i-Line Photoresist Development: Replacement Evaluation of OiR 906-12

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Abstract:

The Marvell Nanofabrication Laboratory's current i-line photoresist, OiR 897-10i, has been discontinued, and in order to maintain i-line lithography, a new resist has to be qualified. To this end, we report the development of optimal coat programs using OiR 906-12 photoresist on the svgcoat1 and subsequent characterization of resulting photoresist profiles. The measurements and data regarding photoresist thickness following different steps of the photolithography process (coat, softbake, development, hardbake or UV bake) have been recorded and presented, along with coat recipes. Images from the LEO scanning electron microscope have been included to display satisfactory resolved features of the photoresist at different thicknesses. Ultimately, the goal of this report is to summarize the findings of the OiR 906-12 photoresist qualification process, as well as discuss and analyze their results, in order to make a seamless transition to it.

I. INTRODUCTION

A. Background Information

Photolithography is the process of transferring geometric shapes on a mask or reticle to a thin film of photoresist on the surface of a substrate, typically a silicon wafer. It is comprised of several different steps. First, the wafers to be used in the process are chemically cleansed in order to remove any particulate matter on their surface. This often includes traces of organic, ionic, and metallic impurities that can often create unwanted defects and interfere with achieving a uniform photoresist coating. Once the silicon wafer has been properly cleaned, photoresist can be applied to it. Photoresist is a photosensitive liquid polymer that chemically changes when exposed to light. The most common application technique, called spin coating, involves high-speed centrifugal spinning to apply photoresist films at a targeted thickness. There is an indirect relationship between spin speed and photoresist coat thickness; the slower the spin speed is, the thicker the photoresist coat will be.

Following the photoresist application, the wafers undergo soft baking. During this step of the photolithography process, almost all solvents are removed from the photoresist film. The resulting film is photosensitive – meaning it will react chemically to light.

Before the silicon wafers can be exposed, mask alignment must take place. A mask, also known as a "photomask" or "reticle" is a square glass plate with a patterned metal film on one side. During this step of the process, the mask is aligned with the wafer so that the pattern has the ability to be transferred, and has correct overlay with existing layers on the wafer.

Once aligned, the photoresist-coated wafers are exposed with high intensity UV light. The wavelength of light at the i-line is 436 nm. The resist solubility in the photoresist developer increases until it becomes completely soluble – this occurs at a threshold.

Positive photoresist is commonly used in the Marvell Nanofabrication Laboratory. When this type of resist is exposed to ultraviolet (UV) light, the chemical structure of the resist changes so that it is more soluble in a developer solution. The developer ultimately dissolves away the exposed resist leaving windows of the bare, underlying material. The mask has the exact copy of what appears on the wafer.

Finally, the wafers are hard baked (or in some cases, UV baked). Hard baking densifies the photoresist further, and improves adhesion of the photoresist to the wafer surface. [1]

B. Project Background

This project has been carried out to qualify the 906-12 OiR resist. It was designed to find optimal conditions that will consistently produce standardized 1.2, 1.7, 2.1, and 2.8 μm films of resist and to resolve 0.7 μm, or better, lines and spaces. The main objective of the project was to qualify the 906-12 OiR i-line photoresist in order to make a seamless switch towards standardizing it as the new i-line resist at the Marvell Nanofabrication Laboratory.

II. EXPERIMENTAL

A. Experimental Setup

This experiment makes use of seven different tools: nanospec, prime oven, svgcoat1, gcaws6, svgdev1, the UV Bake, and the LEO scanning electron microscope. What follows is a brief explanation of each piece of equipment's role.

The nanospec is used to take measurements of the photoresist thickness at different steps throughout the procedure, including pre-development, post development, post hard baking, and post UV baking. The film thickness of the wafer is calculated based on the interference spectra generated when the light from the nanospec passes through the film on the wafer. Measurements are taken throughout the process to gauge accuracy in attaining the targeted 1.2, 1.7, 2.1, and 2.8 μm film thicknesses, as well as to compare thickness lost following the different steps of photolithography.

The prime oven uses HMDS (as wet chemistry) to modify the surface chemistry of the wafers. Priming reduces the water content on the wafer surface, helping photoresist adhere to its surface, once applied.

Svgcoat1 is used to dispense photoresist onto 6-inch Si wafers through the spin coat technique previously discussed. After the coat, this tool performs the soft bake process on wafers in order to prepare them for exposure. For this experiment, the parameters of svgcoat1 were modified to hand dispense 906-12 OiR photoresist, by adjusting the "SPIN" operation in event 3 to "DSP1" for all but the 2.8 μm thick film. Once the switch is officially made to the new photoresist, these modifications to the programs will not be necessary because the resist will be automatically dispensed.

