Chapter 5.35

Rapid Thermal Anneal with AccuThermo AW810M

RTP System for MOS Processes of Si and Ge

(rtp8 – 386)

1.0 Title
Allwin21 Rapid Thermal Processing System – RTP8

2.0 Purpose
Rtp8 is a MOS tool with a dedicated quartz chamber available for MOS activation and anneal processes of 6” and 8” Si and Ge wafers. No photoresist or metals are allowed in this RTP system. Non-MOS wafers are also not allowed in this tool.

3.0 Scope
This manual chapter covers the general description of rtp8 Rapid Thermal Processing system, operation procedure, available processes, recipe set up/programming and some troubleshooting guidelines at the end.

4.0 Applicable Documents
Revision History
4.1 Chapter 5.33 (rtp3)

5.0 Definitions & Process Terminology
5.1 QDR - Quick dump rinse (DI water)
5.2 SRD - Spin rinse dry (DI water and N₂ purge)
5.3 RTP - Rapid thermal annealing, high temperature short time anneal

6.0 Safety
6.1 In the event that user smells ammonia (NH₃) in the vicinity of any rtp equipment, it is most likely coming from the tool. The lab member should immediately turn the gas flow knob to the off position (gas control panel on the wall behind), notify maintenance staff during business hours, and report the problem on Mercury.

6.2 Do not operate the tool at temperatures above 1100°C and the maximum process time is 3 minutes.

6.3 Do not touch the chamber wall or dummy/process wafers that have just been unloaded from the chamber, as they will be hot. The chamber can be opened below 200°C. The dummy wafers are hot and will burn you.

6.4 Do not use the system if the chamber wall temperature is higher than the process equipment cooling water set point (Max. ~ 20°C). The cooling water system will have to be checked by staff before the system can be used.

7.0 Statistical/Process Data
N/A
8.0 *Available Processes, Gases, Process Notes*

**Important Note:** Rtp chambers may be replaced or cleaned in HF from time to time. This changes the light transmission characteristics of the port used by the pyrometer to control process temperature. Members will need to perform their own calibration procedure to determine the correct offset needed for their critical runs, as explained in Appendix 12.1.

8.1 Available Processes/Process Notes

8.1.1 The only available process is MOS activation and anneal processes.

8.1.2 Rtp8 uses a dedicated chamber assigned to MOS activation anneal processes. Additional chambers may be available in Rtp8, as a back up to other systems upon staff approval.

8.1.3 No silicidation process is allowed in Rtp8.

8.2 Pre-RTP Wafer Cleaning

Wafers need to receive proper cleaning before they can enter the Rtp8 system, below.

8.2.1 Non-metalized wafers to be processed in rtp8, must go through the same standard pre-furnace cleaning procedure as wafers destined for any Tystar furnace. This entails a 10 minute piranha dip in Msink8 and Msink6, and an ensuing one minute HF dip for oxide removal if desired. Photore sist coated non-metalized wafers must initially have their photore sist processed in the Matrix Asher or stripped at Msink1 (PRS-3000 bath). This is required for both MOS and non-MOS wafers. The wafers must then be cleaned in Msink8 and Msink6. Msink6 is the pre-furnace clean step prior to wafer introduction into Rtp8. This means photore sist removal from non-metalized wafers requires an additional cleaning at Msink8 regardless of whether the process is MOS or non-MOS. For a complete description of pre-furnace wafer cleaning please see Section 1.3 in Chapter 5.00, Tystar Furnaces Overview.

8.3 Maximum Operating Temperature (and other related precautions)

8.3.1 Annealing at temperatures up to 1100°C from 1 sec to 180 sec (3 minutes) are allowed in rtp8. If you need help with high temperature anneal processing, contact staff.

8.3.2 Check and make sure proper cooling of the chamber has occurred by touching the side panels on the machine, before annealing your next wafer. Make sure it is room temperature before your next run. Cool down time is approximately 5 minutes.

