all three heat transfer modes may be involved in for all heat transfer practices (tool to room, tool to exhaust, and tool to cooling water).

R1-2.6.4 The heat removed by the air and water is determined through calculations involving particular constants (i.e. specific heat and specific gravity).

R1-2.6.5 The heat load calculation is taken in four steps. First estimate the electrical energy delivered to the equipment per year. Next estimate the energy removed per year by exhausted air using the volume of air removed, the input-output air temperature difference, and the "Removal via Air" conversion factor. Then estimate the energy removed per year by cooling water in a similar manner, using the “Removal via Water” conversion factor. Finally subtract the last two energy values from the first to get the heat load of the equipment that is transferred to the room in which the equipment resides.

R1-2.6.6 Once the room heat load of the equipment has been estimated, the “Heat Load Burden” conversion factor can be used to express the energy required to remove that heat from the equipment environment.

R1-2.7 *Electrical Energy*

R1-2.7.1 A conversion factor of 1 is presented for electrical energy. The value thus calculated is the electrical energy supplied to the equipment.

R1-2.7.2 The amount of energy required to generate the electricity is not addressed by this conversion factor of 1. This additional detail may be useful, but the applicable conversion factor will depend on the technologies used to generate and distribute the electricity that is used.

NOTE 2: For example, the energy content of coal is approximately 8000 kWh per ton. If the electricity provider must burn one ton of coal to generate 6000 kWh of electrical energy, the electrical energy conversion factor could be set to 1.33 (no units) to express the actual energy required to produce 1 kWh of electrical energy.

Table R1-2 Energy Conversion Calculation Model and Example

Calculation Model $\begin{bmatrix}\text{Use-rate Measurement}\\ (\textit{processing}\text{ or }\textit{idling})\end{bmatrix} \times \begin{bmatrix}\text{Hours per Year}\\ (\textit{processing}\text{ or }\textit{idling})\end{bmatrix} \times \begin{bmatrix}\text{Energy}\\ \text{Conversion}\\ \text{Factor}\end{bmatrix} = \begin{matrix}\text{Estimated Energy}\\ \text{Consumed}\\ \text{per Year}\end{matrix}$ Estimated Hours per Year: Processing = 6132; Idling = 2190
Example Calculation (processing) Cooling Water (20-25°C) for recipe “X” Use rate measured during processing: 0.500 gal/min = 0.114 m^3/hr Annual amount used for processing: 0.114 m^3/hr x 6,132 hr = 698 m^3 Estimated annual energy equivalent: 698 m^3 x 1.78 kWh/m^3 = 124x10^1 kWh

Table R1-3 Heat Load Calculation Model and Example

Calculation Model 1 $\begin{bmatrix}\text{Heat Input}\\ \text{per Year}\end{bmatrix} = \begin{bmatrix}\textit{Electrical}\text{ energy input to}\\ \text{equipment per year}\end{bmatrix} + \begin{bmatrix}\textit{Other}\text{ Heat Sources}\\ (\textit{e.g. chemical reactions})\end{bmatrix}$ 2 $\begin{bmatrix}\text{Heat Removal}\\ \text{per Year}\\ \textit{air}\end{bmatrix} = \begin{bmatrix}\text{Volume of air}\\ \text{exhausted from}\\ \text{equipment per year}\end{bmatrix} \times \begin{bmatrix}\text{(Inlet air temp)} -\\ \text{(Outlet air temp)}\end{bmatrix} \times \underbrace{\frac{3.24\text{x}10^{-4}\text{ kWh}}{m^3\ °C}}_{\text{Removal via Air Conv. Factor}}$ 3 $\begin{bmatrix}\text{Heat Removal}\\ \text{per Year}\\ \textit{water}\end{bmatrix} = \begin{bmatrix}\text{Volume of water}\\ \text{exhausted from}\\ \text{equipment per year}\end{bmatrix} \times \begin{bmatrix}\text{(Inlet water temp)} -\\ \text{(Outlet water temp)}\end{bmatrix} \times \underbrace{\frac{1.16\text{ kWh}}{m^3\ °C}}_{\text{Removal via Water Conv. Factor}}$ 4 $\boxed{\begin{bmatrix}\text{Heat Input}\\ \text{per Year}\end{bmatrix} - \begin{bmatrix}\text{Heat Removal}\\ \text{per Year}\\ \textit{air}\end{bmatrix} - \begin{bmatrix}\text{Heat Removal}\\ \text{per Year}\\ \textit{water}\end{bmatrix} = \begin{matrix}\textbf{Estimated Heat}\\ \textbf{Burden per Year}\end{matrix}}$

Example Calculation (idling) for Recipe "X"

Electricity
Mean real power = 4.16E + 1 kW
Heat Input per Year = 4.16E + 1 kW × 2190 hr = 9.11E + 4 kWh *(no other heat input sources)*

Air Exhaust
Specified source temperature = 18°C Measured average output temperature = 23°C
Mean temperature difference = 5°C Measured exhaust rate = 50 cfm (5.1E + 3 m^3/hr)
Volume used per year = 5.1E + 3 m^3/hr × 2190 hr = 1.12E + 7 m^3
Heat Removal per year = (5°C × 1.12E + 7 m^3 × 3.24E − 4 kWh/(m^3°C) = 1.81E + 4 kWh

Cooling Water
Specified ambient temperature = 20°C Measured average output temperature = 22°C
Mean temperature difference = 2°C Measured flow rate = 1 L/m (0.06 m^3/hr)
Volume used per year = 0.06 m^3/hr × 2190 hr = 1E + 2 m^3
Heat Removal per year = (2°C × 1E + 2 m^3 × 1.16 kWh/(m^3°C) = 2E + 2 kWh

Room Heat Burden
9.11E + 4 kWh – 1.81E + 4 kWh – 2E + 2 kWh = 7.28E + 4 kWh

NOTICE: SEMI makes no warranties or representations as to the suitability of the standards set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature, respecting any materials or equipment mentioned herein. These standards are subject to change without notice.

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SEMI S24-0705
SAFETY GUIDELINE FOR MULTI-EMPLOYER WORK AREAS

This specification was technically approved by the global Environmental Health and Safety Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on May 20, 2005. It was available at www.semi.org in June 2005 and on CD-ROM in July 2005.

1 Purpose

1.1 This safety guideline provides methods to establish safe working environment where personnel of different companies (entities) share a work area in a fab or where work by employees of one company in one area may comprise a hazard to employees of another company in an adjacent area.

2 Scope

2.1 *Applicability*

2.1.1 This Safety Guideline applies to work areas shared by personnel of different companies, such as equipment suppliers, facility suppliers, user's contractors and users.

2.1.2 This Safety Guideline applies where work by employees of one company in one work area comprises a hazard to employees of another company in an adjacent work area.

2.1.3 The work activities to which this safety guideline applies include installation, start-up, de-installation, wafer size conversion, and overhaul.

2.2 *Criteria Established*

2.2.1 This guideline establishes criteria for the user's, supplier's and contractor's responsibility for a safe working environment.

