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LOW-SILVER BGA ASSEMBLY PHASE I – REFLOW CONSIDERATIONS AND JOINT HOMOGENEITY INITIAL REPORT

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ABSTRACT
Some Ball Grid Array suppliers are migrating their sphere alloys from SAC305 (3% Ag) or 405 (4% Ag) to alloys with lower silver contents. There are a numerous perceived benefits to this move in terms of cost and performance, but process compatibility and reliability concerns have yet to be addressed.

Process compatibility concerns stem from the fact that the low-silver SAC replacement alloys have higher melting temperatures than SAC305, approximately 227C as compared to 221C. Certain families of electronic assemblies, such as consumer portables, are often heat-sensitive and are reflowed in the low end of the established lead-free peak temperature range, typically 230-235C. The small temperature difference between the spheres' melting temperature and the peak reflow temperature raises questions about the reliability of the solder joints that are formed under this tight thermal margin. These are similar to the concerns raised with the backward compatibility of SAC305/405 spheres with tin-lead solder processes. Some of the solutions identified in the lead-free ball/tin-lead paste scenario may apply to the low-silver ball/SAC305 paste combination, but they require review for their applicability with this new set of mixed metals.

A study has been undertaken to characterize the influence of alloy type and reflow parameters on low-silver SAC spheres assembled with backward compatible pastes and profiles. The DOE combines low-silver sphere materials with tin-lead and lead-free solders at different

combinations of peak temperature and times above liquidus. Solder joint formation and reliability are assessed to provide a basis for developing practical reflow processing guidelines.

KEY WORDS: Lead-free, low silver, BGA, reflow, mixed metals

INTRODUCTION

Sometime with notification but often without, BGA component providers are changing the alloy of their lead-free balls. The SAC alloy family – a blend tin, silver and copper – remains the same, but the actual composition and melting point are changed by the reduction in silver. The most obvious benefit of this migration is the lower material cost. In addition to the potential financial benefits, there are also many scientific benefits to the reducing the silver content. Although the information that supports the migration to lower silver is limited, some of the currently perceived benefits of reducing silver content include:

- Improved drop and shock performance
- Suppression of Sn oxidation and improved wetting
- Lower copper dissolution rates in SMT joints
- Slower intermetallic growth under aging
- Less surface roughness
- Reduced intermetallic compounds and occurrences of silver tin platelets
- Elimination of under fill requirement in some cases

PROCESS CHALLENGES

Figure 1. Low Silver BGA sphere with SAC305 solder. Notice the solder reflowed, but the sphere did not collapse.

The narrow thermal margin between the liquidus temperature of the low silver spheres and the peak temperature of the assembly raises concerns about incomplete ball collapse and incomplete mixing of the solder alloy with the sphere material, resulting in non-homogenous solder joints.[4] A sphere with incomplete collapse is shown in Figure 1. This solder joint was formed under temperatures high enough to melt the SAC 305 solder, but too low to melt the SAC105 sphere.

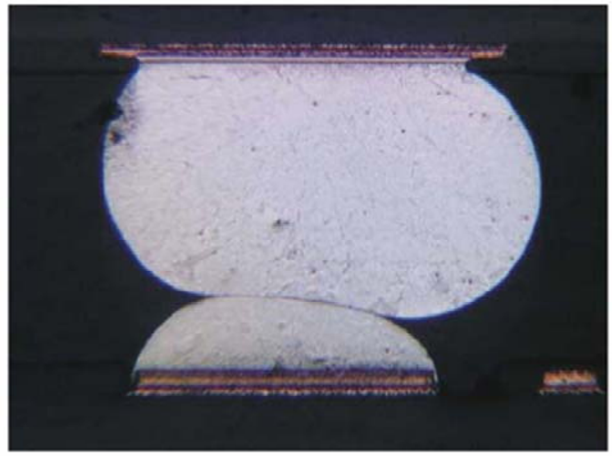

Figure 2. Head-in-pillow effect on BGA joint

This resembles a condition that is commonly referred to as "head-in-pillow" effect. Traditionally, head-in-pillow occurs in systems where both the sphere and the solder alloy are the same material, but an oxide layer at their interface prevents the two molten metals from mixing with each other. In the case of traditional head-in-pillow, both metals reach the liquidus state, and it's the oxide layer that prevents them from fusing into a single, contiguous entity. A typical head-in-pillow joint is shown in figure 2.