Gcaws6 is a fully automated reduction step and repeat camera (stepper). It is capable of projecting sub-micron feature sizes as small as 0.7 μm. Alignment is conducted with this tool using the AWH – automatic wafer handler. This machine exposes the wafers with the designated focus and exposure values users enter in.

Svgdev1 is where the now primed, photoresist-coated, and exposed wafers are developed. The exposed photoresist from gcaws6 becomes soluble, and is removed with OPD 4262 developer. The patterns that appear are exact copies of the mask used during exposure.

For this experiment, 6-inch, p-type, test-grade, Si wafers were used. For each of the targeted 1.2, 1.7, 2.1, and 2.8 μm resist film thicknesses, three wafers were used. One wafer was used to measure resist thickness loss after development and hardbake (not exposed). Another was used to measure resist thickness loss after development and UV bake (not exposed). The third wafer had a test pattern exposed onto it using an ideal focus and exposure time and was later examined with the LEO scanning electron microscope (SEM). For convenience, wafers have been given an ID that corresponds to the target thickness of resist coated on them.

B. Experimental Procedure

First, we primed the wafers in the prime oven with HMDS, using recipe #2, which lasts for eleven minutes at 90 degrees and 780 torr. Then, we coated the bare wafers with the svgcoat1 track. For the 1.2, 1.7, and 2.1 μm thick wafers, we performed a dynamic dispense of the photoresist according to the spin speeds in Table 1. For the 2.8 μm thick wafers, we had to dispense the photoresist statically. In all cases a pipette was used to manually apply resist. In order to do this, we modified the settings for programs 1, 3, 5, and 7. After coating the wafers, we measured the pre-development photoresist thickness.

Following this, we exposed the set of wafers that were to be inspected with the leo SEM (one for each thickness) on gcaws6 with the focus and exposure values summarized in Table 1. These ideal exposure conditions were previously found by using a focus exposure matrix.

We then developed wafers in svgdev1 with the standard post exposure bake and development (1,1). Following this, we took measurements of the wafers to monitor any thickness loss that may have occurred.

Two wafers were then run through the svgdev1 track once again to be hard baked (Program 1 only, no developer dispense), while the third was put in the UV bake machine. Following this, measurements of the wafers were taken and recorded to, again, gauge thickness lost during the process.

Once all the steps were complete, we took the wafers and examined them with the leo SEM to analyze the profile of resolved features. It was important that the observed thickness in the SEM images agreed with that obtained by the nanospec. All the data collected through the findings were recorded in Table 11.

C. Development of New Spin Coat Programs on svgcoat1

In order to attain the correct thicknesses with the new, 906-12 i-line photoresist, the spin speeds in Table 1 had to be taken into account to adjust programs on the svgcoat1 track.

Table 1: Expected spin speeds to produce targeted photoresist thicknesses in the experiment.

Wafer ID	Target Thickness (μm)	Svgcoat1 process to modify	Spin speed (rpm)
1	1.2	(1, 1)	4100
2	1.7	(3, 1)	2000
3	2.1	(5, 1)	1300
4	2.8	(7, 4)	820

These experiment film thickness vs. spin speed values were plotted against the projected, theoretical film thickness vs. spin speed values to create Table 2.

Projected Film Thickness vs. Spin Speed

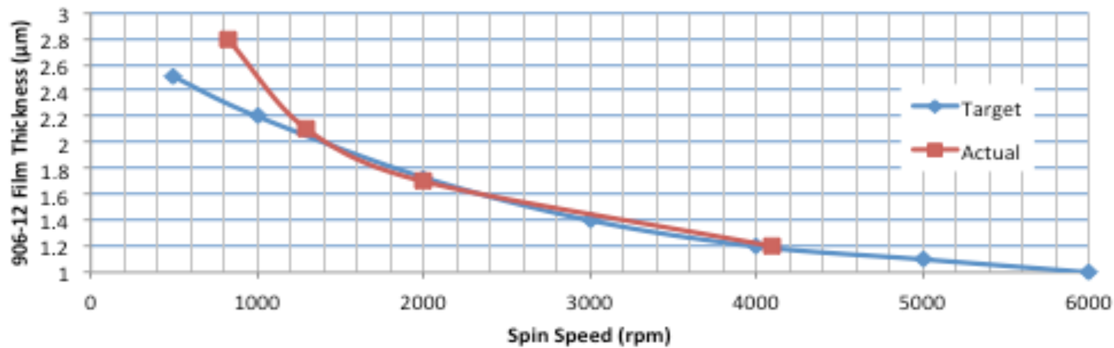


Table 2: Spin speeds with targeted and actual 906-12 film thickness

As the graph reveals, the thicker the desired photoresist film, the slower the spin speed during coating.

