Tystar Furnaces

Tystar #1 Wet/Dry Oxidation Furnace
Tystar #2 Atmospheric Anneal Furnace Tystar #6 LPCVD
Low-stress Nitride Furnace

Figure 1:
Wet/Dry Oxidation - Tystar #1(top)
Annealing Furnace – Tystar #2

Figure 2: LPCVD Nitride - Tystar #6

1. **Introduction**

    Tystar Dry/Wet Oxidation Atmospheric Furnace: It is used for dry and wet oxidation at temperatures between 700-1100°C. Wet oxidation steam is created from the combustion of H_2 and O_2 (a pyrogenic process). Batches of 4" silicon wafers (up to 25 wafers) can be processed at the same time. The oxide uniformity is better than 1%.

    Tystar Atmospheric Anneal Furnace: It is an atmospheric annealing furnace that is capable of processing 4" wafers in an atmosphere of nitrogen, argon, or forming gas (hydrogen in nitrogen). The hydrogen in the forming gas passivates the substrate's surface and deactivates interface carrier traps.

    Tystar LPCVD Low-stress Nitride Furnace: It is a furnace for depositing Silicon Nitride, including standard stoichiometric Si3N4 and low stress SiN. Furnace ramp rate is 10 degrees a minute.

2. **Features**

The system has a number of unique features:

2.1. Bank and Tube: There are two banks and each bank holds the tubes. Bank 1 top tube 1 is for dry/wet oxidation and bank 1 tube 2 is for annealing. Bank 2 tube holds is for nitride deposition. Each tube contains three zones: Load, Flat and Source zone. The samples will be loaded in the flat zone of the respective tube.

2.2. Furnace computer FCS10: There are three touchscreens controlling each tube. These are attached to the respective banks.

2.3. Main computer: This computer is required to input new recipes and maintain the records of the furnace.

3. **Definitions** & **Process Terminology**

3.1. **MOS Furnace**: This kind of furnace is used to fabricate MOS devices (IC), whose performance can be greatly impacted by trace contaminants. Wafers processed in MOS furnaces should absolutely be MOS compatible (IC device).

3.2. **Non-MOS Furnace**: This kind of furnace is used for non-MOS processes such as MEMS. Metals allowed in Tystar include refractory metals such as W. Au is NEVER allowed in this furnace. The staff must approve requests to process metals other than refractory metals in Tystar.

3.3. **Dry/Wet Oxidation**: A high temperature oxidation (dry O_2 or steam) process that oxidizes the underlying Si to form SiO_2. Dry oxidation uses oxygen for better process control. Wet oxidation uses both hydrogen and oxygen (steam) for fast reaction rate.

3.4. **Annealing**: A high temperature process that uses N_2 to keep wafers in an inert atmosphere.

3.5. **LPCVD**: Low Pressure Chemical Vapor Deposition.

3.6. **Stoichiometric (Standard) Nitride**: Chemically balanced silicon nitride Si3N4 that usually has a tensile film stress of over 1000 MPa.

3.7. **Low Stress Nitride (LSN)**: Si rich nitride, which has a film stress around 300 MPa or lower.

3.8. **Furnace Flat Zone**: An area inside the furnace with least temperature variation across it (best place to process wafers).

4. **Safety**

Follow general safety guidelines in the lab and the specific safety rules as per follows:

4.1. This furnace utilizes **high electric power** (high amperages) heating elements. Do not touch high power electrical part inside panels of the furnace.

4.2. Special care must be taken when the process aborts. In some special circumstances, the tube may go into **SPECIAL HOLD**. In either case, inform process staff immediately. The process staff will decide whether the process can be continued, and/or take proper actions to remedy the situation. **Do not try to open the tube, since there may be toxic hazardous gases in it**.

4.3. **Burn Hazard**. Furnace cantilevers, boats, and wafers come out of the furnace are very hot. Wear face shield when loading/unloading wafers. Proceed with caution.

Figure 3: Tube door to open/close during sample loading/unloading respectively

Figure 4: Front Control Panel of the FCS10 Furnace Computer. Furnace status displayed on screen.