2.2.2 This guideline establishes criteria for the responsibilities of each supplier's and contractor's work supervisors.

2.2.3 This guideline establishes criteria for a Safety Supervisors' Communication Council (SSCC) as the organization to ensure human safety in multi-employer work areas and where work by employees of one company in one work area comprises a hazard to employee of another company in an adjacent work area.

2.2.4 This guideline establishes criteria for methods of safety patrol with the user's support in multi-employer work areas and where work by employees of one company in one work area comprises a hazard to employees of another company in an adjacent work area.

2.2.5 This guideline contains the following sections:

- Purpose
- Scope
- Limitation
- Referenced Standards
- Terminology
- General Concept
- User Actions
- Work Supervisor
- Safety Supervisors' Communication Council (SSCC)
- Safety Patrol

NOTE 1: An example of observation check sheet for the safety patrol is given in the RI 1.

NOTICE: This safety guideline does not purport to address all of the safety issues associated with its use. It is the responsibility of the users of this safety guideline to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 This safety guideline is not intended to supersede the applicable codes and regulations of the region where the equipment is used.

4 Referenced Standards and Documents

4.1 *SEMI Standards*

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

SEMI S19 — Safety Guideline for Training of Semiconductor Manufacturing Equipment Installation, Maintenance and Service Personnel

SEMI S21 — Safety Guideline for Worker Protection

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

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *FPD* — Flat Panel Display

5.1.2 *PPE* — Personal Protective Equipment

5.1.3 *SSCC* — Safety Supervisors' Communication Council

5.2 *Definitions*

5.2.1 Definitions in SEMI S2, SEMI S19 and SEMI S21 are incorporated herein by reference, unless the term is defined within this section.

5.2.2 *abnormality* — a condition or behavior different from normal or predetermined state that can result in an incident or accident.

5.2.3 *adjacent work area* — a work area that shares a common boundary with the work area being considered. The common boundary may separate the areas horizontally (e.g., the areas are on opposite sides of a wall) or vertically (e.g., one work area is in a cleanroom and the other in the subfab directly underneath it).

5.2.4 *contractor* — a company hired to accomplish a contractually specified scope of work, such as constructing a facility or providing service.

5.2.5 *de-installation* — the process of disconnecting, disassembling, and moving semiconductor or FPD manufacturing equipment from its point of installation, including movement of assemblies and further preparation (e.g., isolating, decontaminating, component disposal) of chemically contaminated semiconductor or FPD manufacturing equipment for a safe move.

5.2.6 *equipment supplier* — party who provides equipment to and communicates directly with the user. A supplier may be a manufacturer, an equipment distributor, or an equipment representative.

5.2.7 *fab* — a facility in which semiconductor devices or flat panel displays are manufactured.

5.2.8 *facility supplier* — party who provides a facility or facility service (e.g., nitrogen) to, and directly communicates with, the user. A facility supplier may be a construction company, a manufacturer or distributor of facility equipment (e.g., deionization systems), or a facility service provider.

5.2.9 *installation* — the activities performed after the equipment is received at a user site through preparation for initial service, including transportation, lifting, uncrating, placement, leveling, and facilities fit up. [SEMI S8]

5.2.10 *multi-employer fab* — a fab in which employees of more than one company work. The workers may or may not be present at the same time for a fab to be considered "multi-employer".

5.2.11 *multi-employer work area* — a work area in which employees of more than one company work. The workers may or may not be present at the same time for an area to be considered “multi-employer”.

5.2.12 *overhaul* — major disassembly, replacement of components as necessary, and reassembly.

5.2.13 *start-up* — the initial energization of semiconductor or FPD manufacturing equipment from each source of energy that may introduce a hazard to the semiconductor or FPD manufacturing equipment itself, the persons performing the installation, or the facility.

5.2.14 *supplier* — an equipment supplier or facility supplier.

5.2.15 *unit of work* — the extent of work which is directly controllable by a supervisor.

5.2.16 *user* — party who acquires equipment for the purpose of using it to manufacture semiconductors or FPDs.

5.2.17 *work area* — room or defined space where semiconductor or FPD manufacturing equipment is located and where workers are present. This can include service chases and sub-fab areas.

5.2.18 *work supervisor* — person who manages workers directly as a team leader to conduct a unit of work.

6 General Concepts

6.1 The users, suppliers and contractors should reduce risks in their own tasks and have their people work safely.

6.2 The user should coordinate the work schedules of the suppliers and the contractors who work simultaneously in the multi-employer and adjacent work areas.

6.2.1 The user should explain to each supplier or contractor how to communicate unexpected schedule changes to the affected parties.

6.2.2 Each supplier or contractor should submit a work schedule through whole tasks before starting an initial task. The supplier or contractor should submit a revised schedule to the user at every update.

6.2.3 Based on the work schedule, the user should provide the necessary safety information such as PPE, safety alarms, evacuation route, and safety devices (safety net, eye shower, fall protection, etc.) to its employees and to the affected suppliers and contractors.

7 User Actions

7.1 The user should provide the safe working environment for all people who work in its fab. In order to do so, the user should also encourage mutual communication among the suppliers and contractors.

7.1.1 *Safety Management Plan Notification* — Based on the work process, work schedule, and facility layout plan, the user should disclose the safety management plan during the installation/overhaul and startup period including such items as fundamental policy of safety management, target, and important points of hazard prevention.

7.1.2 Provision of safety net and anchorage (hookup facility) point for personal fall protection equipment (safety harnesses) should be included in the safety management plan.

7.2 The user should establish a Safety Supervisors’ Communication Council (SSCC).

7.3 The user should conduct a SSCC meeting in which representatives of the user and all the suppliers and the contractors should participate. The suppliers and the contractors should attend the SSCC meeting each workday.

7.4 The user should coordinate the suppliers’ and the contractors’ workers to work together safely.

7.5 When the workers of different companies conduct work separately in the upper and lower rooms of the same area, they should communicate each other and coordinate their work before and during the work, under the leadership of the user.

7.6 At work locations where the workers may face hazards, relevant work supervisors should communicate well and coordinate with each other for the work under the leadership of the user.

7.7 The user should instruct the suppliers’ and the contractors’ workers so that their tasks should be carried out after setting up incident/accident preventive facilities and preparing PPE.

8 Work Supervisor

8.1 Each supplier should designate a responsible person, called “work supervisor”, as a representative of the supplier for each unit of work.

8.2 The work supervisor should also communicate with the user and other work supervisors and make efforts to reduce the risk to the employees of all of the employers.

8.3 The work supervisor should make himself/herself identifiable by others by wearing an identifying item, such as colored cap, colored band, or badge.

NOTE 2: We recommend identification method is consistent for all supervisors at the given site.

8.4 When the work supervisor leaves the workplace, he/she should transfer his/her responsibility to his/her substitute.

8.5 Tasks of the Work Supervisor — The work supervisor should:

8.5.1 Attend the SSCC meeting.

8.5.2 Present the instructions from the SSCC meeting and safety patrol results to the workers.

8.5.3 Adjust each work schedule with the user and other suppliers or contractors and identify hazardous areas and restricted areas in multi-employer work areas.

8.5.4 Identify the hazardous and restricted areas to the workers.

8.5.5 Conduct a job hazard analysis before work and share the results with all the workers in order to awaken their awareness to hazards and to encourage them to take proper measures.