We modified the coat recipes to dynamically (1.2, 1.7, and 2.1 μm) and manually (2.8 μm) dispense the 906-12 OiR photoresist. For the first three wafers, this only required modifying event 3 to change the dispense operation to the spin operation.

However, the 2.8 μm resist film required many more modifications. Although originally run with a modified event 3, we later completely changed programs 4 and 7 to get accurate results. See the Supplemental Materials section for a complete listing of the program tables, both original and modified.

III. RESULTS AND DISCUSSION

A. 1.2, 1.7, and 2.1 µm

All the 1.2, 1.7, and 2.1 μm thick resist coated wafers went through the same process: dynamic dispensed at the speeds reported in Table 1, along with a contact soft bake.

After coating the wafers with 1.2, 1.7, and 2.1 μm thick films of 906-12 OiR photoresist, we used the nanospec to take measurements of the actual thickness and compare it with the target.

Prior to development, the measurements of the coatings were extremely close to the targeted thicknesses, as summarized in Table 3 below.

Table 3: Pre-development photoresist thickness measurements (μm)

Target Thickness (μm)	Top	Left	Flat	Right	Center	Aver.
1.2 *A*	1.1890	1.1881	1.1853	1.1886	1.834	**1.1870**
1.2 B	1.1759	1.1759	1.1737	1.1752	1.2007	**1.1804**
1.7 *A*	1.6938	1.6928	1.6882	1.6879	1.7156	**1.6957**
1.7 B	1.7454	1.7385	1.7398	1.7412	1.7605	**1.7451**
2.1 *A*	2.1013	2.0926	2.0939	2.0987	2.0927	**2.0959**
2.1 B	2.1279	2.1112	2.1105	2.1146	2.1237	**2.1176**

The focus and exposure values for the wafers of these 3 thicknesses were chosen after careful analysis of previous focus-exposure matrix experiments. They are shown in Table 4 below.

Resist Thickness on Wafer	Exposure	Focus
1.2 μm	1.0	-8
1.7 μm	1.2	-10
2.1 μm	1.8	-10

Table 4: Focus and exposure values for 1.2, 1.7, and 2.1(μm) wafers in this experiment

After this, wafers were run through the svgdev1 track with the standard programs (1, 1). Post-development measurements of the 2.1 μm resist coated wafer is summarized in Table 5.
As the table shows, there was some thickness lost (approx. 0.11 microns)

Table 5: Post-development measurements (μm)

Wafer	Top	Left	Flat	Right	Center	Aver.
2.1	1.9952	1.9877	1.9915	1.9953	1.9917	1.9923

One set of wafers (one of each thickness - 1.2, 1.7, and 2.1 um) was run through svgdev1 again, this time only receiving a hard bake (not developed) at 120° C for 1 min. The measurements taken post-hard bake are located in Table 6. There was more thickness lost during this step.

Table 6: Post Hard Bake Measurements (μm)

Wafer	Top	Left	Flat	Right	Center	Aver.
1.2	1.248	1.277	1.1229	1.1232	1.1268	1.1250
1.7	1.6014	1.6007	1.599	1.6025	2.6269	1.6063
2.1	1.9829	1.9784	1.9783	1.9817	1.9781	1.9799

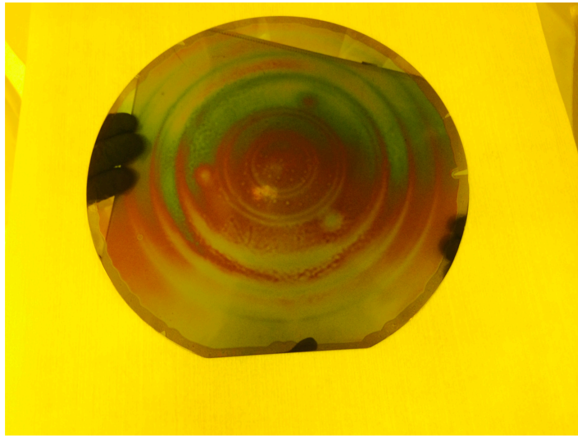
Another set of wafers was run through the UV bake. There was no significance between the UV bake and hard bake in terms of thickness loss.