The only way to get the sphere and solder to fuse together is to raise the temperature of the sphere. This can be achieved by increasing either the peak reflow temperature or the time above liquidus, or a combination of both. Depending on the type of assembly being processed, increasing any aspect of the reflow profile can cause concern. Hotter or longer thermal excursions may induce excessive warpage to the PWB or package body, and the package body itself may be thermally exposed beyond its qualified rating as defined in J-STD-020-D.[1]

Full collapse of the sphere may not be necessary to achieve acceptable reliability of the solder joints, and partial or even full mixing of the two metals can be achieved without collapse. Mixing of the two different metals occurs via diffusion, which is a function of time and temperature, and will happen even if the sphere alloy remains in its solidus state through the entire heat cycle.

If full collapse is not necessary, and partial mixing of the solder joints is adequate, the following questions arise:

- How much mixing is enough to deem a solder joint reliable in its application or end use?
- What is the minimum thermal excursion required to achieve that level of mixing?

EXPERIMENTAL DESIGN

The objective of this study was to define the minimum reflow requirements for low silver BGA spheres in board-level assembly, and to understand the thermal and mechanical reliability of the joints that are formed. Four low-silver sphere alloys were tested. They were:

- SAC 105 - SnAgCu with 1% Ag
- SAC 205 - SnAgCu with 2% Ag
- SACX 0307 – SnAgCu-X with 0.3% Ag + Bi
- LF35 – SnAgCu-X– with 1.2%Ag + Ni

Tin-lead spheres were also used to provide a baseline for comparison. Solder pastes used included:

- Lead-free no-clean
- Lead-free water washable
- Tin-lead no-clean
- Tin-lead water washable

Four different BGA package types were used:

- 1.27mm SuperBGA, 600 I/O
- 1.0mm Plastic BGA, 324 I/O
- 0.8mm ChipArray BGA, 288 I/O
- 0.5mm ChipArray Thin Core BGA, 132 I/O

Each package was used three times per test vehicle assembly.

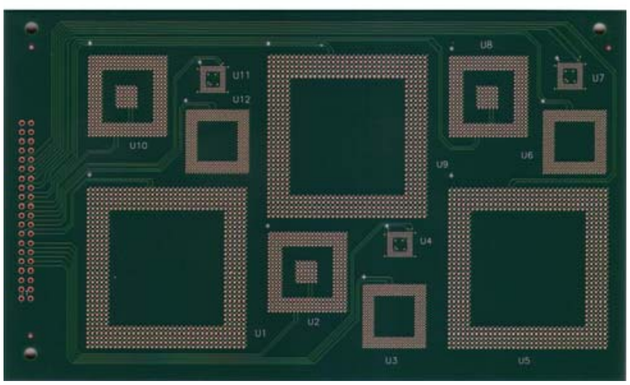

Figure 3. Test vehicle designed by iNEMI mixed metals BGA team used in both studies.

The test vehicle chosen for this study is shown in figure 3. It was designed by the iNEMI mixed metals BGA team to study assemblies with SAC305 or 405 BGA spheres and tin-lead soldering processes. Because the two studies are analogous in nature, duplication of the assembly test vehicle allows for easier comparison between the findings of both investigations. It should be noted that although the studies both address similar phenomena of mixed metallurgy in BGA joints, the actual experiments differ in their structures, as they assess different combinations of mixed metals systems.

The study is divided into four phases. The first phase focuses on the development of reflow profiles and their influence on mixing of the low silver SAC spheres with the tin-lead or SAC305 solder. The second, third, and fourth phases assess thermal fatigue performance, drop shock resistance, and vibration performance of the mixed assemblies, respectively. This report focuses on the first phase of the study.