8.5.6 Put up warning indications identified by SSCC.

8.5.7 Conduct safety patrol on the workplace and observe the adjacent workareas. For avoiding Intellectual Property problems, the SSCC meeting should deal with Intellectual Property issues.

8.5.8 In case of equipment trouble affecting an adjacent work area, notify the user and people working there of the abnormality.

NOTE 3: The following 14 additional tasks are recommended for consideration.

- Prepare a work instruction on the basis of work schedule and notify the workers of it.
- Visually inspect the user cleanroom and its associated facilities as well as all of the plant before starting to work.
- Check facilities for eyewash, shower, anchorage, fire fighting and emergency evacuation.
- Give work instruction to workers after confirming that no unsafe condition exists around the workplace.
- Allocate workers properly in terms of manpower, skill level, prioritization of units of work, schedule, etc., so that the risks should be appropriately managed.
- Carry out arrangement and inspection of tools and jigs and PPE to be used.
- Check if workers are physically able to do a task.
- Give instruction to the relevant worker and have him/her correct it on the spot, whenever unsafe behavior or situation is witnessed.
- Conduct housekeeping and make due preparation for the next day.
- Report work progress status to the user as well as to the superior of the work supervisor.
- Consult with his/her superior and the user in case an incident or accident happens.

9 Safety Supervisors’ Communication Council (SSCC)

9.1 *Organization of the SSCC*

9.1.1 The SSCC consists of representatives of the user and all the suppliers and the contractors. The SSCC meeting should be held by the user every workday to present the work schedule and work layout plan, review work procedures, identify what are unacceptable risks, and discuss how to reduce the risks to acceptable level.

9.1.2 The organization of the SSCC should be as described below. In addition to the user representative, one representative of each facility or equipment supplier and contractor should participate in the council.

SSCC members

9.1.2.1 *User Side*

- EHS Manager
- Facility Administrator(s)
- Equipment Administrator(s)

9.1.2.2 *Supplier Side*

- Each Facility Supplier and its contractors
- Each Equipment Supplier and its contractors
- Each group of independent contractors

9.1.2.3 *Responsibilities of SSCC members*

9.1.2.3.1 An EHS Manager, who is the user’s representative on all kinds of EHS matters, should hold and chair the council meeting and control the council tasks.

NOTE 4: An EHS Manager should assign his/ her representative for his/ her absence due to an unavoidable circumstance.

9.1.2.3.2 An EHS Manager of the user should provide the user’s safety requirements to suppliers and contractors, review work procedures of suppliers and contractors, provide guidance if required, and coordinate safety control.

9.1.2.3.3 Each supplier and contractor should make its workers understand the user's safety requirements, report its own work plan in the cases specified in the ¶9.4, grasp any work plan of other suppliers or contractors that would affect to its own work, and let its own workers know it. Each supplier and contractor should participate in the safety patrol and take a corrective action if the patrol points out any unsafe state or safety violation by its own worker or work area.

9.1.2.4 *Example of Organization Chart of the SSCC*

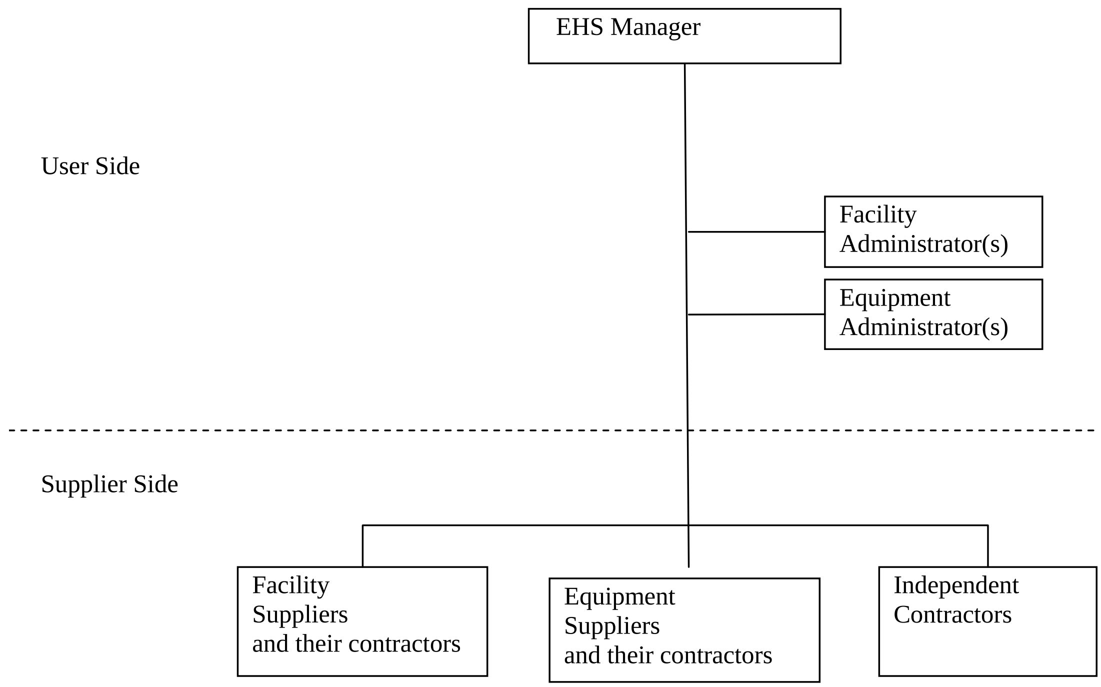

Table 1
Example of Organization Chart of the SSCC

9.2 *Role of the SSCC*

9.2.1 Review and discuss all the safety issues (including concerns escalated by employees) about perceived or obvious unsafe conditions, even though not listed below.

9.2.2 Review the safety of installation/overhaul/startup work based on the work procedure and work schedule.

9.2.2.1 Identify each hazardous task and review the appropriate work procedures.

9.2.2.2 Share the incident/accident information and recurrence preventive actions.

9.2.2.3 Follow the user safety rules. Verify all workers are trained to perform tasks assigned to them.

9.2.2.4 Specify communication channel on hazardous work among affected suppliers and contractors.

9.2.2.5 Share the update of work status.

9.2.2.6 Discuss how to eliminate or mitigate each difficulty reported by safety patrol team.

9.2.2.7 Conduct safety patrol, report the results, such as unsafe action or violation, and take corrective action.

NOTE 5: The SSCC should discuss how to avoid intellectual property issues that might be generated when observing adjacent work areas at a safety patrol.

9.2.2.8 Inform the affected employees how to respond including evacuation route and method in an emergency.

9.3 *Specific activities of the SSCC*

9.3.1 Establish a communication route from the user to the supplier/contractor workers so that results of the SSCC meeting or the safety patrol can be conveyed to everyone smoothly each time. The workers should communicate with each other and coordinate their work by informing each other of their work progress under the leadership of the user.

9.3.2 Have everyone know and follow the instruction of the incident/accident prevention measures after confirming the work procedures based on the work schedule and the work procedures of the adjacent work area.

9.3.3 Cooperate with the user in their safety training so that the user safety rules will be known to everyone and fully carried out.