Table 7: Post UV Bake Measurements (μm)

Wafer	Proc.	Top	Left	Flat	Right	Center	Aver.
1.2	A	1.1020	1.1202	1.0983	1.1020	1.0976	1.1030
1.7	A	1.6250	1.6186	1.6169	1.6316	1.6359	1.6256
2.1	S	1.9407	1.9328	2.9384	1.9551	1.9522	1.9438

B. 2.8 µm Wafers

The 2.8 μm wafer had to have more modifications made to the svgcoat1 program than the other three thicknesses and went through a proximity bake. This was because going through a contact bake left a ghost image of rings on the wafer, as shown in Image 1.



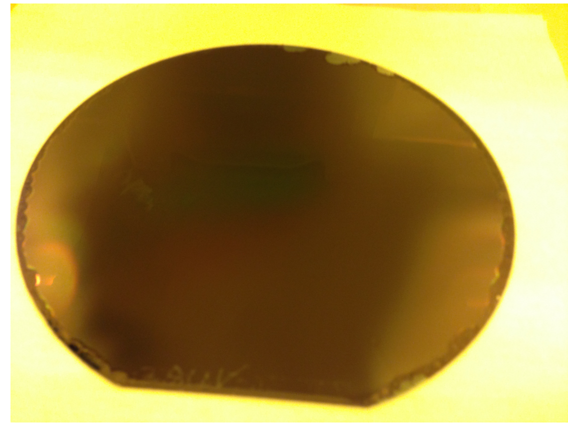


Image 1: The result of doing a contact bake (left) vs. proximity bake (right) on the 2.8 um thick wafer.

Prior to development, the measurements of the coatings were extremely close to the desired thicknesses, as summarized in Table 8.

Table 8: 2.8 Pre-development measurements (μm)

Wafer	Top	Left	Flat	Right	Center	Aver.
2.8 *A*	2.7923	2.8350	2.8379	2.8038	2.8166	2.8170
2.8 B	2.9112	2.8946	2.8410	2.8487	2.8780	2.8747

We were able to accurately achieve the measurements because of the settings we achieved in changing Programs 4 and 7. This was a big change to the measurements taken on July 15th, 2014, when the 2.8 um wafer was run on Program 5 with only a modified event 3:

The focus and exposure values for the 2.8 um wafer are located in Table 9.

Table 9: Focus and Exposure for 2.8 Wafers

Wafer	Exposure	Focus
2.8	3.4	-8

The 2.8 wafers were run through the svgdev1 track with the standard programs. Following their development, we recorded the measurements post-development (μm).

Wafer	Top	Left	Flat	Right	Center	Aver.
2.8	2.6311	2.6270	2.6150	2.6211	2.6131	2.6215

Following this, one set of wafers was run through the svgdev1 again for a hard bake.

Wafer	Top	Left	Flat	Right	Aver.
2.8 *A*	2.6311	2.6270	2.6150	2.6211	2.6131

Table 10: Post hard bake (μm)

There was thickness lost in after the hardbake, but not an appreciable amount. The UV bake, however, resulted in excessive damage to the photoresist film, and thus, it is not recommended to UV bake wafers with resist this tick on them.

C. SEM Images

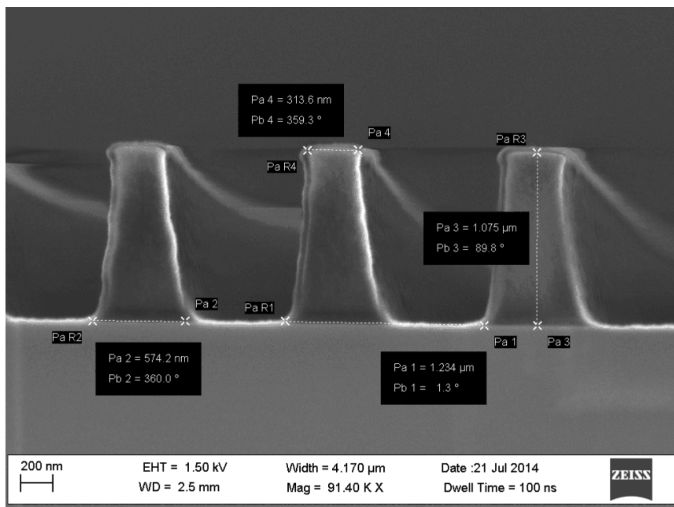
Following the entire photolithography process, we examined the wafers using the LEO scanning electron microscope.

