Tutorial

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SAN JOSE STATE UNIVERSITY

Electrical Engineering Department

Device testing using ICS tools

IC DESIGN GROUP SAN JOSE STATE UNIVERSITY

A tutorial guide for using ICS tools for device testing

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CHAPTER 1: INTRODUCTION

This manual provides step-by-step procedures for the user to be able to create a test and analyze the data with ICS (Interactive Characterization Software). A test setup will be created that measures the spice parameters of a regular MOS, current voltage relationship of a diode, sheet resistance and the C-V characteristic of the MOS CAPS. The measured data will then be plotted and all the parameters will be extracted.

What is ICS?

The Interactive Characterization Software is a Windows based environment designed for Semiconductor testing applications. Measurements for the characterization of devices can be created in a matter of minutes without programming. The ICS is a full featured software tool that is capable of measuring many types of test equipment on a wafer. It uses pre-defined test setups and saves measurements in a database. It also provides the plotting capabilities for report generation.

Overview of ICS

This software allows an environment for the collection of data in three steps: setup, execute, and analyze. The Setup of a measurement typically takes no more than 1-2 minutes. ICS supports several measurement modes to accommodate most testing methods.

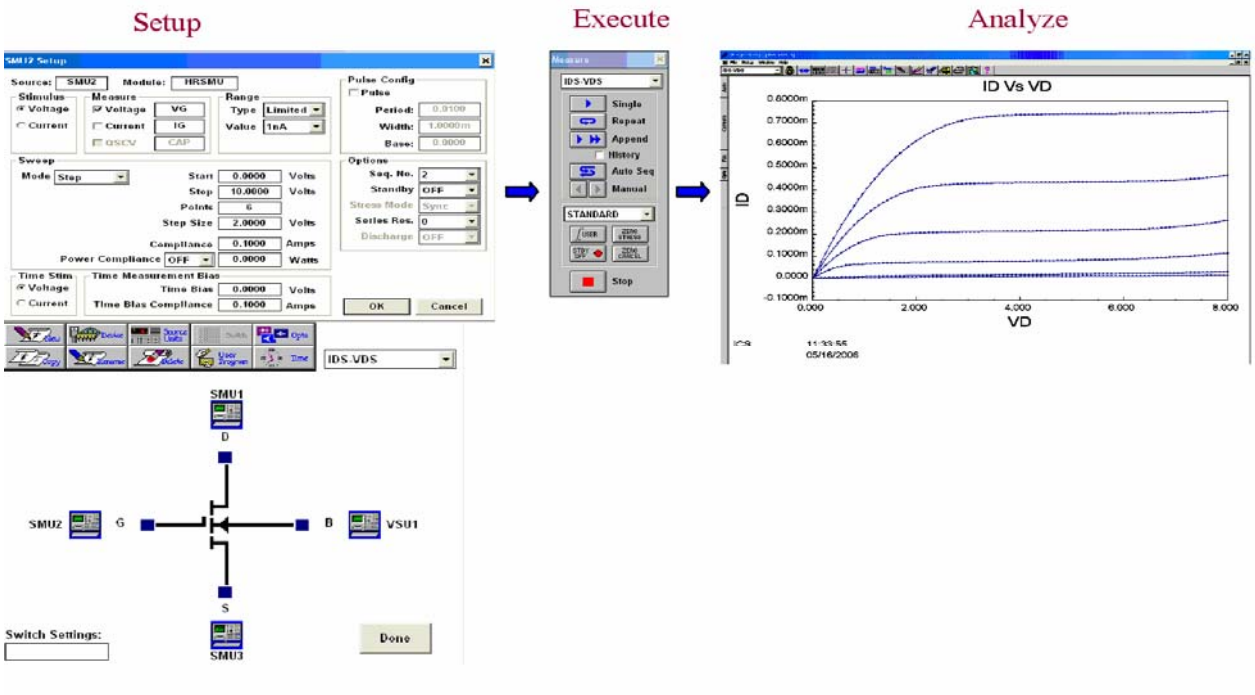


Figure 1: Analyzing Data using ICS tool

Analysis tools in ICS include plotting and data extraction. Once the functions are created, it can be saved with the data. The beauty of ICS is that once a test is created and saved, it can be re-opened and used again, including the analysis.