5. **Main equipment components for user operation**

   There are two main components for user interface as shown in the images below:

6. **Available processes**

   Tystar MOS Dry/Wet Oxidation Atmospheric Furnace:

   - Dry Oxidation
   - Wet Oxidation

   Tystar Anneal Atmospheric Furnace:

   - Hydrogen Anneal
   - Nitrogen Anneal

- Oxygen Anneal
- Low Temperature Anneal

Tystar Low Stress Nitride LPCVD Furnace:

- Low Stress Nitride (LSN) Deposition
- Stoichiometric Nitride Deposition

Please contact process staff for any customized processes you may need

7. <u>**Available Gases**</u>

   Bank 1: Tystar MOS Dry/Wet Oxidation & **Anneal Atmospheric Furnace**:

   - Nitrogen (N_2): Used to purge out room air and keep the process tube in an inert/clean atmosphere.
   - Oxygen (O_2): Used for dry/wet oxidation process.
   - Hydrogen (H_2): Used for wet oxidation.
   - Forming Gas (H_2/N_2): Used for anneal.

   Bank 2: Tystar Low Stress Nitride LPCVD Furnace:

   - Dichlorosilane/DCS (SiH_2Cl_2): Used as a source of Si in all Tystar processes. Decomposition of DCS supplies silicon for LSN films.
   - Ammonia (NH_3): Used as a source of nitrogen in the nitride process. NH_3 is also used after deposition to neutralize HCl, which is a byproduct of DCS decomposition.
   - Ultra High Purity Nitrogen (UHP N_2): Used for process pressure control, tube purging, and venting the furnace tube back to atmospheric pressure.

8. <u>**Process Notes**</u>

   8.1. Absolutely no wafer with metal on it is allowed.

   8.2. The maximum temperature for Tystar is 1050^0C for Bank 1 and 850^0C for Bank 2. Any attempt to go above this temperature will result in damaging the sealing in Bank 1 and the O-rings used for the vacuum sealing in Bank 2.

   8.3. The standby temperature for Tystar is 550^0C. Avoid opening the tube for more than 30 minutes, which will cause the tube temperature to drop significantly. The stress accumulated in the films deposited on the tubes inner wall will crack the tube.

   8.4. All process wafers in Tystar should be loaded facing the back of the furnace (pump direction) for better film uniformity. All dummy wafers are loaded facing the door side of the furnace for quality control with respect to particle accumulation.

9. <u>**Equipment Operation**</u>

   9.1. **General Information and Menu Keypad Definitions**

   This furnace is a three-zone LPCVD furnace. It operates as a stand-alone unit that is made of three modules, wafer load/unload, furnace/process-tube, and gas control. It has its own computer, FCS10, whose display panel and keypad are located on the right side of the wafer load/unload module. The furnace operation is controlled by using menu commands. The furnace temperature is controlled by the TCU computer board, which runs a proprietary PID algorithm. The temperature for each of the three furnace zones, Load, Center, and Source, can be independently set. The process gases are regulated by the MFS460 gas flow controller that has five hardware interlocks to ensure safe operation.

9.1.1. Front panel special function buttons and keypad description (see Section 11.1 for the schematics of the front panel):

MENU: Displays the Main Menu (Please see the Appendix for the description of all menu commands)

ArrowKeys: Used when prompted to select a recipe. Do not use as a DEL/BACKSPACE key when entering alphanumerical inputs. Otherwise the computer will freeze and you will need to find a process staff to reboot.

Alpha-Numeric Keys: Used to enter process parameters, e.g. gas flows, pressure, deposition time, and etc.

ENTER: Used to enter the menu command or alphanumerical inputs.

CLEAR: Used to clear an error on the alphanumerical key input.

RUN: Run the recipe loaded in the computer memory.

EVENT: Acknowledge the process to go to the next recipe step when the current step time has not finished yet. For instance, after you finish loading your wafers and want to close the furnace door before the 20-minute door open step time. Some process steps cannot be cycled through using the EVENT button.

BOAT IN/OUT: Move the boats in/out of the process tube manually, independent of the recipe. These are toggle switches, i.e. push once to turn on and the second time to turn off. If both are ON at the same time, then the boats stop moving.

9.1.2. Commonly used MENU commands (press MENU button, then enter the two letter commands):

DS Displays the current status of the furnace.

DH Displays the process history from the last time the RUN button was pressed until the present time.

DR Displays the contents of the selected recipe.

GS Changes the Display to graphic mode. It shows large characters with only selected process information. Use CMD button to select process parameters to be displayed.