The phase 1 test matrix is shown in Appendix A. It is divided into two subphases, 1A and 1B. Phase 1A is designed to baseline the primary process. Common to all test assemblies in phase 1A are:

- PWB pad finish: Organic Solderability Preservative (OSP)
- Device pad finish: (electrolytic)Nickel-Gold
- Reflow atmosphere: air
- Solder paste: no-clean, SAC305, type 3 paste

Varied in phase 1A are:

- Ball alloy: predominantly SAC105; several assemblies with SAC305 or SnPb for comparison with prior iNEMI study
- Stencil aperture: equally split between 1:1 (maximum amount of solder paste) and 10% reduction of diameter (typical amount of solder paste)
- Peak Temperatures: 7 different temperatures ranging from 210C through 240C
- Time Above Liquidus (TAL): 60, 90 and 120 seconds

Phase 1B is designed to aid in process development. It samples more variations in the assembly than phase 1A. The purpose of extending the variations was to simulate combinations that are currently being experienced or are anticipated in the near term:

- Package pad finish: 2 assembly combinations with OSP on the package pads
- Reflow atmosphere: nitrogen is applied to one assembly combination
- Solder paste: SnPb paste and SAC305 type 4 pastes are applied in selected test cells
- Ball alloy: Five different alloy types are assembled
- Peak Temperature: 8 peak temperatures, based on mixing levels observed in Phase 1A
- TAL: 8 different TALs, also based on mixing levels observed in Phase 1A

PWB ASSEMBLY

The PWBs were assembled at Jabil's Advanced Manufacturing Technology Laboratory in San Jose, California, USA.

The PWBs were printed on a DEK 265 with laser-cut nickel foils. The 5mil (125 micron) nickel foils were created by electrodepositing nickel on a mandrel without any apertures. The apertures were then cut with a laser, similar to the process used for cutting traditional stainless steel foils. The tin-lead paste was Alpha OM-5100; the lead-free paste was Alpha OM-338.

A Koh Young 3030 was used to measure solder paste deposits on all screen printed boards. Volume, height and area were three key parameters that were measured on the paste deposits. Volume measurements are key to the effects of the ball-to-paste ratio.

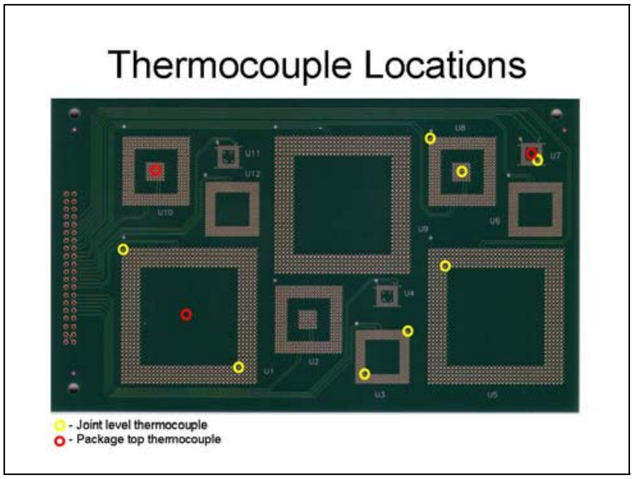

Figure 4. Thermocouple locations. The yellow circles indicate locations within solder joints; the red circles indicate locations on package bodies.

The boards were assembled on Universal GSM pick and place machine and reflowed in an Electrovert OmniFlo 10-zone oven. Thermocouple locations are shown in figure 4.

A total of eighteen profiles were generated for this investigation. A summary chart of key parameters can be viewed in Appendix B.

PRELIMINARY RESULTS AND DISCUSSION
SAC105 SPHERE/SNPB PASTE COMBINATION

The iNEMI study on SAC305 spheres with tin-lead paste showed that the larger spheres are the slowest to achieve mixing, presumably to the larger volume of metal they contain. Therefore, the 1.27mm SuperBGA was the first device to be metallograhpically examined.

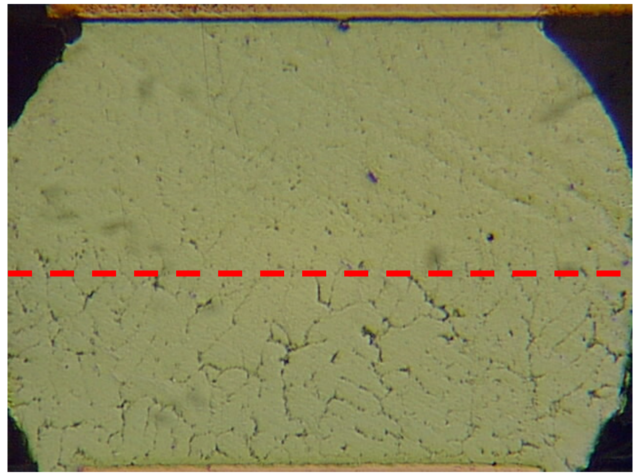

Figure 5. Cross-section of 1.27mm SBGA, **SAC105** sphere with SnPb paste, reflowed with peak temperature of 215C and TAL of 60 seconds.