9.3.4 Have each SSCC member report his/her respective work schedules and contents at respective work sites to the council.

9.3.5 When conflict occurs among the schedules, adjust each work schedule among the user and affected suppliers/contractors, and identify hazardous areas and restricted areas in multi-employer work areas. Notify each company's workers of the adjustments.

9.3.6 Conduct safety patrol in the workplace and, if any unsafe condition, place or behavior is found, give proper advice or instruction to the relevant worker on the spot and report it to the council.

9.3.7 Instruct everyone of the evacuation procedures.

9.3.8 Identify common warning signs.

9.3.9 Share all kinds of safety topics of the previous day.

9.4 *Specific things to be reported to the SSCC*

9.4.1 Floor opening or closing

9.4.2 Work performed on elevated surface

9.4.3 Using a scaffold, stepladder or ladder

9.4.4 Upper floor work or lower floor work

9.4.5 Starting gas or liquid chemical supply in a pipe

9.4.6 Turning on the facility electrical supply to the equipment

9.4.7 There is a possibility of affecting to an adjacent work area.

9.4.8 Having witnessed or caused an incident/accident

9.5 *Inauguration of the SSCC*

9.5.1 When two or more suppliers/contractors are conducting or planning installation, startup, or servicing of equipment in the user fab simultaneously, the user should inaugurate Safety Supervisors' Communication Council.

9.5.2 The user should confirm:

- a supplier/contractor name,
- number of workers,
- a work supervisor's name and how to contact him/her,
- equipment name,
- each tool name for the work,
- qualification required for the work,
- work contents, and
- a training record of each worker.

9.5.2.1 After confirming above, the user should start the council activities, and each council members should carry out their roles. (Refer to ¶9.2.)

9.6 *Enrollment in the SSCC*

9.6.1 Suppliers planning to conduct installation, startup or service work and facility work should report their work schedule to the user. Submission of the work schedule to the user automatically enrolls such suppliers to the SSCC if the SSCC is already set up.

9.6.2 After receiving a work schedule report from a newly enrolling supplier/contractor, the user should report the name and contact of the new supplier/contractor to the other suppliers and contractors working in the same area.

NOTE 6: EXCEPTION — In case of a resource constraint on site for a supplier/contractor, its attendance in the daily SSCC meeting should be determined in accordance with the user's instruction.

9.7 *Withdrawal from the SSCC*

9.7.1 A supplier or contractor who has completed installation, startup or service work, or facility work should be automatically withdrawn from the SSCC by reporting the completion of its work to the user.

9.7.2 The user should report the company name and contact of the withdrawn supplier/contractor to the other suppliers/contractors working in the same area through the SSCC.

9.8 *Dissolution of the SSCC*

9.8.1 The user should announce the dissolution of the SSCC when the number of suppliers/contractors who are conducting installation, startup or service work in an area becomes only one.

10 Safety Patrol

10.1 The SSCC should conduct a safety patrol at least once a week. The SSCC should ask the user to participate in the patrol whenever possible.

10.1.1 *Purpose of Safety Patrol* — The purpose of the safety patrol is to verify that the workers are complying with the rules specified by the user or the SSCC, and to eliminate any unsafe condition or behavior through the interactive job hazard analysis conducted by the suppliers and contractors working at the same area.

10.2 *Execution of Safety Patrol*

10.2.1 The SSCC should organize the Safety Patrol Team(s), which consist(s) of the members of the SSCC, as the execution body.

10.2.2 The SSCC should decide the members of the team, the area to be covered, and the frequency of the patrol.

10.2.3 *Points to observe during Safety Patrol*

10.2.3.1 Warning indications and signs

10.2.3.2 Housekeeping practices around work area

10.2.3.3 Sound execution of the items specified in ¶9.3 and ¶9.4

10.2.3.4 Other points specified by the SSCC

10.2.3.5 Other safety concerns that may affect to multiple suppliers or contractors

10.2.4 If a Safety Patrol Team noticed any unsafe condition or behavior during the patrol, the Team should give an instruction to the worker(s) concerned on the spot and also report the fact to the SSCC.

10.2.5 The SSCC should take a necessary action or ask the supplier or contractor concerned to take a necessary action to improve or eliminate the unsafe condition or behavior observed by the Safety Patrol.

RELATED INFORMATION 1
Observation Check Sheet for the Safety Patrol

NOTICE: This related information is not an official part of SEMI S24 and was derived from work of the Task Force. This Related Information was approved for publication by letter ballot on May 20, 2005.

R1-1 Observation Check Sheet for the Safety Patrol

R1-1.1 The following document (Observation Check Sheet) is an example of the check sheet for the safety patrol.

Table R1-1 Observation Check Sheet

Observation Check Sheet

Year/Month/Day

Country		
Company	Fab.	Bldg.
Name	Dept.	Company Name
Name	Dept.	Company Name

Note: For each category, type or write the items in the blank space under unsafe condition and unsafe behavior columns.

	Items to be observed(*)	Unsafe Condition	Unsafe Behavior
A			
B			
C			
D			
E			
F			
G			
H			
I	Others		

Note: (*) means equipment, facility, smell, work procedure, alert sign, housekeeping, etc.

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SEMI ME1392-0305
GUIDE FOR ANGLE RESOLVED OPTICAL SCATTER MEASUREMENTS ON SPECULAR OR DIFFUSE SURFACES

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1 Purpose

1.1 The microroughness and contamination due to particulates and films on silicon wafers are interrogated with varying forms of light scattering techniques. The angular distribution of light scattered by semiconductor surfaces is a generalized basis for most scanning surface inspection systems and as such may be used to cross-correlate various tools.

1.2 The angular distribution of scatter from optically smooth surfaces, such as polished silicon wafers, can be used to calculate surface parameters or reveal surface characteristics. For example, the total scatter found by integrating the bidirectional reflectance distribution function (BRDF) over the hemisphere can be related to surface roughness. The amount of scatter at a given scatter angle can be associated with a specific surface spatial frequency.

1.3 The angular distribution of scatter is a general property of surfaces that may have direct consequences. Scatter from mirrors and other components in an optical system can be the limiting factor in resolution or optical signal to noise level. Scatter can be an important design parameter for telescopes. Scatter measurements are crucial to correct operation of ring laser gyros. Scatter from a painted surface, such as on automobiles, can influence sales appeal.

2 Scope

2.1 This guide explains a procedure for the determination of the amount and angular distribution of optical scatter from an opaque surface. In particular it focuses on measurement of the BRDF, which is a convenient and well accepted means of expressing optical scatter levels for many purposes.[1,2] Additional data presentation formats described in Related Information 1 have advantages for certain applications. Surface parameters can be calculated from optical scatter data when assumptions are made about model relationships. Some of these extrapolated parameters are described in Related Information 2.

2.2 Optical scatter from an opaque surface results from surface topography, surface contamination, and subsurface effects. It is the user's responsibility to be certain that measured scatter levels are ascribed to the correct mechanism. Scatter from small amounts of contamination can easily dominate the scatter from a smooth surface. Likewise, subsurface effects may play a more important scatter role than typically realized when surfaces are superpolished.