CHAPTER 2: GETTING STARTED

1. Go to start
2. Click on the ICS tool
3. After Opening the ICS tool, the window should look like figure 3.

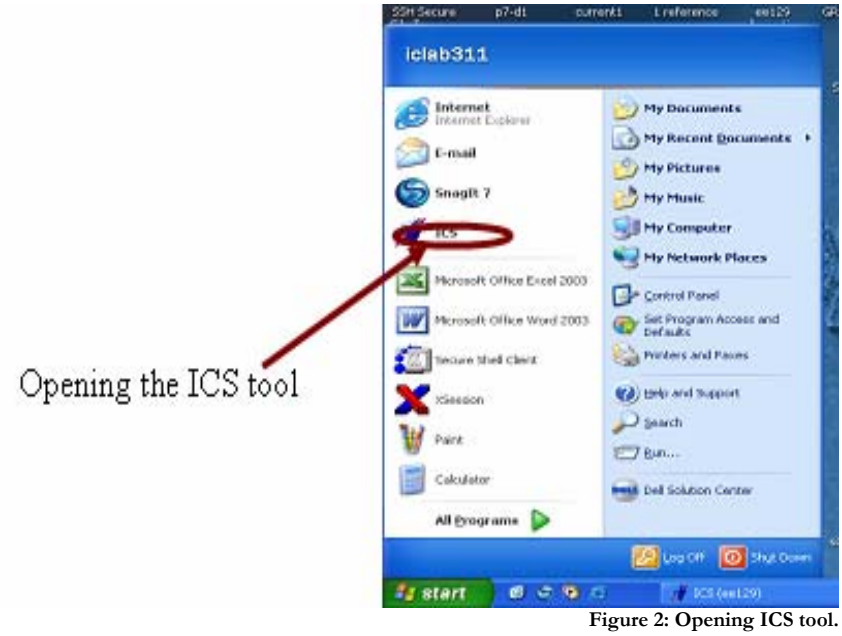


Figure 2: Opening ICS tool.

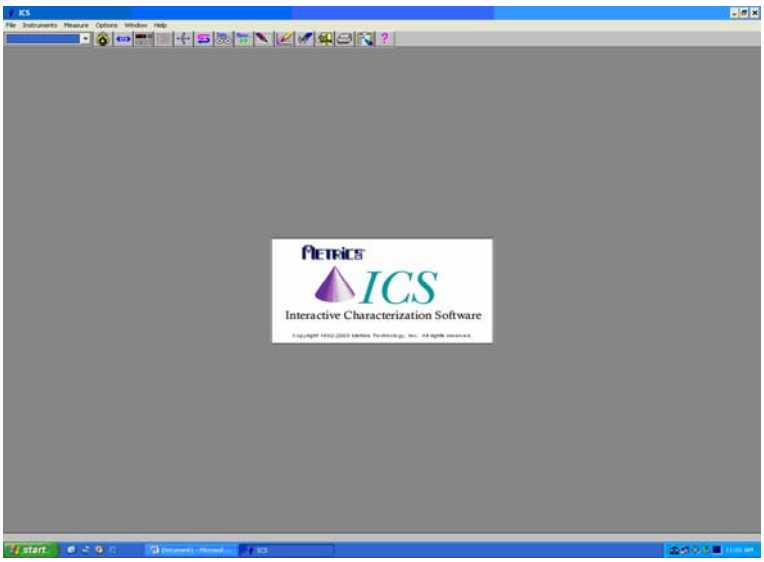


Figure 3: ICS window

Selecting Attribute for EE/MatE129

1. Go to file.
2. Click open.
3. From Attribute#1 select ee129

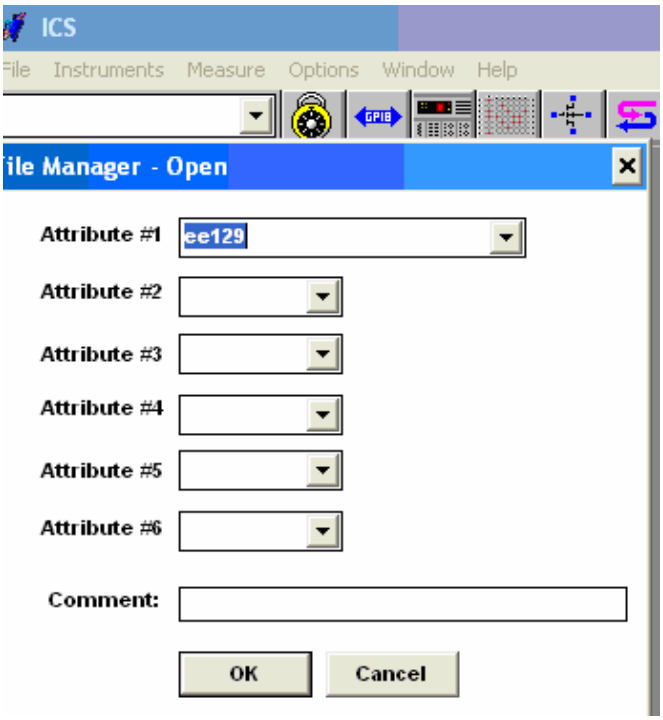


Figure 4: Opening Attribute 1

CHAPTER 3: TESTING DEVICES

Regular MOS testing:

When testing the Regular MOS devices on the wafer shown in Figure 5, the following measurements can be obtained:

1. I-V Characteristics
2. Channel Length Modulation (λ)
3. Effective Channel Length (Leff)
4. Threshold Voltage (Vt) from ID, GM vs. VG graph