Figure 5 shows a typical level of mixing when processed with peak temperature of 215C and 60 seconds time above liquidus. Because the solder is tin-lead, the reference liquidus temperature is that of tin-lead, or 183C. The lead phase is readily visible in the section, and the joint shows approximately 40% mixing.

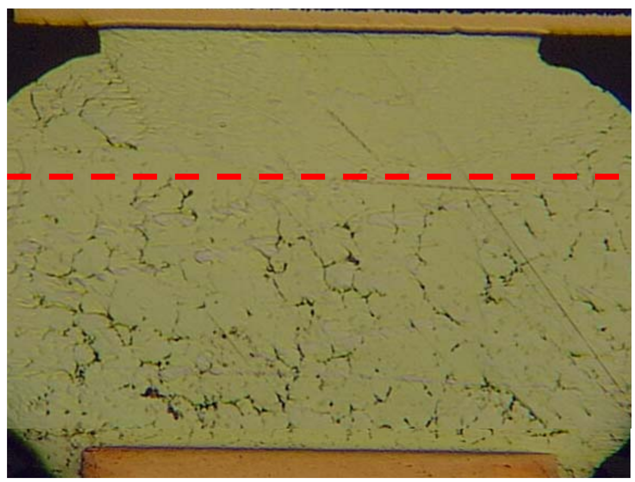

Figure 6. Cross-section of 1.27mm SBGA, **SAC305** sphere with SnPb paste, reflowed with peak temperature of 215C and TAL of 60 seconds.[3]

Figure 6 shows a similar cross section from the iNEMI study that used SAC305 spheres with tin-lead solder. The degree of mixing in the SAC305 is approximately 75%, which is greater than the 40% demonstrated in the SAC 105 joint.

A key finding of the iNEMI study on SAC305 spheres with tin-lead paste was that peak temperature was the most influential parameter on mixing of the two dissimilar metals. Based on that finding, one of the first effects reviewed in this study was effect of peak temperature.

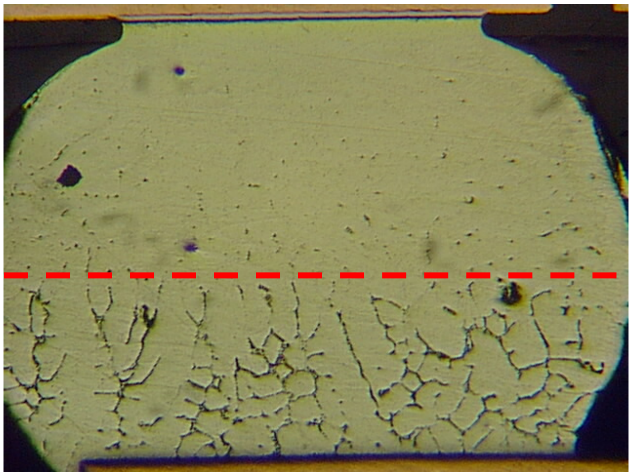

Figure 7. 1.27mm SBGA reflowed with peak temperature of 215C and 90 second TAL.

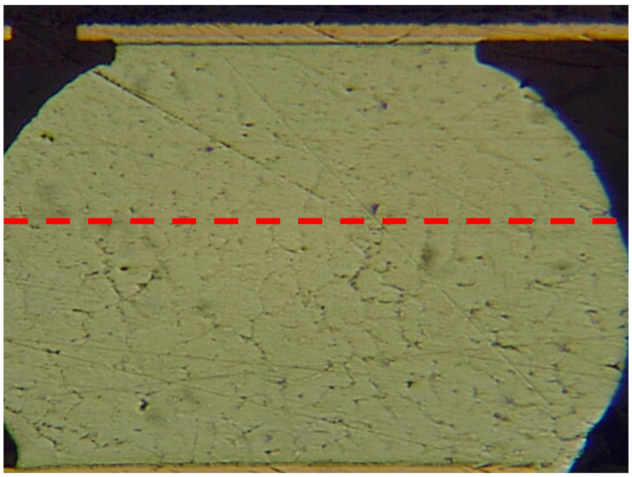

Figure 8. 1.27mm SBGA reflowed with peak temperature of 220C and 90 second TAL.

