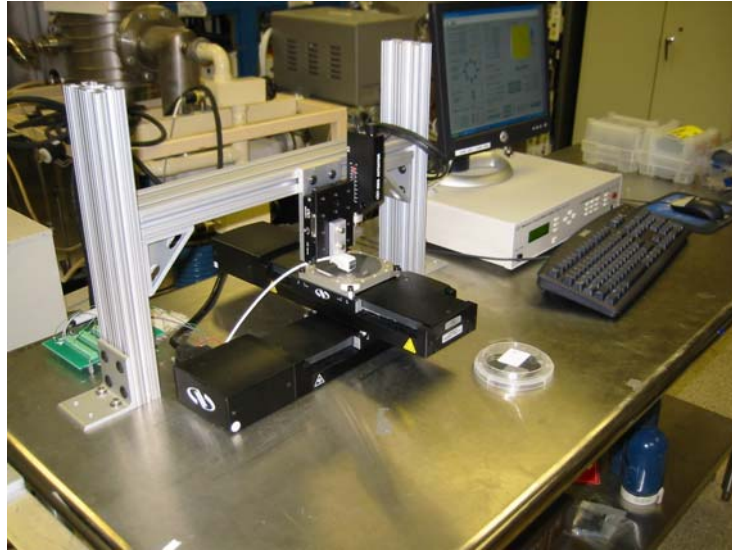


## Standard Operating Procedure for LAMP four point probe sheet resistance measurements



### Overview of 4 point probe station

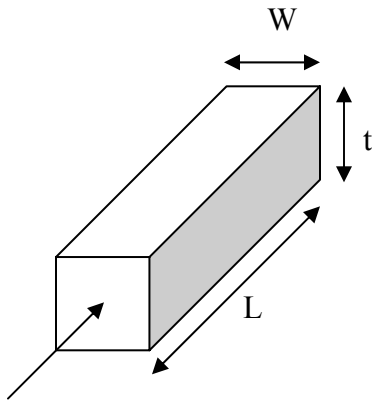
The four point probe station is located in the annex of the Laboratory for Advanced Materials Processing at the University of Maryland and is primarily designed for the thickness mapping of semiconductor thin films via sheet resistance measurements. This system uses a standard four probe sensor mounted on an automated X-Y-Z scanning stage in order to obtain reproducible thickness maps.

The 4 point probe head is a Signatone #SP4-62085TRS. Spacing between Tungsten Carbide tips is 0.0625 inches (1.58 mm) with 85 grams spring pressure. Voltages are delivered and measured by a National Instruments data acquisition board DAQ 6014. The 6014 includes 16 bits 0-10V analog input and outputs. Gain of the DAQ channel should be carefully selected in order to provide to maximum measurement resolution (Table 1). 2 Newport ILS 150 with 150 mm travel and 0.5  $\mu\text{m}$  resolution are used for x and y translation of the sample. A Newport 850G actuator with 50 mm travel is used for the probe z translation. A LabVIEW application was developed for data acquisition and motion control. GPIB communication protocol is used between LabVIEW and the Newport ESP300 controller.

Gain	Input Range	Precision
0.5	-10 / +10 V	305.2 $\mu\text{V}$
1.0	-5 / +5 V	152.6 $\mu\text{V}$
10.0	-500 / +500 mV	15.3 $\mu\text{V}$
100.0	-50 / +50 mV	1.53 $\mu\text{V}$

Table 1 – Measurement precision with DAQ 6014

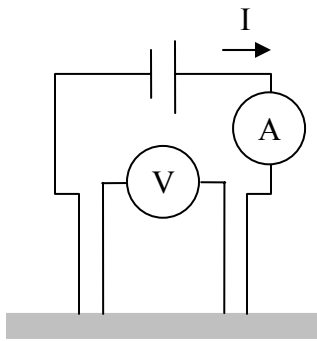
## Sheet resistance measurement principles <sup>1</sup>



The resistance  $R$  of a rectangular block of uniform bulk resistivity is given by:  
 $R = \rho \times L / A$  with  $A = t \times W$  and  $\rho$ : resistivity of the sample.

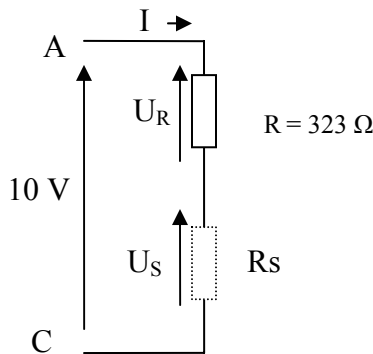
$R = (\rho / t) \times (L / W) = R_s \times (L / W)$ , with  $R_s$ : sheet resistance of a layer of this material

The sheet resistance is expressed in Ohm.square though strictly speaking it should be in Ohm.