8.4 Thermocouple (TC) OR Pyrometer Mode of Operation

8.4.1 Most processes will use the infrared optical pyrometer or ERP for controlling temperature. However, the pyrometer may suffer from temperature control/feedback problems for temperature applications below 600°C, as infrared pyrometry relies on light emission from the back of the wafer. Si is generally transparent in the infrared which make low temperature pyrometry inaccurate. An alternative method of temperature control is to use a thermocouple, which is effective at temperatures < 600°C. Lab members are obligated to purchase their own thermocouple for use, and to learn how to install it on the tool. The equipment engineer in charge of the tool can teach members how to install a thermocouple in Rtp8.

**Note:** It is also highly recommended for members to determine the correct temperature offset for a new thermocouple. This temperature correction can be determined by oxide growth on test wafers, as defined in Appendix 12.1.

**Note:** The Nanolab does not supply thermocouples (TC) for Rtp8. Members are obligated to purchase their own TC. The Nanolab stocks TC’s for purchase.

8.5 Process Gases Available
8.5.1 These gases are available on Rtp8: N₂, NH₃, O₂, Ar, and N₂/10%H₂. Each MFC supports flows up to 10 liters per minute. **NOTE: All gases must be turned off when rtp8 processing is complete. If you fail to adhere to this policy, your account will be charged for gas and associated staff time to replace the cylinder. This is particularly true for high purity Ar.**

8.5.2 NH₃ can be used only with staff permission/training.

### 9.0 Equipment Operation

**Important Note!** For critical processes, members need to perform their own temperature calibration procedure, and determine the correct temperature offset, as explained in Appendix 12.1.

#### 9.1 Loading Your Wafers

9.1.1 Make sure dedicated chamber and paddle are installed for your specific application.

9.1.2 Clean your wafers in the appropriate sink/s prior to RTP step. The instructions are outlined in Section 8.2.

9.1.3 Enable equipment on Mercury.

9.1.4 Make sure the system is powered ON and the correct chamber is labeled on the tool "device" for MOS activation anneal processes. Press LAMP POWER button on front to enable power to the heaters (Figure 1).

9.1.5 Make sure PC is running and is on main menu.

9.1.6 It is recommended that users use a dedicated pair of clean Teflon tweezers when loading/unloading wafers in Rtp8. It is advised to use 2 Teflon tweezers so not to drop the wafers.

**DO NOT USE METAL TWEEZERS and DO NOT USE TWEEZERS BELONGING TO ANY OTHER RTP FOR THIS TOOL!**

9.1.7 It is recommended that you run at least 2 dummy runs to test the recipe stabilization and equipment warmup.

9.1.8 Carefully open the chamber door by lowering the lever (Figure 2).

9.1.9 Pull lever towards you to bring forward the wafer tray. There is always a dummy wafer in the chamber. There are three prongs that are used to support the wafer in the chamber. Carefully remove the dummy wafer and place the process wafer over the 3 prongs and return the door to the closed position. Users should minimize the time that the door is kept open. Be sure not to touch the thermocouple on the quartz holder, if TC is available in the tool at the time of your processing (please note, most processes rely on pyrometer).

9.1.10 Be careful not to touch the quartz holder while loading your wafer. Anything that touches the quartz may melt and contaminate the chamber. Wafer orientation does not matter in the chamber.

#### 9.2 Creating and Running Recipes

9.2.1 Press the "Process for Engineer" button on the Main Menu (Figure 4).

9.2.2 Select the recipe to be edited from the Recipe Files list (Figure 5).

9.2.3 Press **Recipe Edit** to go to the Recipe Edit Screen where recipes can be modified.

9.2.4 Users can create new recipes by hitting the **Recipe New** or F7 button. In case the software would ask to save in the old or the new format, make sure to select the old format to avoid compatibility issues.
9.2.5 Use the up, down arrows or the mouse to select the desired step. Begin with step 1 to define the recipe step by step. Commands can be seen on the bottom of the screen for further clarification.

9.2.6 Move to the Step Function column. Choose between Ramp (R), Steady (S), Delay (D) and Finish (F) functions. Recipe editing is generally explained to the user during qualification. Please contact a superuser before adding new recipes. Make sure to apply the temperature offset for each temperature setting in the recipe (Figure 6).