2.3 This guide does not provide a method to extrapolate data for one wavelength from data for any other wavelength. Data taken at particular incident and scatter directions are not extrapolated to other directions. In other words, no wavelength or angle scaling is to be inferred from this guide. Normally the user must make measurements at the wavelengths and angles of interest.

2.4 This guide applies only to BRDF measurements on opaque samples. It does not apply to scatter from translucent or transparent materials. There are subtle complications which affect measurement of translucent or transparent materials that are best addressed in separate standards (see, for example, ASTM Practice E 167 and ASTM Guide E 179).

2.5 The wavelengths for which this guide applies include the ultraviolet, visible, and infrared regions. Difficulty in obtaining appropriate sources, detectors, and low scatter optics complicate its practical application at wavelengths less than about 0.25 μm. Diffraction effects that start to become important for wavelengths greater than 15 μm

1 Nicodemus, Fred E., "Directional Reflectance and Emissivity of an Opaque Object," *Applied Optics* **4**, 767 (1965).

2 Nicodemus, F. E., Richmond, J. C., and Hsia, J. J., "Geometrical Considerations and Nomenclature for Reflectance," *NBS Monograph 160*, 1977.

complicate its practical application at longer wavelengths. Diffraction effects can be properly dealt with in scatter measurements,[3] but they are not discussed in this practice.

2.6 Any experimental parameter is a possible variable. Parameters that remain constant during a measurement sequence are reported as header information for the tabular data set. Related Information 3 gives a suggested reporting format that is adaptable to varying any of the sample or system parameters.

2.7 This guide applies to flat or curved samples of arbitrary shape. However, only a flat, circular sample is addressed in the discussion and examples. It is the user's responsibility to define an appropriate sample coordinate system to specify the measurement location on the sample surface for samples that are not flat.

2.8 The apparatus and measurement procedure are generic, so that specific instruments are neither excluded nor implied in the use of this guide.

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Referenced Standards

3.1 *SEMI Standards*

SEMI M20 — Practice for Establishing a Wafer Coordinate System

SEMI MF1048 — Test Method for Measuring the Effective Surface Roughness of Optical Components by Total Integrated Scattering

3.2 *ASTM Standards*

E 167 — Practice for Goniophotometry of Objects and Materials[4]

E 179 — Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials[4]

E 284 — Terminology Relating to Appearance[4]

3.3 *ANSI Standard*

ANSI/ASME B46.1— Surface Texture (Surface Roughness, Waviness, and Lay)[5]

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

4 Terminology

4.1 Definitions of terms not included here will be found in Terminology E 284 or ANSI Standard B 46.1. Additional graphic information will be found in Figures A1-1 through A1-3 in Appendix 1.

4.2 *Definitions*

4.2.1 *angle of incidence, θ_I,* — polar angle between the central ray of the incident flux and the *ZB* axis, normal to the sample surface.

4.2.2 *beam coordinate system, XB YB ZB* — a Cartesian coordinate system with the origin on the central ray of the incident flux at the sample surface, the *XB* axis in the plane of incidence (PLIN) and the *ZB* axis normal to the surface.

4.2.2.1 *Discussion* — The angle of incidence, scatter angle, and incident and scatter azimuth angles are defined with respect to the beam coordinate system. This coordinate system is illustrated in Figure A1-1.

3 Smith, Sheldon M., "Reflectance of AMES 24E, Infrablack and Martin Black," SPIE **967**, 251 (1988).

4 *Annual Book of ASTM Standards*, Vol 06.01, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Telephone: 610-832-9500, Fax: 610-832-9555, Website: www.astm.org.

5 American National Standards Institute, New York Office: 25 West 43rd Street, New York, NY 10036, USA. Telephone: 212-642-4900; Fax: 212-398-0023, Website: www.ansi.org.

4.2.3 *bidirectional reflectance distribution function, BRDF* — the sample radiance divided by the sample irradiance.

4.2.3.1 *Discussion* — The procedures given in this practice are correct only if the field of view (FOV) determined by the receiver field stop is sufficiently large to include the entire illuminated area for all angles of incidence of interest. BRDF is a differential function dependent on the wavelength, incident direction, scatter direction, and polarization states of the incident and scattered fluxes. In practice, it is calculated from the average radiance divided by the average irradiance as follows:

$$\mathrm{BRDF} = \frac{L_e}{E_e} = \frac{\frac{P_s}{\Omega A \cos\theta_s}}{\frac{P_i}{A}} = \frac{P_s}{P_i \Omega \cos\theta_s} \left[\mathrm{sr}^{-1}\right] \quad (1)$$

The BRDF of a lambertian surface is independent of scatter direction. If a surface scatters nonuniformly from one position to another then a series of measurements over the sample surface must be averaged to obtain suitable statistical uncertainty. Nonuniformity may be caused by irregularity of the surface microughness or film, optical property nonhomogeneity, or subsurface defects.

4.2.4 *cosine-corrected BRDF* — the BRDF times the cosine of the scatter polar angle.

4.2.4.1 *Discussion* — The $\cos\theta_s$ in the BRDF definition is a result of the radiometric definition of BRDF. It is sometimes useful to express the scattered field as normalized scatter intensity [(watts scattered/solid angle)/incident power] as a function of scatter direction. This is accomplished by multiplying the BRDF by $\cos\theta_s$.

4.2.5 *delta beta,* $\Delta\beta$ — the projection of $\Delta\beta$ onto the *XB-YB* plane, that is, the delta theta angle measured in direction cosine space.

4.2.5.1 *Discussion* — For scatter in the PLIN, $\Delta\beta = \sin\theta_s - \sin\theta_i$. For scatter out of the plane of incidence (PLIN), the calculation of $\Delta\beta$ becomes more complicated (see §R1-2).

4.2.6 *delta theta,* $\Delta\theta$ — the angle between the specular direction and the scatter direction.

4.2.7 *incident azimuth angle,* ϕ_i — the fixed 180° angle from the *XB* axis to the projection of the incident direction onto the *XB-YB* plane.

4.2.7.1 *Discussion* — It is convenient to use a beam coordinate system (refer to Figure A1-2), in which ϕ_i = 180°, since this makes ϕ_s the correct angle to use directly in the familiar form of the grating equation. Conversion to a sample coordinate system is straight forward, provided the sample location and rotation are known.

4.2.8 *incident direction* — the central ray of the incident flux specified by θ_i and ϕ_i in the beam coordinate system.

4.2.9 *incident power,* P_i — the radiant flux incident on the sample.

4.2.9.1 *Discussion* — For relative BRDF measurements, the incident power is not measured directly. For absolute BRDF measurements it is important to verify the linearity, and if necessary correct for the nonlinearity, of the detector system over the range from the incident power level down to the scatter level which may be as many as 13 to 15 orders of magnitude lower. If the same detector is used to measure the incident power and the scattered flux, then it is not necessary to correct for the detector responsivity; otherwise, the signal from each detector must be normalized by its responsivity.

4.2.10 *instrument signature* — the mean scatter level detected when there is no sample scatter present expressed as BRDF.