$R_s$  can be determined by four probe measurement by applying a DC current in between the 2 outer current probes and measuring the voltage at the 2 inner voltage probes:  
 $R_s = V/I \times CF$

The correction factor  $CF$  is dependant on the sample size and shape. Our default correction factor is 4.532 which assume that the diameter of the sample, e.g., 4 inch, is more than 200x the spacing of the probe (62.5 mils or 0.062 in or 1.58 mm). For different conversion factors based on specific sample sizes, consult “four point probe information” at <http://www.four-point-probes.com/>



The DAQ 6014 providing only an analog output voltage, a 10 V signal between A and C is applied and the intensity  $I$  is determined by measuring the voltage  $U_R$  at the resistor  $R$ .

Therefore, the thickness  $t$  is given by:

$$t = \rho / (R \times U_S / U_R) / 4.532$$

In the case of tungsten films, the bulk resistivity  $\rho$  is 5.39E-6 ohm.cm.

<sup>1</sup> Adapted from <http://www.ece.gatech.edu/research/labs/vc/theory/sheetRes.html>

For materials with a low sheet resistance  $R_s$ , e.g., metals with thickness  $\sim 0.1-1 \mu\text{m}$ , the voltage  $U_s$  will be small. In this case, the input range for the measurement of  $U_s$  should be  $-50 / +50 \text{ mV}$ .

For materials with smaller thicknesses (10-100 nm range) or higher bulk resistivity,  $U_s$  will increase and a higher input range (see Table 1) should be selected.

## Operation of 4 point probe system

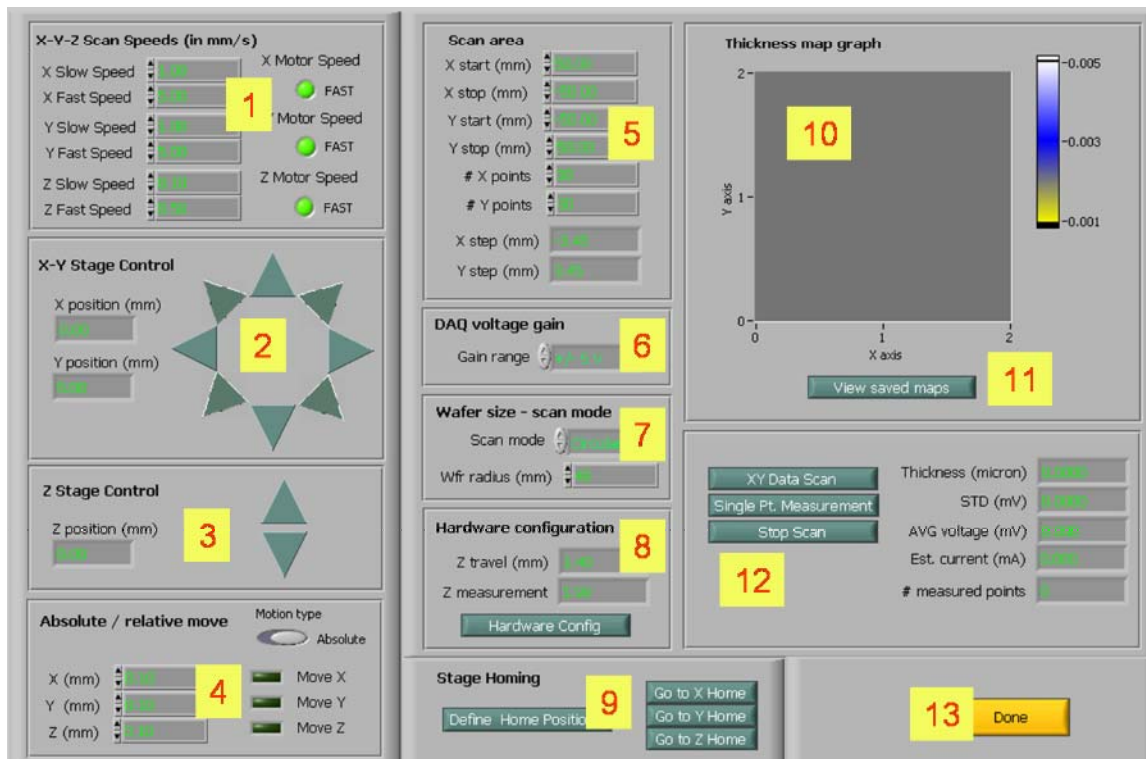


Fig. 3 – LabVIEW 4 point probe graphical user interface

*Notice: Make an effort to keep the x and y stages as clean as possible. If particles coming off the wafer accumulate it will damage the high resolution motors.*

1 – Turn On ESP 300 controller and wait  $\sim 10$  seconds for initialization. The 3 motors are OFF (see display of ESP 300).