9.2.6.1 **Ramp (R):** The ramp step occurs in the cycle when the temperature rises or falls from one temperature to another temperature in a given time. Ramp rates should not exceed 50°C/sec as damage to the tool or to the wafer might occur.

9.2.6.2 **Steady (S):** The steady step occurs in the cycle when the temperature is kept at a constant/steady-state temperature for a specified time.

9.2.6.3 **Delay (D):** The delay step occurs during the cycle when the lamps in the chamber are off (no heating occurs) and the purge gas is flowing through the system. This step is most commonly used at the beginning or the end of the cycle. The initial delay purges any gases from the process chamber before heating the wafer. The final delay cools down the chamber before the user can remove the wafer. The recipe always has to start with this step.

9.2.6.4 **Intensity (Intn):** The constant intensity step can be used instead of the steady step. This indicates a constant intensity of the lamp (between 0 and 80%) instead of a constant temperature.

9.2.7 **Finish (F):** The fourth step is the last step of the process.

9.2.8 There are four different gases available for processing: Ar (gas1), N₂ (gas2), O₂ (gas3) and NH₃ (gas4) controlled by MFCs. Each step in the recipe can be set up with different gas flows from 0 to 10 LPM. The first step of the recipe is suggested to be a 60 sec delay with the process gas flowing, to properly purge the chamber. **Always set up the last step for a duration of 120 sec to purge with nitrogen,** especially when processing with ammonia.

9.2.9 In each of the steps, the user can specify the **Time (s)** and **Temperature (°C)** or **Intensity (%)** columns. A **Steady Intensity Factor** can also be specified (between 0.01 and 20) to compensate for undershooting or overshooting during temperature ramp. A larger **Steady Intensity Factor** will cause a larger overshoot and a smaller one will cause an undershoot. In annealing above 450°C, you should write a two-step process. The first should ramp to 450°C and stay in the delay step for 30s; then ramp to the desired temperature. The first step is applied to avoid thermal shock to the wafer.

9.2.10 Members can select pyrometer or thermocouple mode of controlling the temperature in the recipe. In case the pyrometer is used, make sure to have 77.04 set up for the emissivity. DO NOT USE non-silicon wafers with the pyrometer.

9.2.11 Click the **Recipe Validate** or **F10** button to check if the recipe is okay. Press **OK** to validate the recipe.

9.2.12 Press **Save** to save the validated recipe

9.2.13 Press **Exit** to go to the Process Menu.

9.2.14 Press **Start Process** to run your process. The Recipe Graph window should pop up, displaying the ideal and actual temperatures of your run.

9.3 **Unloading Wafers**

9.3.1 Wait until the chamber cools down to at least 200°C before unloading the sample.

9.3.2 Return the dummy wafer on the prongs and close the door
9.3.3 Exit out of the software to the Main Menu.
9.3.4 Shut off power to the tool by pressing LAMP POWER on front.
9.3.5 Disable the equipment on Mercury.

9.4 Operational Instructions for NH₃ Process
This process is only allowed during regular business hours (8:00 AM-5:00 PM, Monday-Friday). If NH₃ odor is smelled, immediately alert staff. Do not attempt to flow flammable gases (NH₃, N₂/10%H₂ and oxidizing gases (O₂, N₂O), simultaneously.

9.4.1 Enable Rtp8 on Mercury, check standby temp, chamber wall temp.
9.4.2 Run your desired recipe once on dummy wafer, just using N₂ gas.
9.4.3 With clean Teflon tweezers, unload dummy and load wafer, close chamber completely.
9.4.4 Put "danger" hang tag on handle of Rtp8.
9.4.5 In the first step of the recipe, let N₂ flow for 2 minutes. Next, let NH₃ flow for 2 minutes.
9.4.6 During cool down following process, set up a step to vent the chamber with N₂.
9.4.7 Gently open the chamber. Make sure that no smell of NH₃ is present.
9.4.8 Remove your wafer and replace it with a dummy.