RL Loads process recipes. You will be prompted to use the Arrow Keys to select a recipe. Afterward, press the ENTER button twice. The computer will prompt you to enter process parameters if needed.

9.2. **Available Recipes**

The process recipes available on this furnace are listed below. Staff should be consulted whenever a new recipe is needed. The desktop computer is used for setting up new recipes. **Tystar MOS Dry/Wet Oxidation Atmospheric Furnace**:

i. **DRYOX.001**: Dry oxidation recipe. Dry oxidation is slower than the wet process due to oxygen's slower rate of diffusion through the silicon dioxide layer to the silicon/oxide interface where the oxidation reaction occurs. It produces a high-density pinhole-free oxide.

ii. **WETOX.001**: Wet oxidation recipe. Wet oxidation is used for growing thicker ($>$ 100 nm) layers of silicon dioxide.

Tystar Anneal Atmospheric Furnace:

i. **H2ANNEAL.002**: Anneal in forming gas environment

ii. **LTAN550.002**: Low temperature anneal at 550^0C

iii. **N2ANNEAL.002**: Anneal in nitrogen rich environment

iv. **O2ANNEAL.002**: Anneal in oxygen rich environment

Tystar Low Stress Nitride LPCVD Furnace:

i. **STANDBYA.006**: Standby recipe. It purges a small amount of nitrogen through the process tube at low pressure to keep it clean.

ii. **STDNITA.006**: Stoichiometric Nitride LPCVD recipe. The process condition is fixed. The stress can reach above 1000MPa.

iii. **LSNSTDA.006**: Standard Low Stress Nitride LPCVD recipe. The deposition condition is fixed. Enter only the deposition time, based on your target film thickness, when loading recipe.

9.3. **Loading a Recipe and Wafers**

Recipe variables

Before running the furnace, the user needs to input the time and temperature of deposition. The time directly determines the thickness of the film. For oxidation, the user can refer to the website called oxidation calculator (http://www.lelandstanfordjunior.com/thermaloxide.html) or check on the excel sheet on the main computer with data of previous users to estimate the time of deposition. For nitride deposition, user can check the file named NWUNITRIDET6.xls (See latest data sheet, units in angstroms) on the furnace computer and estimate the time. The temperature of deposition can be kept the same as the programmed recipes. For any variations please contact the staff

Figure 5: Furnace ready for venting
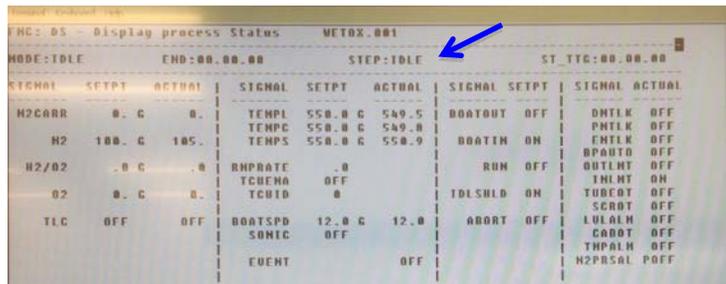
Figure 6: Screenshot of IDLE mode before venting furnace

Venting the Tube

The furnace in IDLE mode for Bank 1 and STANDBY recipe for Bank 2, under vacuum when idle. The furnace tube needs to be vented to atmosphere before the door can be opened. Do not attempt to open the door if the tube is not vented to atmosphere. It will severely damage the furnace. Enable this tube on FOM.

9.3.1. Before starting to vent furnace check that the orange light is ON (Fig. 5). It means that the system is in IDLE state. To check on computer if the IDLE/STANDBY recipe is on press

MAIN MENU, then press DS and ENTER. On top of the screen you should be able to read IDLE/STDBY.006. (Fig. 6).

9.3.2. Press EVENT, and the process should advance to BKF1 (Back Fill 1). It takes 12 minutes for the venting process to finish. Afterwards, the process ends and the furnace status changes to IDLE mode. The door will now slowly open.