2 – Launch the LabVIEW 4 point probe application from Desktop (Fig.3).

3 – The 3 X,Y and Z Newport motors should be On at this point.

4 – Homing of the X, Y and Z stages. THIS STEP IS VERY IMPORTANT.

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**Not following this procedure carefully can result in major damage to the probe (\$500) and to the stages (\$10000...). So if you are not sure how to do it after reading these instructions, stop here and ask someone who knows before it is too late!**

**Notice:** *The zero position assumed by the ESP 300 controller is the position the stage is at when the controller is turned on and initialized. Therefore redefining the Zeroes should be necessary only if the ESP 300 controller was turned off while the stages were not at their homing positions*

After turning on the ESP 300, check the metric scale on the 850G actuator (Z stage) and make sure it is accurately at 0 mm. The position read on the ESP 300 controller as well as the Z position read on the LabVIEW application should both read 0 mm (Fig.3 – label 3). If not, it is critical to redefine the zeros: with the Z Up and Down buttons on the software interface [Fig.3 – label 3], position the Z stage at 0 mm on the actuator scale (not on the software or the ESP 300 controller). Once positioned, click the “Define Home Position” button [Fig.3 – label 9] and redefine Z homing.

To figure out the settings of the X-Y scan limits (Xmin, Xmax, Ymin, Ymax) [Fig.3 – label 5], it is easier if the zero position in X and Y corresponds to the center of the wafer. Therefore redefine the zeros for the X and Y stages by following the same procedure as for the Z stage if necessary.

### **5 – Defining the Z travel limits for wafer map scan.**

**Notice:** *Once again be vigilant as this step can result in serious damage to the equipment if tuning is not done carefully. As with the stage Homing, redefining the Z travel should only be done occasionally, for example if new wafers with a different substrate thickness are used (our standard wafer thicknesses are 0.5 mm)*

While scanning over the wafer, the z stage will be automatically translated between a travel position (up) and measurement position (down) that are both defined by clicking on Hardware Configuration button [Fig.3 – label 8]. The Z travel position is typically at 1.5 mm, meaning that at this position, you should be able to translate your sample in X and Y without the probe touching the wafer. In the Measurement position, e.g., 2 mm, the spring loaded pins should come in contact with the sample and be slightly retracted by ~0.1-0.2 mm (see Fig. 4).

Forcing the pins to retract after contact by more than 0.5 mm will damage the springs and the sensor so be vigilant. With a standard 0.5 mm thick wafer, you should never bring the Z stage above 2.2 mm in Z.