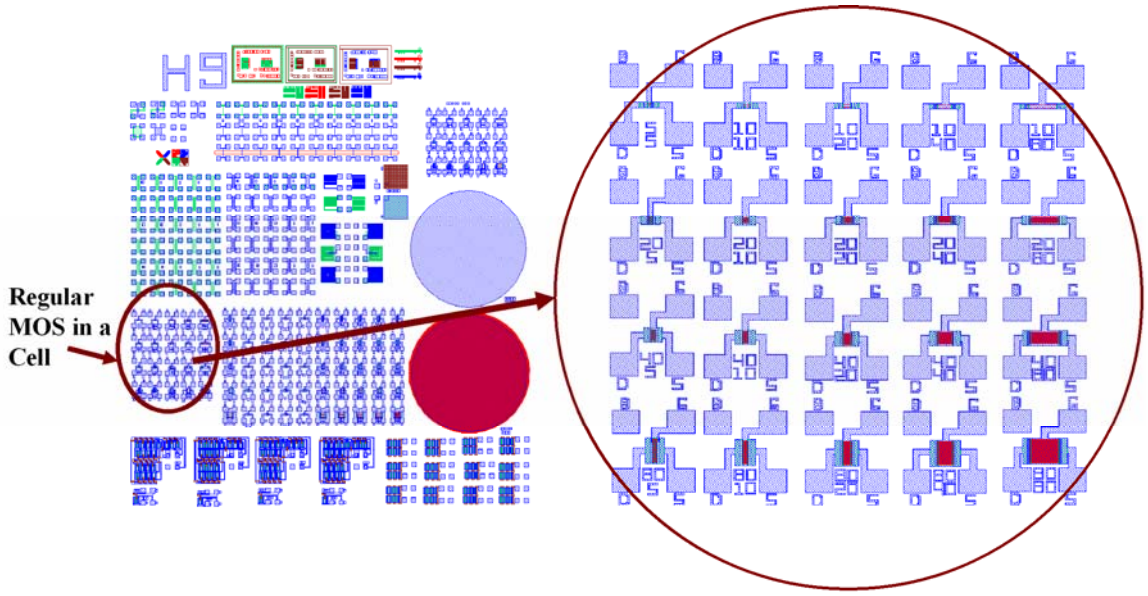


Figure 5: Regular MOS in a cell

1. I-V Characteristics:

To get the ID vs. VD graph

1. In the ICS window select IDS-VDS,
   as shown in Figure 6.
2. Click on Measure icon from the menu bar as shown in Figure 7
3. The Measure window should look like Figure 8.
4. Click on Single on the Measure window

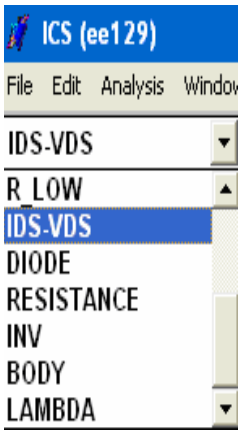


Figure 6: Selecting IDS-VDS testing

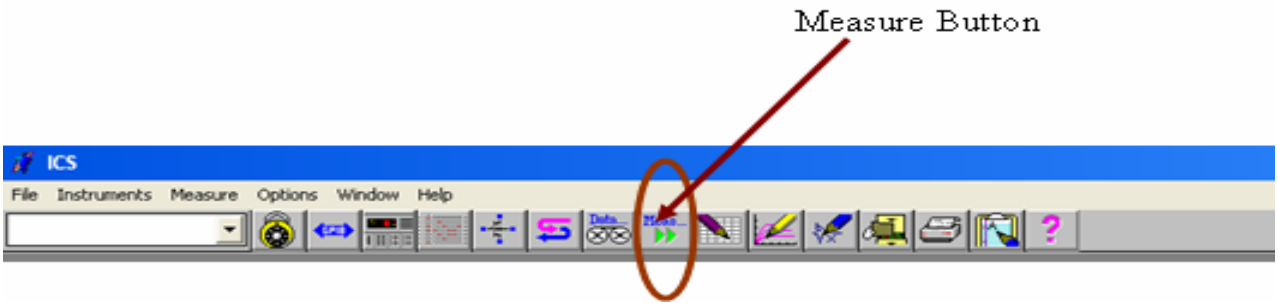


Figure 7: ICS Menu bar, clicking on Measure icon

Figure 8: Measure window

5. To see the arrangement of the probe connections on the MOS, click on the Setup Editor icon on the menu bar, shown in Figure 9.