Load and Run a Process Recipe

9.3.3. Make sure the process tube is properly vented.

9.3.4. Press MENU button, and then enter RL and the screen will show a list of the available recipes (Fig. 7). Use the arrow keys to highlight the recipe that you plan to load, and then press ENTER twice. Ask staff in case you need to modify any recipe parameter other than temperature. Do not modify any existing recipe on the tube computer by pressing Recipe Modify button since this will change original recipe database for subsequent users.
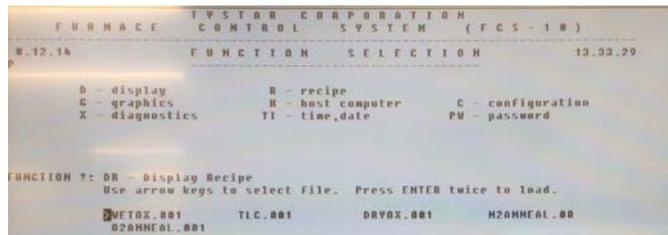
Figure 7: Screenshot of available recipes
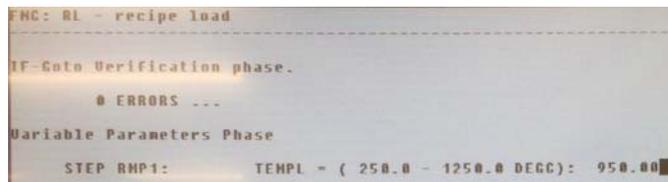
Figure 8: Enter first zone temperature
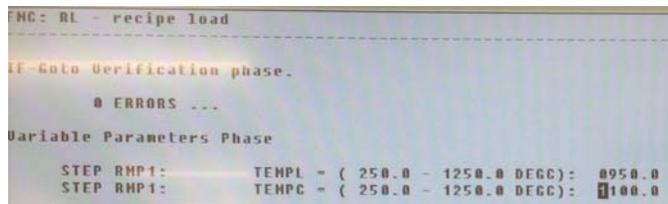
Figure 9: Enter second zone temperature
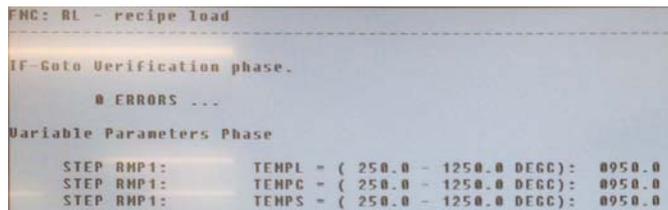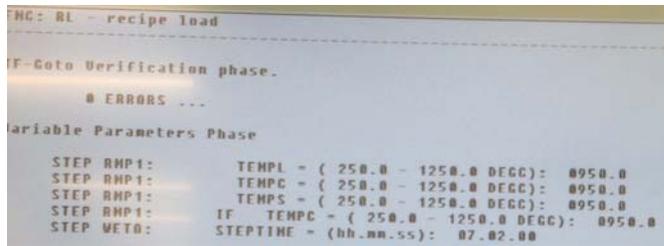

Figure 10: Enter third zone temperature

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Figure 11: Enter process time

9.3.5. The computer will prompt you to enter some process parameters (time and temperature for Bank 1 and only time for Bank 2) if needed (Fig. 8). Input values of the previous run will be displayed for your reference. Enter your value with the same format (number.00). For Bank 2 go directly to step 9.3.7. Press ENTER after typing each process variable value. You will be asked to enter the temperature variable for the Center, Flat and Source zone of the furnace (Fig. 8, 9, 10). Usually the same number is entered for all the three zones.

9.3.6. Time is entered in the format of HH.MM.SS. Do not enter 00.00.00 since it will hold the process at the step indefinitely (Fig. 11). Press ENTER to show the recipe load complete message on screen (Fig. 12).
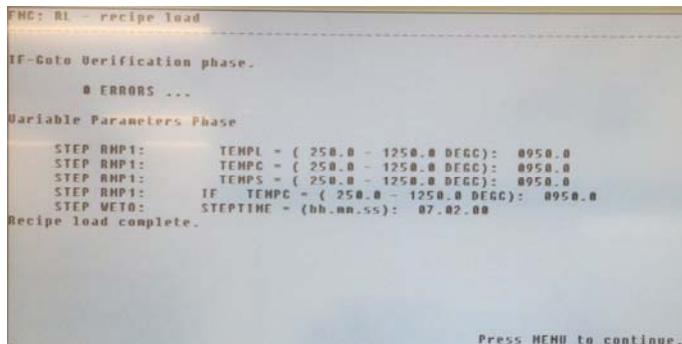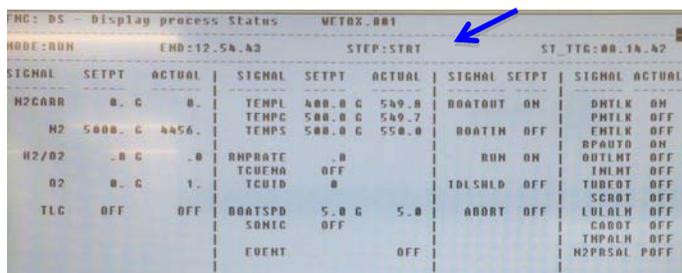

