Important preliminary notices:

- USE OF VACUUM GREASE OR OF BLUE TAPE IN THIS EQUIPMENT MEANS, UNLESS AGREEMENT WITH CMI STAFF, THAT IT IS THE LAST PROCESSING STEP TO BE PERFORMED IN THE CLEANROOM.

- THIS EQUIPMENT IS MICROELECTRONIC COMPATIBLE, SO BEFORE INTRODUCING MATERIALS SUCH AS PYREX OR FLOAT GLASS YOU NEED AGREEMENT WITH CMI STAFF.

Contents:

I. Introduction
II. Equipment description
III. Standard processes
IV. How to use the system
V. Metrology
VI. Photos gallery
VII. References

I. Introduction

Alcatel 601 E is a Deep Reactive Ion Etching (DRIE) equipment with high performances, in particular for obtaining high aspect ratio profiles into Silicon (Si).

1. Some special hardware arrangements provide these performances:
   - A high density plasma source: Inductively Coupled Plasma (ICP)
   - A cryogenic and biasing mechanical chuck controlled in temperature from -170 °C to room temperature
   - A powerful gas process pumping arrangement
   - An efficient and user friendly control software
   - Optimized loadlock/chamber transfers

2. Processes can be separated in 3 specific families: pulsed\(^1,2\) (Bosch process) and none pulsed at
The major advantages of this system compared to capacitive coupled reactors (also called RIE: Reactive Ion Etching) are:

1. Wafer voltage biasing independent from the inductively coupled plasma creation
2. Creation of a low pressure (0.1 à 20 Pa) and high density (10^{11} à 10^{12} cm^{-3}) plasma without reactor walls sputtering

This dissociation between the plasma density (radicals and ions) and the ions energy offers large processes development opportunities.

II. Equipment description

Graphic user Interface

The Alcatel 601 E etcher is totally driven through a very intuitive computer Graphic User Interface (GUI). The only manual handlings are the pluggings/unpluggings of liquid nitrogen to the machine (to thermalise the chuck) and the loadings/unloadings of the wafers into the loadlock. Figure 1 depicts the way recipes are edited. All parameters linked to the etching process are adjustable.

[Image: Figure 1: Editing of a recipe using the A601E software]

Wafer loadlock

The loadlock/transfer arm system is designed in such a way that the process chamber is always under high vacuum during loadings/unloadings procedures of the wafers, which optimizes processes durations.

Processing chamber

Figure 2 shows a global view of the 601 E processing chamber. Main parts are visible: ICP source, diffusion chamber, cryogenic and biasing substrate holder, pumping systems and gas lines. The machine is also fitted with an End Point Detection (EPD) system.
ICP source
ICP source is made with an antenna connected to an RF power supply and wrapped around an alumina cylinder. RF power (2 kW maximum) is coupled to the plasma through an inductive mode. The oscillating current in the antenna at 13.56 MHz induces an electromagnetic field (E/B) in the alumina cylinder. For plasma ignition, some primary electrons collect the E/B field energy (ions are too heavy to get the energy from E/B field). Inelastic collisions between hot electrons and neutrals (injected gas mixture) give ions/electrons pairs. This is the way how the main plasma is created inside the cylinder where the gas mixture and pressure are controlled. A coil surrounding the plasma source gives a permanent magnetic field for a better plasma confinement and to avoid wasting too much charged species.

Diffusion chamber
The diffusion chamber is located between the ICP source and the substrate holder. It is a buffered zone to get better plasma uniformity. Permanent magnets surrounding the chamber limit charged particles wasting on the wall and keep a better plasma density.

Cryogenic substrate holder
The cryogenic substrate holder allows thermalization of 4 or 6 inches (special kit) wafers between -170 °C and room temperature. Substrate holder temperature control is assured via a liquid nitrogen circulation and several heating resistances controlled by a Proportional Integral Derivative (PID) controller. The wafer is fixed onto the substrate holder via a mechanical clamping (ring pressing down the periphery of the wafer). This is compatible with double face etching, the untreated surface not being in contact with the substrate holder. Energy transfers between the wafer and the substrate holder are assured by an helium interface whose pressure is adjustable. The substrate holder biasing is done by a RF generator (500 W maximum), which enables control of the ions mean energy value during the etching process.

Pumping systems
The combination of a 1000 l/s turbo pump and a rough primary pump gives a secondary vacuum of few 10-7 mb without process. In process, the powerful pumping capacity makes possible the use of high gas flow (to enhance etch rate) at a low pressure (few Pa). A secondary turbo pump / primary pump combination is fitted to the machine for load lock pumping.