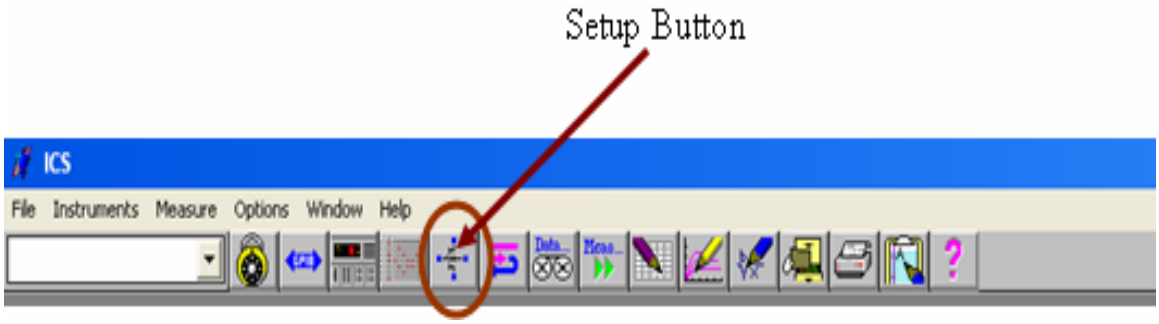


Figure 9: Setup Editor icon on menu bar

6. Setup Editor should look like Figure 10.
7. To sweep the value of the gate voltage(VG) click on SMU2 in the Setup Editor window.
8. SMU2 Setup window should look like Figure 11.

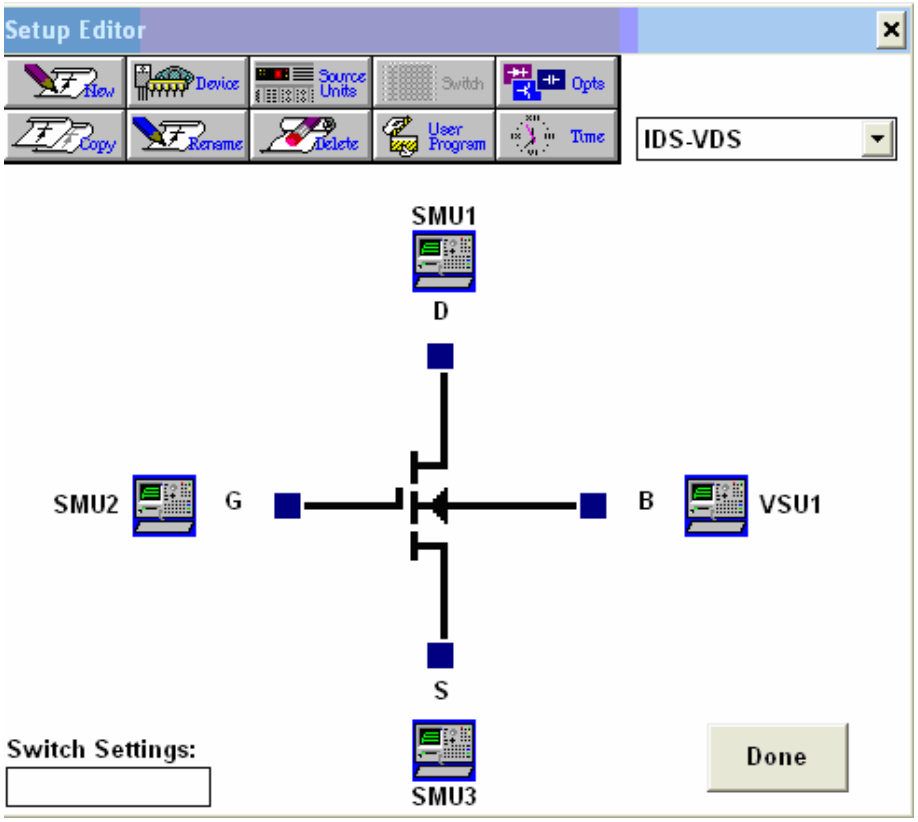


Figure 10: Setup Editor window

9. VG is varied from 0 to 10 volts, and its step size is every 2V; data entries are as shown in Figure 11.
10. To see the ID vs. VD graph, go to the menu bar and click on Setup Plot View icon, see Figure 12
11. Setup Pot View window should like Figure 12

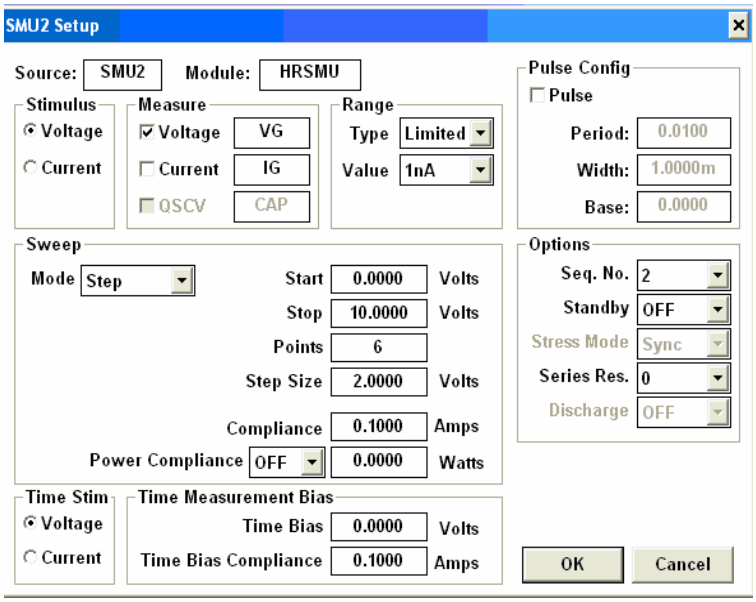


Figure 11: Gate Voltage Setup

12. Select VD for x-axis and ID(*) for y axis.
13. Click Apply and then click Done.
14. Figure 13 shows the graph of the ID Vs VD with a stepped VG