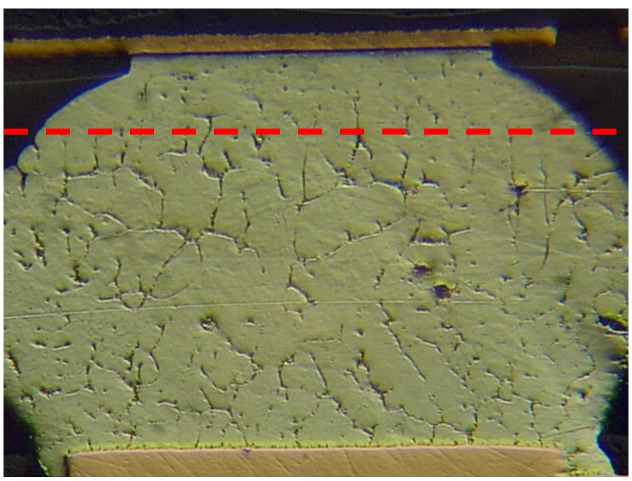

Figure 9. 1.27mm SBGA reflowed with peak temperature of 225C and 90 second TAL.

The solder joints shown in figures 7 through 9 depict increasing peak temperatures with constant TALs of 90 seconds. The joint formed at 215C exhibited approximately 40% mixing, the joint formed at 220C exhibited approximately 60% mixing, and the joint formed at 225C exhibited approximately 80% mixing.

The iNEMI study also showed that TAL was a factor, although not as influential as peak temperature. Interestingly, the comparison between two joints formed at 215 with TALs of 60 and 90 seconds (figures 5 and 7) do not appear to differ greatly in level of mixing. As more analysis is performed, the effect of TAL at temperatures below the sphere's solidus point will be further investigated. Any contradictory conclusions based on the small sample size currently available would be premature and imprudent.

CONTINUING WORK

The investigation continues, with the majority of the analysis yet to be performed. Results will be published as they become available.

REFERENCES

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[2] "Post Reflow Open/Intermittent BGA Solder Connections (Head-in-Pillow Effect)," Picchone, L., Trotsky, M., Bulwith, R., CE Analytics Report, 2005

[3] "Solder Joint Reliability of Pb-Free Sn-A-gCu Ball grid Array (BGA) Components in Sn-Pb Assembly Process," Kinyanjui, R., et al, Proceedings of SMTA International, 2007

[4] G. Henshall, et al., "Manufacturability and Reliability Impacts of Alternate Pb-Free BGA Ball Alloys," 2007. Available at: http://www.inemi.org/cms/projects/ba/Pb-Free_Alloys.html

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APPENDIX A
PHASE 1 TEST MATRIX

Phase 1A: Primary Process

Surface Finish	Package Pad Finish	Atm	Mesh Type	Ball Alloy	Stencil	Temp (C)	TAL (sec)	Board Count				Total Boards	Component Count				Cross-section/part type	Dye n Pry
								SnPb Mixed	SAC 305 Mixed	SnPb Baseline	LF Baseline		1.27	1	0.8	0.5		
OSP	NiAu	Air	3	SnPb	10%	210	60	0	0	2	0	2	6	6	6	6	4	0
				SAC 305	10%	235	60	0	0	0	2	2	6	6	6	6	4	0
				SAC 105	"1:1"	210	120	2	0	0	0	2	6	6	6	6	4	0
						215	60	2	0	0	0	2	6	6	6	6	4	0
							90	2	0	0	0	2	6	6	6	6	4	0
							120	2	0	0	0	2	6	6	6	6	4	0
						220	60	2	0	0	0	2	6	6	6	6	4	0
							90	2	0	0	0	2	6	6	6	6	4	0
						225	60	2	0	0	0	2	6	6	6	6	4	0
							90	2	0	0	0	2	6	6	6	6	4	0
						230	60	2	0	0	0	2	6	6	6	6	4	0
					10%	230	60	0	2	0	0	2	6	6	6	6	4	0
							90	0	2	0	0	2	6	6	6	6	4	0
							120	0	2	0	0	2	6	6	6	6	4	0
						235	60	0	2	0	0	2	6	6	6	6	4	0
							90	0	2	0	0	2	6	6	6	6	4	0
							120	0	2	0	0	2	6	6	6	6	4	0
						240	60	0	2	0	0	2	6	6	6	6	4	0
								18	14	2	2	36	108	108	108	108	72	0