Gas lines
Injection of gas mixtures is assured by 8 Mass Flow Controllers (MFC):

- O₂ [0-100 sccm]
- SF₆ [0-300 sccm]
End Point Detection (EPD) system

EPD is a non intrusive technique which enables the detection of different materials transitions during process. It is based on the fluorescence intensity observation of a specific specie (with the use of an optical fiber/photomultiplicator/spectrometer/computer system). The SiF\textsubscript{2} molecule, which radiates at 440.5 nm, is usually used because it represents an etch product of Si, SiO\textsubscript{2} and Si\textsubscript{3}N\textsubscript{4} etching. The radiation intensity of this molecule is related to the etched material.

Gas treatment before drainage

Downstream the pumping system, outlet gases are treated before being drained. A M150	extsuperscript{2} Gas reactor column\textsuperscript{2} from EDWARDS collects toxic compounds such as chlorine or fluorine through absorption in a cartridge tank heated between 450°C and 550°C.

III. Standard processes at CMI

Table 1 gives an overview of the different standard processes available on 601 E at CMI. A photos gallery is given in section VI to illustrate the processes.

- Before doing the first silicon etching process (and only the first one), it is strongly advised to prime the processing chamber by performing the process on a dummy wafer for ~5 min.

### Materials to be etched and Temperature

<table>
<thead>
<tr>
<th>Materials to be etched and Temperature</th>
<th>Process name</th>
<th>Mask material</th>
<th>Selectivity to mask</th>
<th>Material etch rate (µm/min)</th>
<th>End Point Detect</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO\textsubscript{2} at 20°C</td>
<td>SiO2</td>
<td>PR</td>
<td>&gt; 1</td>
<td>0.34</td>
<td>YES</td>
</tr>
<tr>
<td>Si\textsubscript{3}N\textsubscript{4} at 20°C</td>
<td>Nitrure\textsubscript{1}</td>
<td>PR</td>
<td>&gt; 0.85</td>
<td>0.26</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>Nitrure\textsubscript{2}</td>
<td></td>
<td>&gt; 1</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Si “isotropic” at 20°C</td>
<td>Si_release</td>
<td>PR</td>
<td>&gt;100</td>
<td>0.5</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td>SiO\textsubscript{2}</td>
<td></td>
<td>&gt;200</td>
<td>V\textsubscript{lateral} x 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>If thin layer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Si_isoslow</td>
<td></td>
<td></td>
<td>V\textsubscript{vertical} x 0.5</td>
<td>\textsuperscript{h}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V\textsubscript{lateral} x 0.25</td>
<td></td>
</tr>
<tr>
<td>Si “anisotropic” deep etching. Bosch processes at 20°C</td>
<td>Si_ambient1</td>
<td>PR</td>
<td>&gt; 100</td>
<td>6 to 9</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td>SiO\textsubscript{2}</td>
<td></td>
<td>&gt; 200</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Si_ambient2</td>
<td></td>
<td>&gt;200</td>
<td>7 to 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SiO\textsubscript{2}</td>
<td></td>
<td>&gt;400</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Si_ambient3</td>
<td></td>
<td>&gt; 50</td>
<td>3 to 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SiO\textsubscript{2}</td>
<td></td>
<td>&gt;100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si “anisotropic” thin layer at 20°C</td>
<td>Si_opto</td>
<td>PR</td>
<td>&gt;20</td>
<td>1 to 2</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>SiO\textsubscript{2}</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PR: Photo Resist

Table 1: standard etching processes available on 601 E

IV. How to use the system
Preliminary remark: wafers with PR as etching mask MUST have an Edge Bead Removal (EBR), unless agreement with CMI staff

1. Login on the 601 E on zone 2 computer.
2. Login on 601 E computer (username: 1, password: 1).
3. Select your process (refer to Standard processes at CMI). Go to "edition" and select the process in the right list. Select the etching steps and hit "modify". Check the parameter "etching time" and if necessary modify it (and only this parameter) to match your needs.

4. Substrate holder thermalization:
   ● Load a dummy wafer (use those at disposal by the machine) on the loadlock substrate holder
   ● Run the thermalization program (therm20 °C or other)
   ● Go in the grey zone, behind the 601 E, to connect the liquid nitrogen N2 to the machine (this procedure is available behind the 601E):
     a. Put on glasses and protection gloves
     b. Remove the stopper (obturateur) from the 601 E (loosen the tube gland (presse-étoupe) )
     c. Remove the top cap from the liquid N2 deware
     d. After checking the effective presence of the O-ring on the deware, connect N2 pipe
        ■ to the deware for the longest part
        ■ to the machine for the shortest part
     e. On the machine, tighten the tube gland (just enough so you cannot get the pipe out)
     f. On the deware, put on and tighten the collar
     g. Open the gas nitrogen N2 valve upstream of the pressure regulator (quarter turn valve to be turned counter-clockwise)
     h. The pressure regulator is already set to get the working pressure of 0.1 bar on the pressure gauge located on the top of the deware. This pressure takes time to rise, particularly when the deware is almost empty.
       ● Wait for the machine to unload the wafer, which means that thermalization is effective.