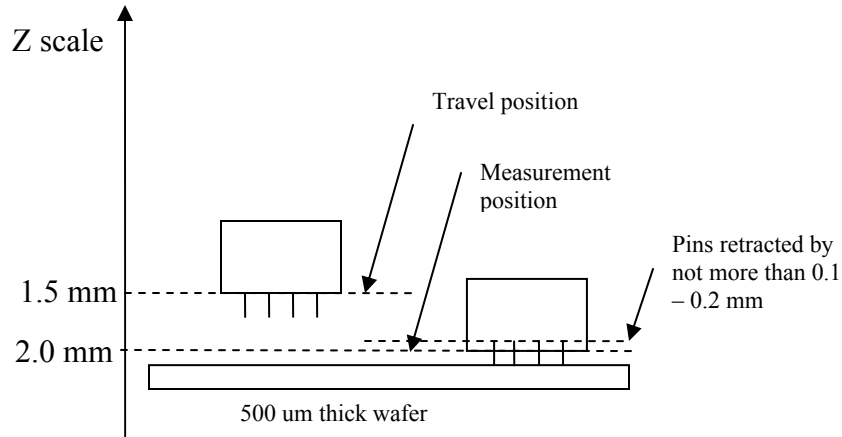


Figure 4 - Typical positions of the probe in Travel and Measurement positions

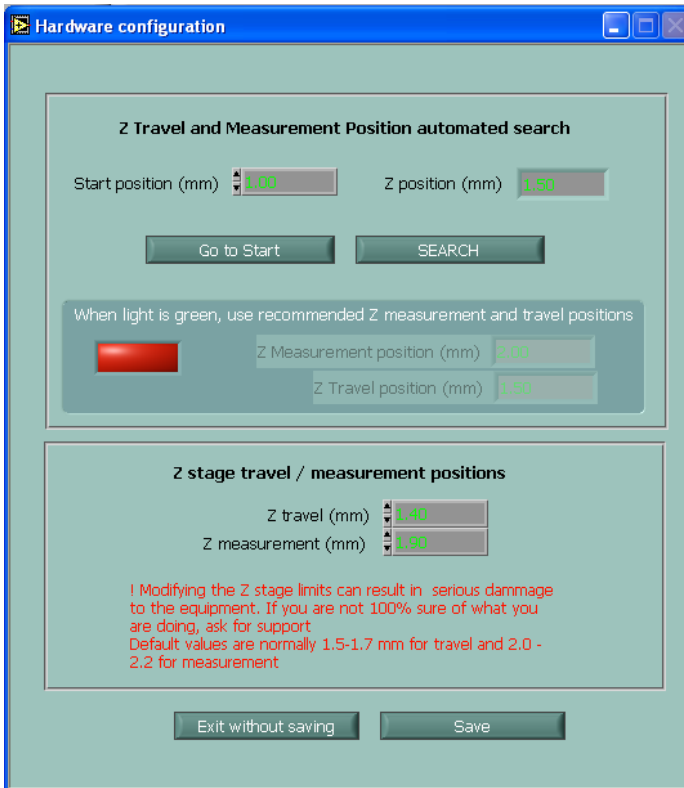


Figure 5 - LabVIEW Hardware Configuration sub-vi to optimize Z Travel and Measurement positions

To determine the optimal Z travel and measurement positions:

**Warning!** The following tool only works for conducting samples. Do not use the Hardware Configuration subVI for dielectric materials or you might damage the probe as the application will fail to detect a current loop at the contact point. Instead visually determine the point of contact.

- Choose an X and Y position (for example center of wafer) and click on Hardware Configuration. The window showed on Fig. 5 will open. Z Travel and Z Measurement can be defined in the lower window. By clicking on Save, the 2 values will be automatically saved to the Config.txt file located in the same directory as the LabVIEW application so that these values will be automatically recalled when the application is launched at a later time.
- To find the Z Travel and Z Measurement, enter a Z position in Start Position field for which you know the probe tips will be a few millimeters above the surface of the wafer (for example 1.5 mm in standard configuration). Then press SEARCH. The probe will lower by 0.1 mm each time you press SEARCH and a potential will be applied between the tips. If there is no contact, the current will be zero and the light on the subVI will be red. If contact, there will be current assuming you are testing a conducting film and the light will turn green. 2 recommended values for Z Travel and Z Measurement will be then displayed. Enter these 2 values in the lower window and SAVE.
- Make sure, the new Z limits are displayed properly in [Fig.3 – label 8]

#### 6 – Determine optimal DAQ Voltage gain

To obtain the best measurement resolution, the smallest adequate voltage range should be selected. However you must make sure that the range you selected will be adequate over the whole area you want to scan. Prior to do a complete scan, you should therefore make a few manual measurements at different X and Y locations by using the “Single Point Measurement” function [Fig.3 – label 12] and make sure you have selected the optimal range [Fig.3 – label 6]. A range too small will result in saturated measurements as the voltage  $U_s$  is above the selected range in which case negative values for the measured voltage and current will be returned.

The lower the sheet resistance, the smaller the voltage range.

Ex: for micrometer W films, select 50 mV range. For thinner films (<100 nm), you may use 500 mV range. Materials with a higher resistivity should require also a higher voltage range.

#### 7 – determine X and Y scan limits

Enter your scan coordinates [Fig.3 – label 5] for Xmin, Xmax, Ymin, Ymax. Select the number of point in X and Y. In order to maintain the aspect ratio of the thickness map

displayed by LabView [Fig.3 – label 10] it is recommended to select the number of points in X and Y so that the X and Y step is the same.

#### 8 – Circular / rectangular scan area

When scanning over circular sample (e.g., 100 mm wafers), it is recommended to select the circular scanning mode [Fig.3 – label 7] so that points which are within the rectangular scan area defined by the user but beyond the wafer radius are skipped during scanning.

#### 9 – Scan wafer thickness map

Press X-Y Data Scan when ready to start scanning [Fig.3 – label 12]. Press Stop Scan if you need to abort the current scan.

Notice: Pressing Stop Scan will not abort the motion immediately as the on going motion must be completed before the Stop Scan command is taken into consideration by LabView. **If you need to stop immediately the motion, you must turn off the motors by pressing the Stop All Axes red button on the ESP 300 controller.**

#### 10 – Save maps

Once the scan is completed, a window will be opened to ask you to save the data. You can save the thickness maps as well as Voltage, Current and Voltage Standard deviation maps as a 2D array of the corresponding values that can be read by Excel or the integrated LabVIEW View Graph [Fig.3 – label 11]. You can also to select the thickness values with the corresponding X and Y positions to be read with our Matlab application.

#### 11- View Saved Maps

You can open Saved Maps by clicking on View Maps [Fig. 3 – label 11] and Open data file. Make sure to open a 2D thickness array as this subVI will not read the files saved for Matlab analysis (see section 10)

#### 11 – EXIT application

To close application, always click on the DONE button [Fig.3 – label 13]. By doing so, all the stages will be returned to their home positions. The ESL can then be safely turned off if needed.