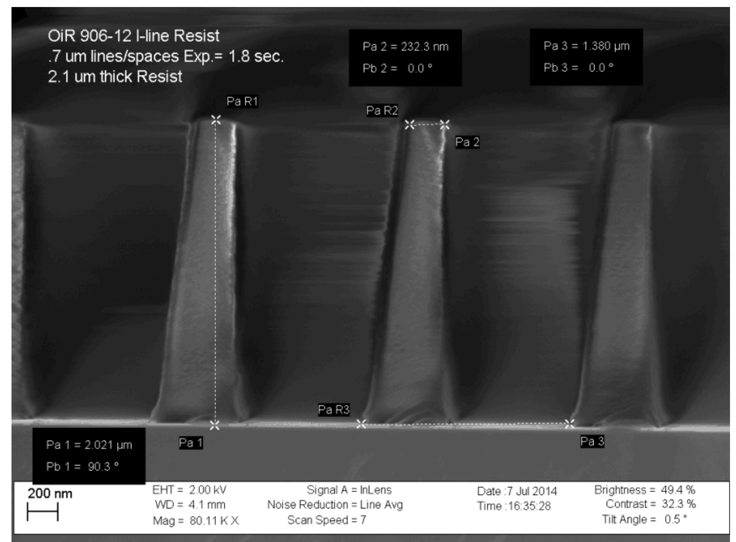
This allowed us to check for uniformity across the film of photoresist on the wafer. In addition to this, we were able to observe the profile of resist lines and spaces.

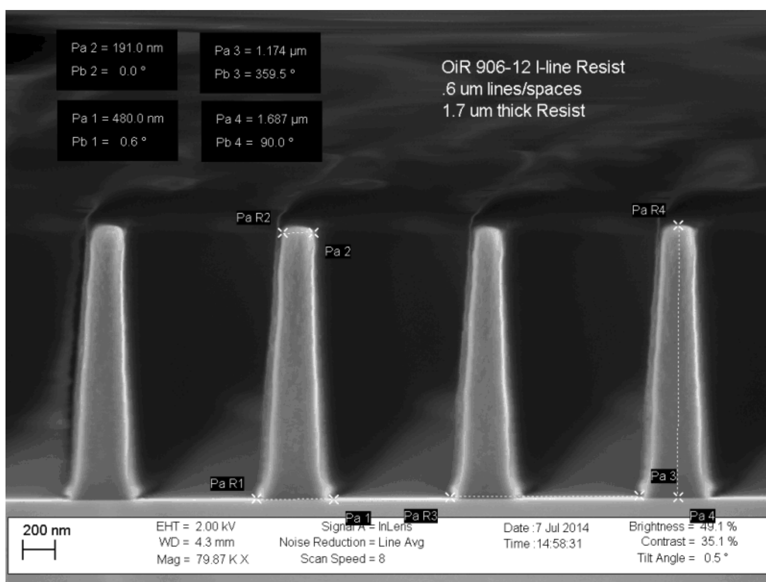
The images we collected displayed uniformity across the wafers, and we were able to detect features as small as 0.5 microns.

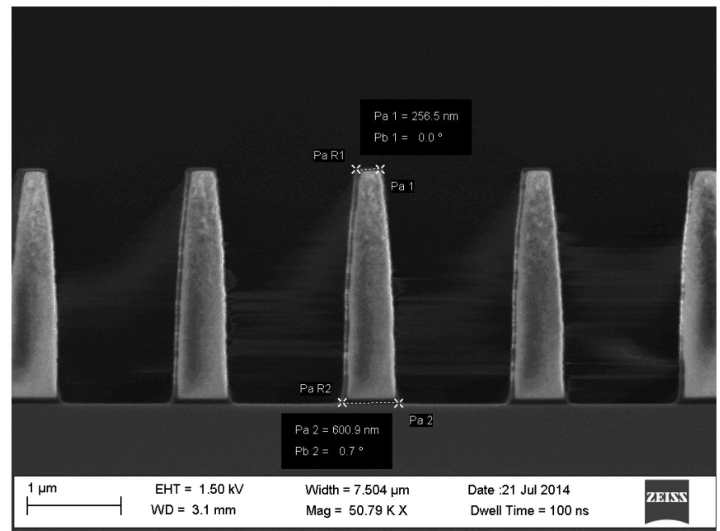
The images are displayed below.