5. Load the wafer to be etched (check mask compatibility with selected process and cleanliness of backside), validate an EPD program if required and start the process.

If etching silicon, it is advised to prime the processing chamber especially when previous process was SiO2 or SiN etching.

6. When the process is over, check the results (refer to "V. Metrology" part)
7. Repeat the procedure to etch other wafers
8. Once all your processes are finished, put the equipment on stand-by mode. To do so :
   ● Go in the grey zone, behind the 601 E, to disconnect the liquid nitrogen N2 (this procedure is available behind the 601E):
     a. Put on glasses and protection glove
     b. Close the gas nitrogen N2 valve upstream of the pressure regulator (quarter turn valve to be turned clockwise)
     c. Totally unscrew the screw-nut of the pressure valve (black) on top of the deware to release the gas pressure
     d. Unscrew and remove the collar from the deware
e. Unscrew the tube gland at the 601 E liquid N2 entry
f. Remove the N2 pipe from the machine and deware (pay good attention to the O-ring !)
g. Put the top cap back on the deware
h. Put the stopper back on the machine and tighten the tube gland (just enough so you cannot get the stopper out)
• Run the program « Arrêt therm » WITHOUT wafer
• Perform 601E logout on zone 2 computer

V. Metrology

Optical Microscope
• Specific vernier observation after etching gives a good idea of the anisotropy
• Bottom etch observation tells if there is some roughness
• Depth is measurable by focusing on the bottom first, resetting the zero of the optical microscope fine adjustment tool and focusing on the top of the sample. The measurement accuracy is 1µm.

Mechanical profiler
Mechanical profiler in zone 4 (alpha-step) gives accurate step measurements in the range 0.1µm to 2mm. The system does not work when the aspect ratio becomes too high; the stylus cannot reach the bottom.

Interferometry
Spectro-reflectometer (Nanospec) in zone 3 gives accurate thickness measurements for transparent layers (SiO₂ or Si₃N₄ for example) on Si. This metrology is useful to estimate etching selectivity. However, it is not suitable for thickness less than 10nm.

Scanning Electron Microscope (SEM) and Focus Ion Beam (FIB)
SEM LEO 1550 in zone 1 is a very powerful tool to study profiles after etching (verticality, roughness, depth, selectivity…). It is very often necessary to cleave the wafer to get a full etching characterization. When it is not possible to destroy the wafer, a local cross section can be performed with FIB.

VI. Photo gallery

Deep etching using a pulsed room temperature process (Si ambiant):

20 minutes de gravure avec Si ambiant
(plaquette 4 pouces, 5 % de silicium exposé)
Figure 3: SEM image (cross view) of a deep etching realized using a pulsed room temperature process, observation of various aperture sizes (test CMI).

Highlight of the microloading effect:

30 minutes de gravure avec Si ambiant (plaquette 4 pouces, 5 % de silicium exposé)

Figure 4: SEM image (cross view) of a deep etching realized using a pulsed room temperature process for a micro-actuator fabrication (LPMO project done by Ch. Edouard)

Figure 5: SEM image (tilted view) of a deep etching realized using a room temperature process (test CMI)
Figure 6: SEM image (tilted view) of a deep etching realized using a room temperature process (test CMI).

Figure 7: SEM image (cross view) of a deep etching realized using a pulsed room temperature process for micro-grating fabrication.
Figure 8: SEM image (cross view) of a pattern bottom through a substrate opening on a SiO₂ membrane (test CMI). Done with a pulsed room temperature process.

Figure 9: SEM image (cross view) of a SiO₂ micro-nozzle obtained with a Si mold (2 successive deep etchings of different diameters in silicon) and released by an anisotropic etching of SiO₂ followed by an isotropic etching of Si.

Figure 10: SEM image (cross view) of a cone-shaped hole through a Si substrate, project of Microshutters® Colibrys S.A., Neuchâtel, CH.
Figure 11: SEM image (tilted view) of an anisotropic etching of a thick polySi layer realized with a continuous process at room temperature, project of Microshutters\textsuperscript{6} Colibrys S.A., Neuchâtel, CH.

Figure 12: SEM image (cross view) of an anisotropic etching in Si d'une gravure anisotrope dans Si realized with a continuous process at room temperature, project of Optosimox\textsuperscript{7}, EPFL-DE/MET,
Figure 13: SEM image (cross view) of Si gratings deep etching realized with the cryogenic process (test CMI). Highlight of the "microloading effect"

VII. References