Figure 12: Recipe loaded successfully

Figure 13: Screen when recipe starts (STRT)

9.3.7. Once you have finished entering all of your required values, press MENU, then DS to check that the recipe is loaded properly (Recipe name will display on top of the screen. For ex: STDNITR.006). Press RUN to start the process (Fig. 13). The furnace light will turn green and the screen will display STEP: STRT. The tube door will open and the boats come out (Fig. 14, 15). It will ring the alarm as soon as the boat is all the way out. Once out ALRM comes on. Acknowledge it by pressing ALARM ACK.

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Figure 14: Boat moves out

Figure 15: Sample check ready to load

9.3.8. After the boats move out completely, remove dummy wafers and load your wafers in the furnace chuck. Do not use your own sample holder near the furnace since the furnace temperature is very high. Step on a stepping stool if required (Fig. 16). Avoid putting your head close to the door since warm air will come out. Put the wafer in the middle of the boat with the shiny side towards the outside. The primary flat is normally facing the top. If you have multiple wafers arrange as shown in Fig. 17. The boats will remain out for 20 minutes and the screen will display LDWF command (Fig. 18). If the boat start moving in and you have not finish loading your wafers, press EVENT before the door closes, the boat will come out, and you will have another 20 minutes.
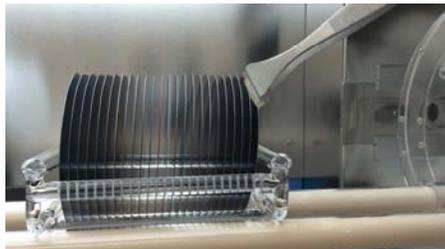

Figure 16: Wafer loading

Figure 17: Loading of multiple wafers

Figure 18: Screenshot at wafer loading (LDWF)

*** Do not leave the door open for more than 30 minutes, since it will create a large temperature gradient in the tube and causes the thick film deposited on the tube wall to crack and create particulate problems. It may also crack the process tube. In case a wafer is broken when loading, and you need to obtain another clean one, press HOLD then BOATIN. After you are ready to load again, press BOATOUT and wait for the boat to come out. Load your wafer, then press RUN.

9.3.9. Press EVENT, and the boats will start moving into the tube. The screen will show BTIN command. When the door closes completely, the tube will be pumped down and the deposition process start. On the screen the next step is displayed. Note the END time (number of hours) and you can leave the cleanroom and come back when the process is complete.

Unload Sample

9.3.10. Return to cleanroom after the estimated time of your recipe is complete. If the deposition process completes successfully, the recipe will stop at the HLD1 step and the tube will be purged with nitrogen, held at low pressure at a temperature of 550^0C. Press EVENT to start venting the tube.

9.3.11. After 12 minutes, the process will hold at the HLD2 step.

9.3.12. Press EVENT and the tube door will open and the boats will come out.

9.3.13. Press EVENT again, and boats will start moving into the tube. When the door closes completely, the recipe ends. Wait till door seals and then follow step below. The status will be IDLE. The tool is now ready for the next user.

Load and Run the Standby Recipe

9.3.14. Press MENU, and then enter RL. Use the arrow keys to highlight the standby recipe. Press ENTER twice.

9.3.15. Press MENU, and then enter DS. Check and make sure that the recipe is loaded.

9.3.16. Press RUN. Make sure that the orange light is on and door is securely closed before you leave.

Sample measurement

Measure the sample thickness with reflectometer. Write down the log in the excel sheet on the FOM computer named NWUNITRIDET6.xls for nitride deposition or NWUOXIDET1.xls for oxide deposition or NWUANNEALT2.xls for annealing as guideline to next user.