10.0 Troubleshooting Guidelines
10.1 Chamber wall temperature > 20ºC. Please contact staff for refilling cooling water, after which the wall temperature should gradually come down to 20ºC.
10.2 Error messages show up after starting recipe – reboot the PC by flipping power switch on front.
10.3 PC turned OFF. Turn PC ON, at DOS prompt run RTP_PRO and wait for the main menu to be displayed.
10.4 System reboot – If a system reboot is necessary, please turn power OFF on the unit, turn OFF PC, and then restart unit and then restart PC (Figure 3).
10.5 It is imperative that you make sure all gases are turned off when you are finished with your process on rtp8. This particularly includes high purity Ar.
11.0 Figures & Schematics

Figure 1 - Front View of Rtp8
Emergency off on left, temperature display, lamp power switch, and chamber door on right.

Figure 2 - Rtp8 With Chamber Door Open
Figure 3 - Heatpulse8 Control PC Located Below Equipment

Figure 4 - Allwin21 Software With Main Menu
Figure 5 - Allwin21 Software With Recipe Selection Menu

Figure 6 - Allwin21 Software With Recipe Editing Menu
12.0 Appendices

12.1 Temperature Correction by Oxide Growth on Test Wafers

12.1.1 Reason for Temperature Correction (Determining the Temperature Offset Needed)

The chamber and the wafer holder plate in rtp devices may occasionally need cleaning to remove the accumulated contamination on their surfaces. During this process the quartz-ware is dipped into a 25:1 HF bath, which reduces the thickness of a window used by the pyrometer to monitor/control the chamber temperature. A pyrometer in rtp4 is used to control the diffusion/anneal processes at high temperatures and by looking at the light emitted from the backside of the wafer in the chamber. This means light transmission characteristics of the port (thickness of above noted window) can easily impact the temperature measurement, therefore, members will need to determine the offset needed to arrive at a correct process temperature (actual) for a new and/or a cleaned up chamber, the procedure being explained in the following sections.

Members also need to pay close attention to any film layers deposited on the backside of their wafers, which can easily impact the emissive pyrometer readings. Such film may need to be removed before RTP processing. Substrate materials other than silicon (Germanium, SiC, SiGe) can also impact the pyrometer reading. The emissivity value needed for silicon substrates (entered in the software) is 77.04 (standard silicon wafers used in the Microlab).

12.1.2 Wafer Preparation for Calibration (Determining Required Temperature Offset)

Temperature offset is determined by oxide growth on silicon substrates. The test wafer needs to receive piranha clean at sink6 for 10 minutes to remove possible organic contamination, followed by a quick dump rinse (QDR). Next, HF dip the wafer until its surface dewets, followed by a QDR /N₂ gun dry, and a quick move into the rtp machine.

12.1.3 Wafers Oxidation and Temperature Offset Measurement

This process is done by measuring oxide layer grown on P-type clean wafers and comparing them with known previous data to determine the temperature offset required by a new or cleaned up chamber. The cleaning steps and specifically wafer transfer into the chamber shall be done as quickly as possible to avoid thermal oxide growth.

Rtp Recipe Setup

The historical data in the range of 750°C - 1050°C with the smallest intervals of 50°C are available for the Rtp 610 RTP Systems, which can be used to determine the correct offset for this tool. Follow the instruction for the recipe set up and operation of rtp machine for the oxidation test. Make sure to have plenty of N₂ to purge the chamber when you introduce the test wafer into the chamber.

Use standard recipes available for different processing temperatures i.e. OX_950.RCP for the 950°C oxidation process. Set up a new recipe with your desired oxidation temperature, if a standard recipe for a particular target temperature is not available. See below 850°C oxidation recipe as a template to set up your own recipe, if needed.
There is a suggested warm-up step to avoid thermal shock to the wafer. This should be set at 450°C for 30 seconds prior to the oxidation step. Do not exceed the ramp up rate of 50°C/sec as it could harm the machine, also could result in slilines or dislocations on your wafers. Intensity factors needs to be adjusted to avoid temperature overshooting or undershooting at a particular step. Usually a value between 1.2 and 1.6 is used at each steady phase to better control the temperature during the RTP process. The main oxidation step is set to run for 180 sec, and after this step no ramp-down rate is defined, simply call up a temperature value for the machine to cool down to. The wafer should be removed after the chamber temperature has dropped below 200 °C shown on an external display just to the left of the chamber door. The number shown on this red display needs to be multiplied by 10 for the actual reading.