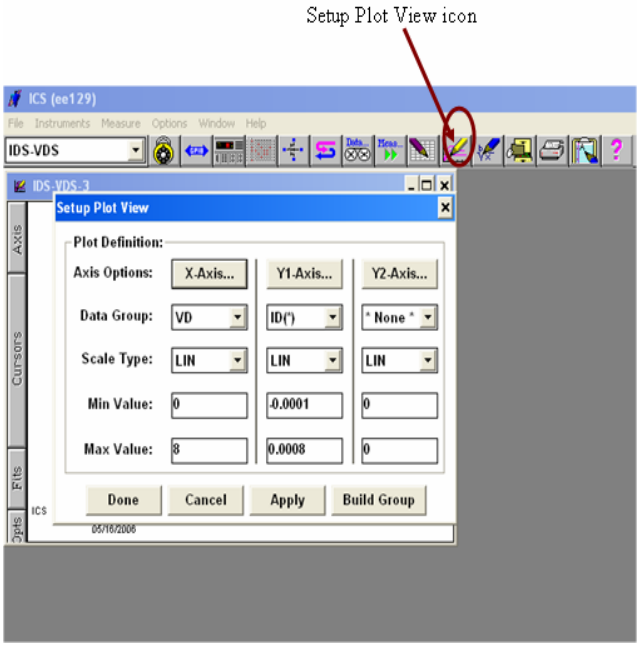


Figure 12: Setup Plot View icon and Setup Plot View window

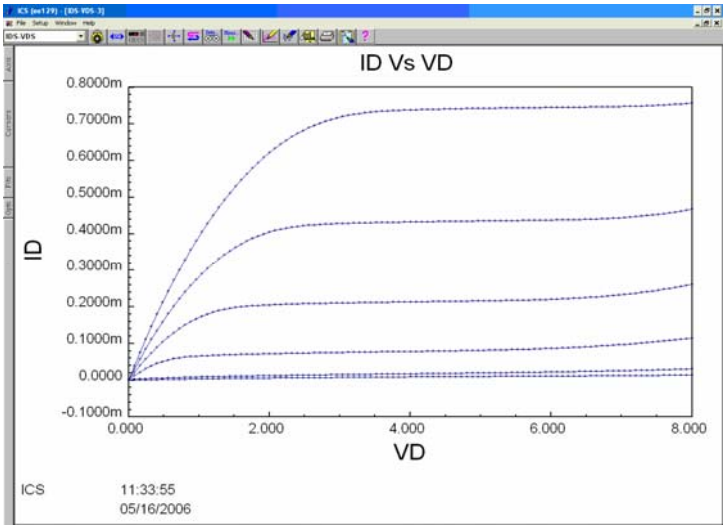


Figure 13: ID Vs VD graph with a stepped VG

15. To change the title of the graph click on Opts icon on the left side of the ICS window, see Figure 14.
16. Then click on Title which is shown in Figure 14 and 15. Title window will pop-up, shown in Figure 14

Selecting Opts

Figure 14: Opt icon, Title button to change the title of the graph, and

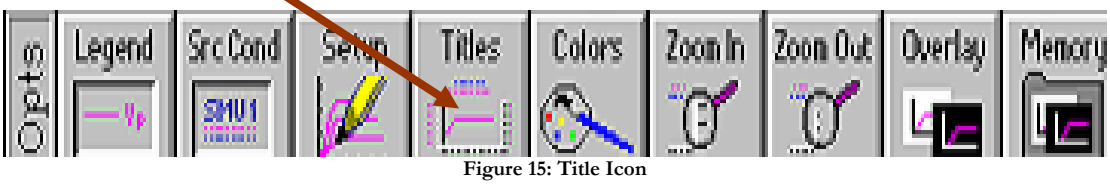
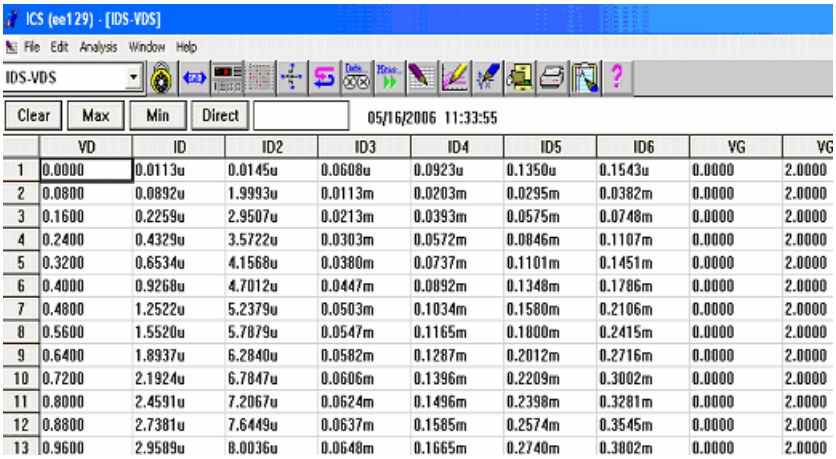