Phase 1B: Process Development

Surface Finish	Package Pad Finish	Atm	Mesh Type	Ball Alloy	Stencil	Temp	TAL	Board Count				Total Brd	Component Count				Cross-section/part type	Cross-section/part type
								SnPb Mixed	SAC 305 Mixed	SnPb Baseline	LF Baseline		1.27	1	0.8	0.5		
OSP	NiAu	Air	3	SACX	1:1	T1	t1	2	0	0	0	2	6	6	6	6	4	0
						T2	t2	2	0	0	0	2	6	6	6	6	4	0
						T3	t3	2	0	0	0	2	6	6	6	6	4	0
						T4	t4	2	0	0	0	2	6	6	6	6	4	0
						T5	t5	2	0	0	0	2	6	6	6	6	4	0
						T6	t6	2	0	0	0	2	6	6	6	6	.	0
					10%	T9	t9	0	2	0	0	2	6	6	6	6	4	0
						T10	t10	0	2	0	0	2	6	6	6	6	4	0
			3 (60/40Pb)	SAC 105	1:1	T1	t1	2	0	0	0	2	6	6	6	6	4	0
			4		1:1	T1	t1	2	0	0	0	2	6	6	6	6	4	0
	OSP		3	LF35	1:1	T1	t1	2	0	0	0	2	6	6	6	6	4	0
						T2	t2	2	0	0	0	2	6	6	6	6	4	0
	NiAu		3	SAC 205	1:1	T1	t1	2	0	0	0	2	6	6	6	6	4	0
						T2	t2	2	0	0	0	2	6	6	6	6	4	0
		N2	3	SAC 105	1:1	T1	t1	2	0	0	0	2	6	6	6	6	4	0
								26	4	0	0	30	90	90	90	90	56	0

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APPENDIX B
THERMAL PROFILE SUMMARY

Profile ID #	Liquid Temp (C)	Target: Peak Temp(C) min	Target: Peak Temp(C) max	Target: TAL (sec)	Actual: Max Peak Temp (C)	Actual: Min Peak Temp (C)	Actual: Delta Peak Temp (C)	Actual: Max TAL (sec)	Actual: Min TAL (sec)	Actual: Delta TAL (sec)	Actual: Overall PCB Delta Peak Temp (C)	Actual: Overall PCB Delta TAL (sec)
1	183	205	210	60	209.1	205.2	3.9	70.5	65.6	4.9	11.3	9.1
2	217	235	240	60	235.9	234.1	1.8	67.6	58.1	9.5	5.8	12.7
3	183	205	210	120	211.4	210.0	1.4	126.6	120.6	6.0	5.9	12.4
4		210	215	60	216.8	211.4	5.4	68.3	65.9	2.4	10.6	4.3
5				90	215.6	212.5	3.1	97.0	95.8	1.2	9.1	7.4
6				120	215.8	213.8	2.0	126.2	120.9	5.3	6.2	12.1
7		215	220	60	221.2	215.3	5.9	69.9	68.1	1.8	12.1	4.7
8				90	221.0	217.6	3.4	94.9	90.6	4.3	8.1	6.8
9		220	225	60	227.6	219.7	7.9	80.1	74.3	5.8	12.6	7.6
10				90	223.6	220.1	3.5	91.1	90.2	0.9	7.6	4.7
11		225	230	60	228.0	219.9	8.1	75.9	70.4	5.5	13.3	6.2
12	217	230	235	60	232.0	230.2	1.8	67.3	55.7	11.6	4.5	12.5
13				90	231.4	230.0	1.4	101.5	78.0	23.5	4.8	20.6
14				120	230.7	230.1	0.6	126.6	121.1	5.5	3.4	13.1
15		235	240	60	235.9	234.1	1.8	67.6	58.1	9.5	5.8	12.7
16				90	236.0	234.7	1.3	97.3	89.7	7.6	5.7	16.6
17				120	236.7	236.1	0.6	122.1	112.4	9.7	4.0	9.7
18		240	245	60	247.4	240.1	7.3	70.5	59.8	10.7	7.6	10.7