After running the oxidation recipe (at least two different temperatures), measure the oxide thickness on the Sopra ellipsometer. An oxide-temperature curve can then be generated with preferably 3 or more data points, consequently compared with previous graphs to determine the correct temperature offset needed to process current runs. The curve fitting can be accomplished by trying out different offset values to force the new curve to match an old curve with a known offset value. This will result in temperature delta (offset) and a sign associated with it to accurately process the run by either increasing or decreasing the temperature entries in the recipe. Following are some examples:

1) Offset value of – 70°C (minus 70°C) for a 850°C process will require entering 780°C in the recipe.

2) Offset value of + 70°C (plus 70°C) for a 850°C process will require entering 920°C in the recipe.

Note: It is highly recommended that members run their own calibration test any time they need to process wafers that need exact RTP temperature. This is because a small drift in the electronic circuitry and/or chamber pressure (N₂) can change the actual temperature by 30°C - 50°C Therefore, do not solely rely on the offset value determined earlier for a particular tool post. Calibration data reported after a chamber clean or chamber change may drift over time.

12.1.4 Thin Film Measurement (Sopra)

The thickness of the oxide layers grown for above temperature calibration can be precisely measured using ellipsometry on Sopra. The standard equipment initialization and measurement should be followed, as in the Sopra manual, Chapter 8.32.

a. Show Screen - Wavelength = 380 nm
   Analyzer angle = 45°
   Incident angle = 75°
   Check linearity and polarization box
Check attenuator1 and attenuator2 box
Click the run button and adjust the count if necessary to go over $10^6$.

Microspot usage is not necessary for this case. The standard polarizer angle of 75° was used at frequency range of 290 nm to 800 nm. To measure the curve, incremental steps of 20 nm is suggested.

b. Parameter Screen - Check and if necessary enter parameters (sub-screens), as in Sopra manual.

c. Click measurement on the GESPACQ screen. Click run on the next screen to start data collection.

d. Oxide thickness can be determined by using WINNELLI software to analyze the collect measured values. The first method of data analysis $\tan(\psi)$ and $\cos(\Delta)$ should be used for this purpose, which is specially suited for thin film layer measurements.

12.1.5 Calibration Data (curve fitting as a final step)

Newly collected oxide data from the Sopra machine can be plotted alongside previous (old) data for curve fitting purposes, and ultimately determining the temperature offset value. Table 2 below, shows historical data (tests) in different shaded color columns with the measured oxide values shown on the right side of it. These oxide values corresponding to temperature values entered in the recipe, which are listed in the far left two columns (in centigrade and in Kelvin). The $|\Delta T|$ values shown on the top left columns for these shaded areas were generated based on the shift required to move the curves to a correct position, hence overlapping the old baseline (initial) curve. Corresponding temperature values after the shift (true temperatures) are also shown in the columns just to the left of the measured oxide columns (Kelvin).

In the cases discussed above, $\Delta T$ required to move the curves to a baseline position were positive 80°C or 120°C (added) shift, see Figure 12.1.1 below. This means temperature settings that were used (temperature entries in the far left column, Table 2) produced thicker oxide film than the baseline curve. In other words in reality we were overshooting with these temperature settings, therefore, correct temperature values for the consequent product runs needed to have a negative $\Delta T$ offset to get properly processed. This means members made a $-80^\circ C$ adjustment for the runs performed after 9/13/05, and $-120^\circ C$ for the runs after 7/7/05, and again $-80^\circ C$ for runs after 3/9/06.