4.2.10.1 *Discussion* — Since BRDF is defined only for a surface, the instrument signature provides an equivalent BRDF for the no-sample situation. The limitation on instrument signature is normally stray scatter from instrument components and out-of-plane aperture position errors for receiver positions near the specular direction. For high grade electronic detection systems, at large scatter angles, the limitation on instrument signature is normally Rayleigh scatter from molecules within the volume of the incident light beam that is sampled by the receiver field of view. As θ_s approaches 90°, the accuracy of θ_s becomes important because of the $1/\cos\theta_s$ term in BRDF. The signature can be measured by scanning a very low scatter reference sample in which case the signature is adjusted by dividing by the reference sample reflectance. The signature is commonly measured by moving the receiver near the optical axis of the source and making an angle scan with no sample in the sample holder. It is necessary to furnish the instrument signature when reporting BRDF data so that the user can decide at what scatter direction the sample BRDF is lost in the signature. Preferably the signature is several decades below the sample data and can be ignored.

4.2.11 *noise equivalent BRDF, NEBRDF* — the root mean square (rms) of the noise fluctuation expressed as equivalent BRDF.

4.2.11.1 *Discussion* — Measurement precision is limited by the acceptable signal to noise ratio with respect to these fluctuations. It should be noted that although the detector noise is independent of θ_s, the NEBRDF increases at large values of θ_s because of the $1/\cos\theta_s$ factor. Measurement precision can also be limited by other experimental parameters as discussed in Section 10. The NEBRDF can be measured by blocking the source light.

4.2.12 *plane of incidence, PLIN,* — the plane containing the sample normal and central ray of the incident flux.

4.2.13 *receiver* — a system that generally contains apertures, filters and focusing optics that gathers the scatter signal over a known solid angle and transmits it to the scatter detector element.

4.2.14 *receiver solid angle, Ω* — the solid angle subtended by the receiver aperture stop from the sample origin.

4.2.15 *sample coordinate system* — a coordinate system fixed to the sample and used to specify position on the sample surface for the measurement.

4.2.15.1 *Discussion* — The sample coordinate system is application and sample specific. The Cartesian coordinate system shown in Figure A1-1 is recommended for flat samples. The origin is at the geometric center of the sample face with the *Z* axis normal to the sample. A fiducial mark must be shown at the periphery of the sample; it is most conveniently placed along either the *X* or *Y* axes. For silicon wafers, the fiducial mark is commonly placed on the periphery of the wafer at the −*Y*-axis as defined in SEMI M20.

4.2.16 *sample irradiance, E_e* — the radiant flux incident on the sample surface per unit area.

4.2.16.1 *Discussion* — In practice, E_e is an average calculated from the incident power, P_i, divided by the illuminated area, *A*. The incident flux should arrive from a single direction; however, the acceptable degree of collimation or amount of divergence is application specific and should be reported.

4.2.17 *sample radiance, L_e* — a differential quantity that is the reflected radiant flux per unit projected receiver solid angle per unit sample area.

4.2.17.1 *Discussion* — In practice, L_e is an average calculated from the scattered power, P_s, collected by the projected receiver solid angle, $\Omega \cdot \cos\theta_s$, from the illuminated area, *A*. The receiver aperture and distance from the sample determines Ω and the angular resolution of the instrument.

4.2.18 *scatter* — the radiant flux that has been redirected over a range of angles by interaction with the sample.

4.2.19 *scatter azimuth angle, ϕ_s,* — angle from the *XB* axis to the projection of the scatter direction onto the *XB-YB* plane.

4.2.20 *scatter direction* — the central ray of the collection solid angle of the scattered flux specified by θ_s and ϕ_s in the beam coordinate system.

4.2.21 *scatter plane* — the plane containing the central rays of the incident flux and the scatter direction.

4.2.22 *scatter polar angle, θ_s,* — polar angle between the central ray of the scattered flux and the *ZB* axis.

4.2.23 *specular direction* — the central ray of the reflected flux that lies in the PLIN with $\theta_s = \theta_i$ and $\phi_s = 0$.

5 Apparatus

5.1 *General* — Non-specular reflectometers or instruments[6] used to measure scattered light utilize some form of the five components described in this section. These components are described in a general manner so as to not exclude any particular type of scatter instrument. To achieve (θ_i, ϕ_i; θ_s, ϕ_s) positioning the instrument design must incorporate four angular degrees of freedom between the source, sample holder, and receiver assemblies.

6 Hsia, J. J. and Richmond, J. C., "A High Resolution Laser Bidirectional Reflectometer with Results on Several Optical Coatings," *J. Res. NBS-A. Physics and Chemistry* **80A**, 189-205 (1976).

5.2 *Source Assembly* — containing the source and associated optics to produce irradiance, E_e, on the sample over a specified spot area, *A*. If a broad band source is used, the wavelength selection technique should be specified. Depending on the bandwidth and selection techniques, the detector assembly may affect the wavelength sensitivity. If a laser source is used, it is usually sufficient to specify the center wavelength; however, it is sometimes necessary to be more specific, such as providing the particular line in a CO_2 laser.

5.2.1 A source monitor is used to correct for fluctuations in the source intensity. If it is located at the source output it only measures variations in the source power and is not sensitive to variations due to angular drift or downstream transmission. The source monitor should monitor incident power as close to the sample as possible while minimizing additional system scatter. Attention should be paid to possible laser mode hopping and consequent wander of the beam on spatial filter pinholes and to fluctuations in source polarization.

5.2.2 Collimated or slightly converging source light can be used to measure *BRDF*. Most instruments use a converging beam focused at the receiver. If the convergence angle is small, the uncertainty introduced by a non-unique angle of incidence is usually negligible. The same considerations apply if a curved sample is measured. It is the user's responsibility to assure that any spread in θ_i does not compromise the results. Normal practice limits convergence to f/20 or greater with a focus at the receiver to increase the angular resolution of measurements near the specular beam or diffraction peaks.

5.2.3 Typically the source assembly is fixed in position and variations in θ_i are made with the sample holder. Good reduction of the instrument signature requires baffling around the source assembly and use of a spatial filter to limit off-axis light. The final mirror (or lens) which directs light to the sample should have low scatter, since it contributes directly to small angle scatter in the instrument signature.

5.2.4 A means should be provided for controlling the polarization state of the incident flux as this can impact the measured BRDF. Orthogonal source polarization components (parallel, or *p*, and perpendicular, or *s*) are defined relative to the plane defined by the source direction and the sample surface normal.

5.2.5 Absorbing samples may be heated by the incident flux and may change their scatter characteristics, mechanically distort or burn. Special care must be taken with IR laser sources on absorbing samples.

5.3 *Sample Holder* — The sample holder should provide a secure mount for the sample that does not introduce any warp. The rotation axes of the stages that achieve the (θ_i, ϕ_i, θ_s ϕ_s) positioning must be relative to the sample front surface; this can be accomplished by orienting the sample holder or the source, or both, and receiver assemblies. Some sample mounts incorporate positioning stages for a raster scan of the sample surface at fixed incident and scatter angles. The sample mount must be kept unobtrusive so that it does not contribute stray flux to the signature or block large θ_s scatter.

5.4 *Beam Dump* — It is important to trap any specular reflection from the sample so that it cannot contribute to the scatter signal through lab/instrument reflections. Examples of beam dumps are black paper, a razor blade stack, absorbing glass plates, or a tapered blackened glass tube.