Beginning with left-most image, moving counterclockwise → 1.2, 1.7, 2.1, and 2.8 μm thick.









IV. Conclusion

Table 11: Finalized measurements

Wafer ID	Svgcoat1 Process to be modified	Svgdev1 Process	Spin Speed (rpm)	Target Thickness (μm)	Measured Thickness Pre-dev (μm)	Measured Thickness Post-dev(μm)	Thickness after Hard-Bake	Thickness after UV Bake	Min Res Feat
1	(1,1)	(1,1)	4100	1.2	1.1870	--	1.1250	1.1030	0.5
2	(3,1)	(1,1)	2000	1.7	1.6957	--	1.6063	1.6256	0.6
3	(5,1)	(1,1)	1300	2.1	2.0959	1.9923	1.9799	1.9438	0.6
4	(4,7)	(1,1)	820	2.8	2.8170	2.6131	2.6113	--	0.6

Table 12: Focus and Exposure values – final

Wafer Thickness (μm)	Focus	Exposure (sec)
1.2	-8	1.0
1.7	-10	1.2
2.1	-10	1.8
2.8	-8	3.4

Tables 11 and 12 summarize the data from the entire experiment.

The values provided in the tables provided consistent measurements throughout the entire project, and thus have proved to be reliable.

VI. Acknowledgements

Thank you to Jeff Clarkson for mentoring me throughout my time at the Nanolab, helping me execute this entire project every step of the way, and guiding me on how to present its findings in this report.

Thank you to Cheryl Chang for teaching me the general photolithography process, showing me how to use the different tools that comprise it, and providing me with previous data that proved helpful in shaping this project.

Thank you to Kim Chan for helping me whenever problems arose, taking pictures on the LEO SEM for reference, and adjusting program settings to provide accurate results.

Thank you David Lo and Greg Mullins for maintaining lithography equipment that performed very well during my experiments.

VII. References

[1] "Photolithography Basics." *CEPSR Clean Room*. Columbia University Center for Engineering and Physical Science Research, PDF file. 20 July 2014. <https://www.clean.cise.columbia.edu/process/Photolithography_Lessons.pdf>

V. Supplemental Material

1.2 ORIGINAL Program						
P	**E**	**O**	**A**	**T**	**S**	**A**
1	1	SPIN	0	30.0	0.00	00
1	2	SPIN	0	01.0	0.50	00
1	3	DSP1	1	--	0.50	50
1	4	SPIN	0	01.5	0.50	20
1	5	SPIN	0	30.0	4.1	50
1	6	END	0	0.00	0.00	00
Modified Program						
P	**E**	**O**	**A**	**T**	**S**	**A**
1	3	SPIN	0	10.0	0.50	50

2.1 ORIGINAL Program						
P	**E**	**O**	**A**	**T**	**S**	**A**
5	1	SPIN	0	30.0	0.00	00
5	2	SPIN	0	01.0	0.50	50
5	3	DSP1	1	--	0.50	50
5	4	SPIN	0	01.5	0.50	20
5	5	SPIN	0	30.0	1.30	50
5	6	END	0	0.00	0.00	50
Modified Program						
P	**E**	**O**	**A**	**T**	**S**	**A**
5	3	SPIN	0	10.0	0.50	50

1.7 ORIGINAL Program						
P	**E**	**O**	**A**	**T**	**S**	**A**
3	1	SPIN	0	30.0	0.00	01
3	2	SPIN	0	01.0	0.50	50
3	3	DSP1	1	--	0.50	50
3	4	SPIN	0	01.5	0.50	20
3	5	SPIN	0	30.0	2.00	50
3	6	END	0	0.00	0.00	00
Modified Program						
P	**E**	**O**	**A**	**T**	**S**	**A**
3	3	SPIN	0	10.0	0.50	00

2.8 Modified Program						
Coat						
P	**E**	**O**	**A**	**T**	**S**	**A**
7	1	SPIN	0	15.0	0.00	01
7	2	SPIN	0	03.0	0.50	01
7	3	SPIN	0	30.0	0.82	01
7	4	END	0	30.0	0.00	00
Oven						
P	**E**	**O**	**A**	**T**	**S**	**A**
4	1	STEP	000.0	0.15	00	4
4	2	STEP	005.0	0.10	00	4
4	3	STEP	100.0	0.05	00	4
4	4	COOL	006.0	--	00	4
4	5	END	000.0	--	00	4