For instance, for a process that required a 900°C, they would have entered 820°C after 9/13/05.
### Recipe entered T [°C] vs. Film Thickness [Å]

<table>
<thead>
<tr>
<th>Recipe entered T [K]</th>
<th>[ΔT] value of 80°C T [K]</th>
<th>Film Thickness [Å]</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>1103</td>
<td>27</td>
</tr>
<tr>
<td>800</td>
<td>1153</td>
<td>34</td>
</tr>
<tr>
<td>850</td>
<td>1203</td>
<td>48</td>
</tr>
<tr>
<td>900</td>
<td>1253</td>
<td>69</td>
</tr>
<tr>
<td>950</td>
<td>1303</td>
<td>85</td>
</tr>
<tr>
<td>1000</td>
<td>1353</td>
<td>103</td>
</tr>
<tr>
<td>1050</td>
<td>1403</td>
<td>154</td>
</tr>
</tbody>
</table>

### |ΔT| value of 120°C T [K] vs. Film Thickness [Å]

<table>
<thead>
<tr>
<th>Recipe entered T [K]</th>
<th>Offset value of + 80°C T [K]</th>
<th>Film Thickness [Å]</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>1103</td>
<td>25</td>
</tr>
<tr>
<td>800</td>
<td>1153</td>
<td>32</td>
</tr>
<tr>
<td>850</td>
<td>1203</td>
<td>46</td>
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<tr>
<td>900</td>
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<tr>
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<td>103</td>
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<tr>
<td>1000</td>
<td>1353</td>
<td>154</td>
</tr>
<tr>
<td>1050</td>
<td>1403</td>
<td>236</td>
</tr>
</tbody>
</table>

### Table 2 - Historical Calibration Data Sets Shown in Different Shaded Areas

12.1.6 Example

On 7/2/10 four test runs were performed on rtp8 at temperature entries between 850°C - 1150°C shown in the far left column of Table 3 below.

### Table 3 – Rtp8 Test Performed on 7/2/10

<table>
<thead>
<tr>
<th>Recipe entered T [°C]</th>
<th>Recipe values T [K]</th>
<th>[ΔT] value To be determined!</th>
<th>Film Thickness [Å]</th>
</tr>
</thead>
<tbody>
<tr>
<td>850</td>
<td>1123</td>
<td>?</td>
<td>31</td>
</tr>
<tr>
<td>950</td>
<td>1223</td>
<td>?</td>
<td>60</td>
</tr>
<tr>
<td>1050</td>
<td>1323</td>
<td>?</td>
<td>114</td>
</tr>
<tr>
<td>1150</td>
<td>1423</td>
<td>?</td>
<td>255</td>
</tr>
</tbody>
</table>

The blue curve in Figure 12.1.1 is representative of temperature/oxide data shown in Table 3, above. As it can be seen, the oxide grown at these temperatures was exactly as expected by the baseline curves (historical data, different shades of red curves on the same graph).
In this case, there is no need to apply a temperature change (ΔT) to match to previous curves. As of 7/2/10, the offset of the pyrometer is determined to be zero.

12.2 Additional Notes Information

12.2.1 Oxidation of N-Type and P-Type Wafers
The oxide growth rate for p-type wafers are slightly higher than for n-type wafers. The B dopant used in p-type wafers, diffuses directly into the freshly formed oxide layer during the oxide growth process. N-type doped (P) wafers behave differently, as the dopant remains in Si and piles up close to the reaction surface reducing the reaction speed.

After calibration at 950°C, p-type wafers have 10-11 Å more oxide than n-type wafers. At 1050°C, the difference increases up to 35-40 Å.

12.2.2 Dislocations
Using high temperatures for longer intervals might result in having slip lines on the wafer surface. These were observed on temperatures higher than 1000°C in 2-3 minute runs. They appear as thin 0.5-1 cm long lines on the edges parallel to the <100> crystalline directions of the wafer. The dislocation density tends to be higher on epitaxial wafers.

12.2.3 Uniformity
Spots were measured around the center and by the sides on different calibration wafers with the Sopra ellipsometer. The standard deviation was always below 5%, therefore layer thickness measurements can be done on any selected area. Orientation of the wafer in the chamber during the process neither does matter.