5.5 *Receiver Assembly* — If the system design includes angular degrees of freedom at the receiver for achieving the scatter direction, then the receiver assembly should normally have provisions for rotating about an axis on the front face of the sample in order to vary θ_s. If out of the PLIN measurements are required, the receiver assembly may also rotate out of the PLIN. This capability may also be provided by pitch, yaw, and roll of the sample, but it becomes more difficult to dump the specularly reflected beam.

5.5.1 The acceptance aperture for the receiver must be well defined, since the solid angle, Ω, subtended by the receiver aperture stop from the sample, is used in the BRDF calculation and defines the angular resolution. The field of view of the detector must include the entire irradiated area, *A*. There can be an exception to these requirements if a relative BRDF or relative total reflectance normalization is used. In that case it is the user's responsibility to ensure that the system parameters remain constant between measurements.

5.5.2 If the acceptance aperture is too small and a coherent source is used to irradiate the sample, speckle may cause strong, unpredictable variations in the scatter. This is a common problem when measuring diffuse (that is, rough) samples. It is sometimes desirable to spin a diffuse sample about its normal to average the effects of speckle while making a measurement. It is the user’s responsibility to ensure that BRDF features are not due to speckle. The user may wish to employ a variable aperture stop to trade sensitivity for angular resolution when measuring specular surfaces, since best angular resolution is needed near specular where BRDF has a steep slope. Best sensitivity is needed at larger angles where BRDF might approach the NEBRDF.

5.5.3 It may be necessary to use an optical bandpass filter on the detector to minimize acceptance of background light. This can also be accomplished by modulating the amplitude (with a mechanical chopper) of the source light, and using a synchronized, phase sensitive (lock-in) amplifier with the detector.

5.5.4 Since depolarization can occur in scattering, complete characterization of scatter requires measurements with a polarization analyzer at the receiver. The scatter reflux can be broken into perpendicular and parallel components that are respectively perpendicular and parallel to the scatter plane (see Figure A1-2).

6 Calibration and Normalization

6.1 *General* — Instrument calibration is often confused with measurement of P_i. Calibration of a BRDF instrument involves systematic standardization and verification of its quantitative results. Incident power must be measured for correct normalization of the scattered power. Absolute measurement of powers is not required as long as the P_s/P_i ratio is correctly measured. Alternatively, a reference sample can be used as a normalization reference.

6.2 *Calibration* — A leading cause of inaccuracy in BRDF measurement is a lack of instrument calibration. An error analysis of the four quantities defining the BRDF (P_i, P_s, Ω, θ_s) can help to accomplish a calibration.[7] Each of these four independent variables is a function of system parameters. For example, P_s depends on receiver linearity, electrical noise and system alignment parameters. The total error is also a function of incidence angle and scatter angle. It is reasonable to expect errors in the 3 to 10% range for measurements taken a few degrees from specular to about $\theta_s = 85°$. System nonlinearity is a major contributor to error in this central region. At either end of this central region errors rise dramatically. Near specular, this is caused by out of plane receiver position error, and near the grazing angle the increase is due to uncertainty in θ_s. Error is also a function of the type of sample being measured. For example, larger errors are expected in the relatively steep BRDF associated with specular samples than for the flatter response of a diffuse surface.

6.2.1 The receiver and preamplifier must be calibrated together over their useful operating range. The final result is a calibration curve showing relative optical power versus voltage for each preamplifier gain setting. Operating regimes are selected for each gain setting to avoid saturating the detector while remaining on a low gain setting. The source monitor must also be calibrated in the same way.

6.2.2 There are several ways to vary the optical power and make this calibration curve. Optical filters with a known attenuation can be used, but multiple reflections and coherent effects (interference between the two filter faces) can change the attenuation. An excellent method of changing the optical power at the receiver is by moving away from a diffuse source for $1/r^2$ attenuation. Other methods include crossed polarizers or changing the duty cycle of a chopper. The user must select an attenuation method with suitable reproducibility to perform the calibration.

6.2.3 The receiver and preamplifier each have a maximum output voltage to avoid saturation, but there is also a minimum electronic noise level which should be kept in mind to avoid reporting noise as BRDF. When electronic noise is expressed as NEBRDF, note that although the noise may be constant, NEBRDF depends on the receiver solid angle, Ω, the incident power, P_i, and $\cos\theta_s$. This means NEBRDF can be lowered by changing these system parameters.

6.2.4 A full system calibration is not required on a daily basis, but the system should be checked daily. This check can be accomplished by measuring the instrument signature and a stable reference sample that provides data over several decades. Changes from past results are an indication of calibration problems and the cause of the change must be determined. It is good operating practice to maintain a reference sample at the scatter facility for this calibration check. Recalibration must be accomplished when components are changed, repaired, or realigned. Include a data file number for the most recent reference sample measurement with every set of BRDF data as a record of instrument response in case the data set is questioned at a later time.

6.3 *Normalization* — There are four acceptable methods for normalizing the scattered power to the incident power. Each method is dependent on different measured parameters.

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7 Cady, F. M., Bjork, D. R., Rifkin, J., and Stover, J.C., "BRDF Error Analysis," *Proceedings* SPIE **1165**, 154-164 (1989).

6.3.1 *Absolute* — An absolute normalization is made by moving the receiver assembly onto the optical axis of the source with no sample in the sample holder. *This method depends on extending receiver calibration to high power levels*. The entire incident beam must enter the receiver assembly and a voltage, V_{di}, is recorded. If the unsaturated detector response is R_λ (watts/volt):

$$P_i = V_{di} R_\lambda \tag{2}$$

It is not necessary to know R_λ for the sample BRDF calculation if it remains constant. The source monitor voltage, V_{mi}, must also be recorded at this time.

6.3.2 *Relative BRDF* — A relative normalization is made by measuring a reference sample that has a known BRDF level. *This method depends on knowing the reference sample BRDF*. This reference sample is usually a high reflectance, diffuse surface. They are readily available for visible wavelengths and the BRDF is the same for a large range of θ_i and θ_s. Ideally the reference sample has a known BRDF that is similar to the unknown sample to be tested in both magnitude and incident/scatter directions, but this is rarely true. The reference sample should be spatially uniform and isotropic to alleviate alignment concerns.

6.3.2.1 The reference sample is inserted in the sample holder and a detector voltage, V_{di}, corresponding to the scattered light for the known BRDF is recorded. The following can now be calculated:

$$P_i = \frac{V_{di} R_\lambda}{\mathrm{BRDF}\ \Omega\ \cos\theta_s} \tag{3}$$

It is not necessary to know Ω or θ_s for the sample BRDF calculation if they remain constant. The source monitor voltage, V_{mi}, must also be recorded at this time.

6.3.3 *Relative Specular Reflectance* — An alternative relative normalization can be made with a specular reference sample having a known specular reflectance, *R*. *This method depends on knowing R for the same collection solid angle as used in the* P_i *measurement.*

6.3.3.1 Insert the specular reference sample in the sample holder and measure the detector voltage, V_{di}, for the entire specular beam into the receiver assembly. The following can now be calculated:

$$P_i = \frac{V_{di} R_\lambda}{R} \tag{4}$$

It is not necessary to know R_λ for the sample BRDF calculation if it remains constant. The source monitor voltage, V_{mi}, must also be recorded at this time.