Figure 15: Title Icon

16. Using the Snagit software, take a snapshot of the ID vs. VD graph and Excel Spreadsheet (shown in Figure 15), which will be created automatically after each single test
17. Save the graphs on Word and the data spreadsheet on Excel



	VD	ID	ID2	ID3	ID4	ID5	ID6	VG	VG
1	0.0000	0.0113u	0.0145u	0.0608u	0.0923u	0.1350u	0.1543u	0.0000	2.0000
2	0.0800	0.0892u	1.9993u	0.0113m	0.0203m	0.0295m	0.0382m	0.0000	2.0000
3	0.1600	0.2259u	2.9507u	0.0213m	0.0393m	0.0575m	0.0748m	0.0000	2.0000
4	0.2400	0.4329u	3.5722u	0.0303m	0.0572m	0.0846m	0.1107m	0.0000	2.0000
5	0.3200	0.6534u	4.1568u	0.0380m	0.0737m	0.1101m	0.1451m	0.0000	2.0000
6	0.4000	0.9268u	4.7012u	0.0447m	0.0892m	0.1348m	0.1786m	0.0000	2.0000
7	0.4800	1.2522u	5.2379u	0.0503m	0.1034m	0.1580m	0.2106m	0.0000	2.0000
8	0.5600	1.5520u	5.7879u	0.0547m	0.1165m	0.1800m	0.2415m	0.0000	2.0000
9	0.6400	1.8937u	6.2840u	0.0582m	0.1287m	0.2012m	0.2716m	0.0000	2.0000
10	0.7200	2.1924u	6.7847u	0.0606m	0.1396m	0.2209m	0.3002m	0.0000	2.0000
11	0.8000	2.4591u	7.2067u	0.0624m	0.1496m	0.2398m	0.3281m	0.0000	2.0000
12	0.8800	2.7381u	7.6449u	0.0637m	0.1585m	0.2574m	0.3545m	0.0000	2.0000
13	0.9600	2.9589u	8.0036u	0.0648m	0.1665m	0.2740m	0.3802m	0.0000	2.0000

Figure 16: Excel Spreadsheet for ID vs. VD graph

2. Channel Length Modulation (λ):

1. In the ID vs. VD graph choose one curve for a particular VG
2. On the left side of the ICS window click on Cursors, shown in Figure 17 A window like Figure 18 should pop-up
3. Then select two cursors by choosing two shapes. Click the OFF buttons next to the shapes, making them Y2 and Y1, shown in Figure 18

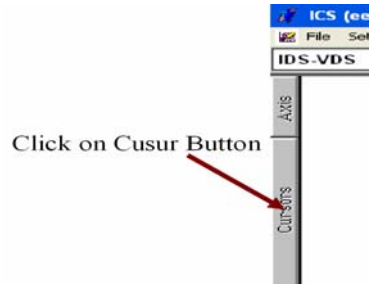


Figure 17: Cursors button location on the left side of ICS window

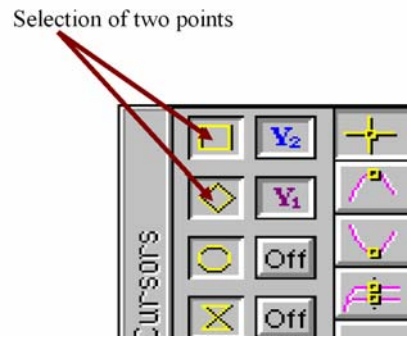


Figure 18: Cursors window

4. Look for X- intercept on the graph in Figure 19. It will show up in the table right below the graph.
5. The X-intercept is the Early voltage (VA).
6. Channel Length Modulation is equal to the (1/ VA).