6.3.4 *Relative Total Reflectance* — The fourth method involves integration of relative BRDF over the hemisphere and adjustment of constants to match the directional hemispherical reflectance, ρ (also referred to as total hemispherical reflectance). Normalization can only be accomplished after sufficient scatter data are accumulated to define the integral. *This method depends on a separately measured directional hemispherical reflectance and knowing relative scatter over the entire hemisphere*. It is best suited to isotropic, diffuse samples.

6.3.4.1 When sufficient scatter data has been accumulated the following integral is performed.

$$\rho_{calc} = \int_0^{2\pi} \int_0^{\pi/2} \mathrm{BRDF} \cos\theta_s \sin\theta_s \, \mathrm{d}\theta_s \, \mathrm{d}\phi_s \tag{5}$$

BRDF is obtained with constants, $V_d R_\lambda / P_i$, removed from the integral. These constants are adjusted to make ρ equal to the externally measured ρ. The constants are then returned to Equation 7 for calculation of absolute BRDF.

6.3.4.2 A perfectly reflecting (ρ = 1) and diffuse sample has constant BRDF and integration of the above equation shows that it is equal to $1/\pi$. A diffuse sample depolarizes incident plane polarized light, therefore care must be exercised so that the polarization state of the light is taken into account for both the scatter and directional hemispherical reflectance measurements.

7 Procedure

7.1 Sample cleanliness can be a significant factor in the scatter level. The user should adopt a procedure for cleaning samples prior to measurement and this cleaning procedure should be reported with the BRDF results.

7.2 Correct alignment of the source, sample, and receiver are essential for accurate BRDF measurements. A typical example of a subtle error that can be introduced by misalignment occurs when the receiver does not rotate in θ_s about the sample face. As θ_s increases, the receiver field-of-view “walks off” the illuminated area, *A*, and the measured BRDF is then lower than actual BRDF. Although it is not necessary to perform a total system alignment every day, alignment must be verified on a daily basis for movable components.

7.3 After cleaning the sample and verification of alignment, the sample is inserted in the sample holder. The detector voltage, V_d, and the source monitor voltage, V_m, are recorded for each parameter set of interest. For example, BRDF measured in the plane-of-incidence requires changing θ_s while holding other parameters constant. The measurement results consist of three columns of data for θ_s, V_d, and V_m. The constant parameters, θ_i and ϕ_s, are retained in the header information for this data set. Post processing is used to calculate BRDF and express the results in the desired tabular or graphical format, but P_s can be calculated at this time. In this calculation, the ratio of source monitor voltages is included to correct for variation of source intensity:

$$P_s = \frac{V_d R_\lambda V_{mi}}{V_m} \tag{6}$$

where V_{mi} = source monitor voltage (see ¶6.3.1).

7.4 BRDF can exhibit strong sensitivity to azimuthal orientation, spot size and position changes on the sample face. Good operating practice dictates checking for sensitivity to these and other system parameters.

8 Calculation

8.1 The BRDF of an unknown sample is calculated at each incident and scattered direction from the following relationship:

$$\text{BRDF} = \frac{P_s}{P_i \Omega \cos\theta_s} = \left(\frac{V_{mi}}{V_m}\right)\left[\frac{V_d R_\lambda}{P_i \Omega \cos\theta_s}\right] \quad [\text{sr}^{-1}] \tag{7}$$

The value of P_i is determined by the normalization method used. The correct angular variables may also be calculated in post processing with BRDF. In all cases θ_i and θ_s are referenced to the sample normal.

8.2 Many facilities prefer to store only raw data and calculate BRDF and display variables as required to produce a graph or data table. If data are sent to another facility, it is essential to convert to BRDF and the angular variables defined in this practice. A suggested reporting format is given in Related Information 3.

9 Report

9.1 BRDF data is expressed in tabular or graphical format as a function of the variable parameter. It is necessary to state the accuracy of angular measurements and the size of the receiver solid angle, Ω. These latter parameters are important for small angle scatter. It is usually meaningless to measure within 1° of specular or to measure very narrow “diffraction spikes” when Ω spans several degrees.

9.2 It is necessary to furnish the instrument signature with the sample BRDF data so that the user can make an informed decision about the angle where the sample’s scatter becomes lost in the signature. Correct comparison of the signature with BRDF data requires multiplying the signature by the sample's specular reflectance for that portion of the signature due to instrument scattered stray light (usually the case for θ_s near specular). The portion of the signature due to electronic noise is not reduced by the sample reflectance.

9.3 It is necessary to furnish the normalization method with BRDF data. If a relative normalization is used the source of the reference sample BRDF must be stated.

9.4 BRDF data can span many decades so it is usually expressed in base ten exponential form or plotted on a logarithmic scale.

9.5 Related Information 3 provides a reporting format suggested for use. This format is general in nature and allows for variation of any sample or system parameters.

10 Precision and Bias

10.1 *Precision* — The precision of the procedure outlined in this guide is inconclusive based on the results of an interlaboratory round robin conducted in 1988.[8] This round robin was conducted at a single wavelength (632.8 μm), angle of incidence (10°), polarization state (*s* incident) and with four specific sample surfaces. It was found that precision depends on the BRDF level and scatter angle.[9] Additional information on precision was accumulated in a 10.6 μm round robin conducted in 1989.[10]

10.1.1 A white diffuse sample with mean BRDF = 0.27/sr gave a fractional deviation (standard deviation of the 18 measurement sets divided by the mean BRDF) close to 17% at scatter angles from 15 to 70°. A black diffuse sample with mean BRDF = 0.01/sr gave fractional deviations from 24 to 39% depending on scatter angle. Specular mirrors gave fractional deviations from 31 to 134% depending on scatter angle. Variations were larger at large scatter angles where detector noise levels of some instruments and errors in θ_s had a large effect. These variations are much larger then expected from a typical error analysis.

10.2 *Bias* — There is no bias inherent in this practice. BRDF is a number derived from the ratio of physical parameters that can be specified in absolute units. However, individual laboratories may have measurement errors that lead to systematic offsets, such as an inaccurately measured solid angle. Other possible mechanisms are discussed in the literature.[9] It is not possible at this time to separate these systematic errors from bias; however, intralaboratory measurements on the same instrument typically repeat within 5%.[7]

11 Keywords

bidirectional reflectance distribution function (BRDF); diffuse; irradiance; power spectrum; radiance; reflectance; reflectance factor; roughness; scatter; specular; total integrated scatter

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8 Leonard, Thomas A. and Pantoliano, Michael, "BRDF Round Robin," *Proceedings* SPIE **967**, 226 (1988).

9 Leonard, Thomas A., "The Art of Optical Scatter Measurement," *Proceedings, Laser Induced Damage in Optical Materials: 1988 Symposium*, Special Publication 775 (National Institute of Standards and Technology, Gaithersburg, MD, 1988), pp. 42–47.

10 Leonard, Thomas A., Pantoliano, Michael, and Reilly, James, "Results of a CO_2 BRDF Round Robin," *Proceedings* SPIE **1165**, 444-449 (1989).