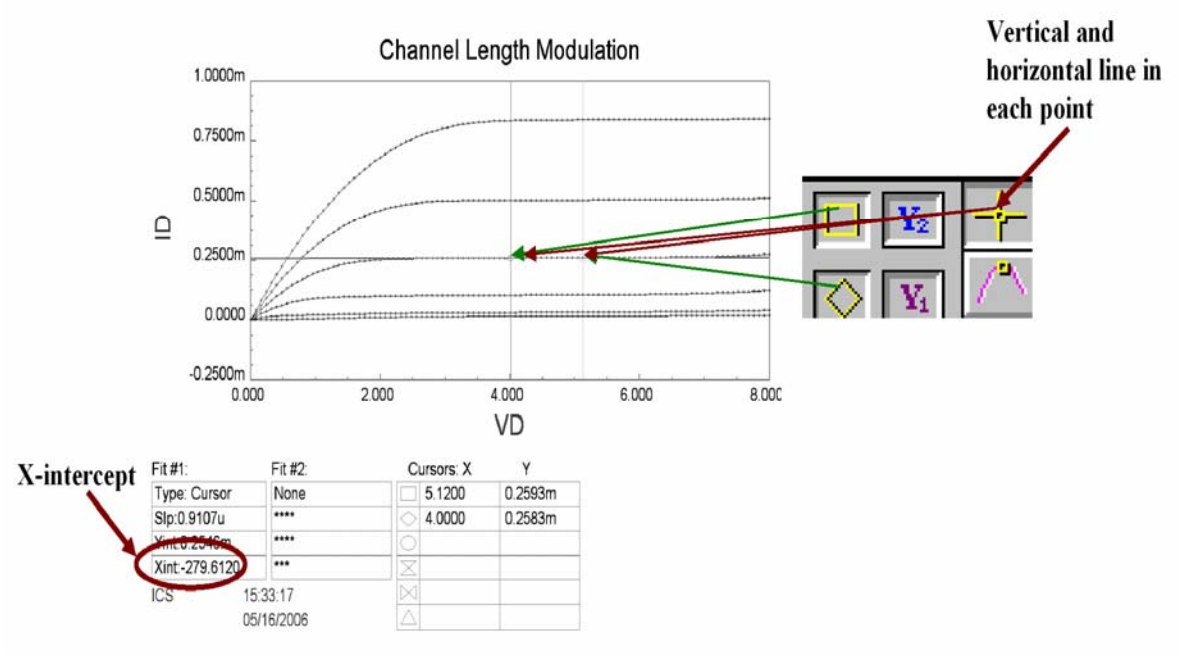


Figure 19: Channel Length Modulation (□) extraction

3. Effective Channel Length (L-eff):

1. To calculate effective channel length, locate four transistors in a cell, use the regular MOS transistors. All four transistors need to be the same widths but different lengths, see Figure 20 and 21. See Figure 22 for an oversize view of the widths and lengths of the Regular MOS transistors.

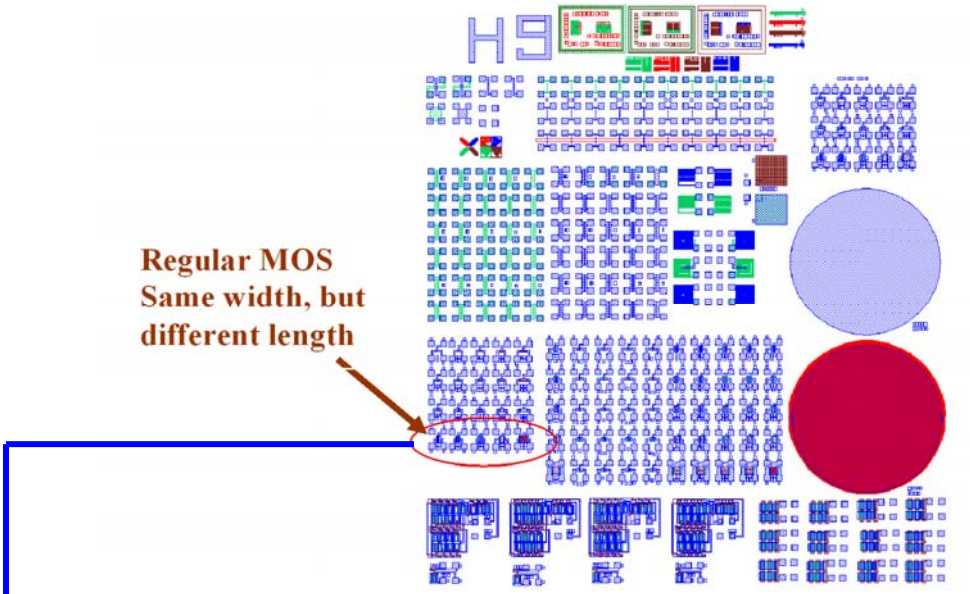


Figure 20: Regular MOS in a cell

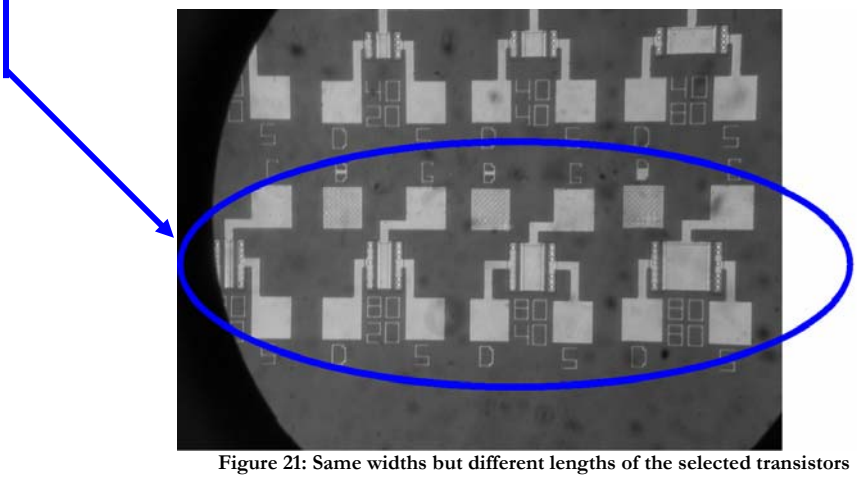


Figure 21: Same widths but different lengths of the selected transistors

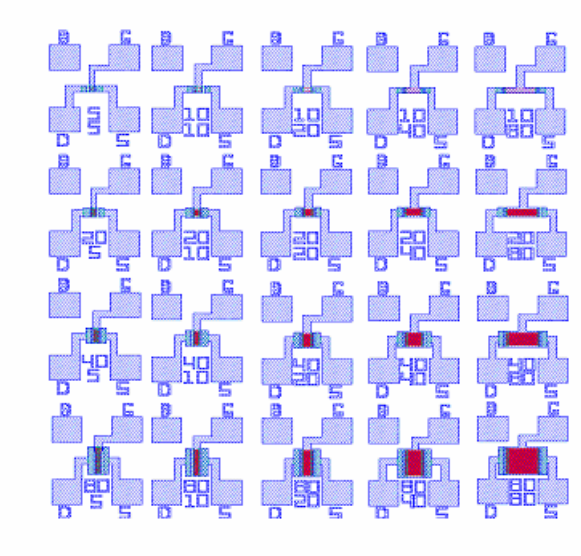


Figure 22: Oversize view of Regular MOS from a cell.

2. For each transistor do a GM vs. VG graph.
3. This time use Append in the Measure window seen in Figure 23, so that all the curves will be shown on one graph, like Figure 24.

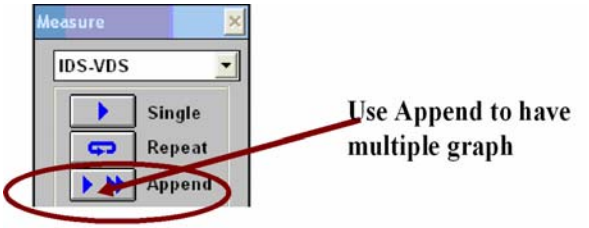


Figure 23: Measure window, click on Append

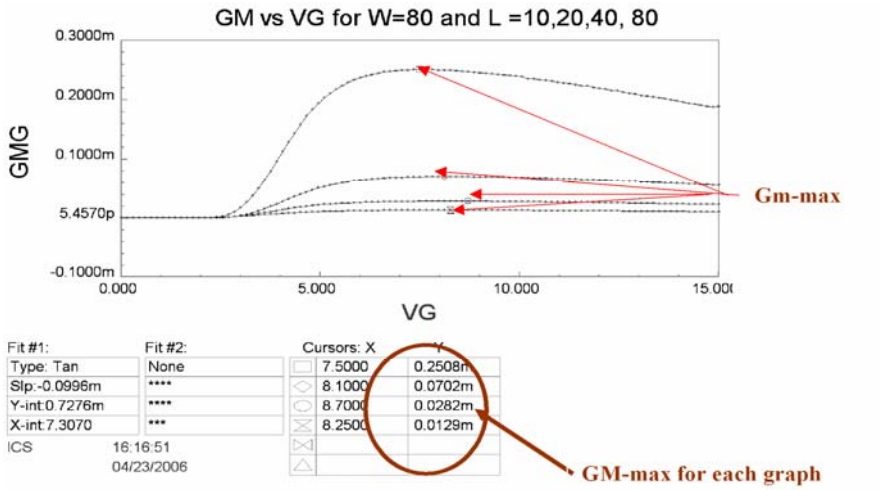


Figure 24: GM Vs VG curves on the same graph of transistors with the same widths but different lengths.

4. Use Cursors to find the GM (max) for each curve, see Figure 24.
5. The values are shown in a table below the graph in Figure 24.
6. Use Excel spreadsheet to find the 1/Gm(max) for each length, which is shown in Figure 26.
7. Plot the 1/Gm(max) vs. Length graph on Excel as shown in Figure 27. Add a trend line to the graph and display the equation.
8. Calculate the x-intercept, which is ΔL.
9. From the gate length subtract ΔL, and that will result to be L-eff, see Equation 1

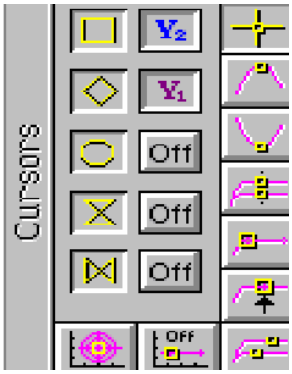


Figure 25: Figure 22: Cursors window

107	Length	1/GMGmax
108	10	4.67E+03
109	20	1.54E+04
110	40	3.89E+04
111	80	8.06E+04

Figure 26: 1/Gm(max) vs. Length table for four same width transistors in the same cell

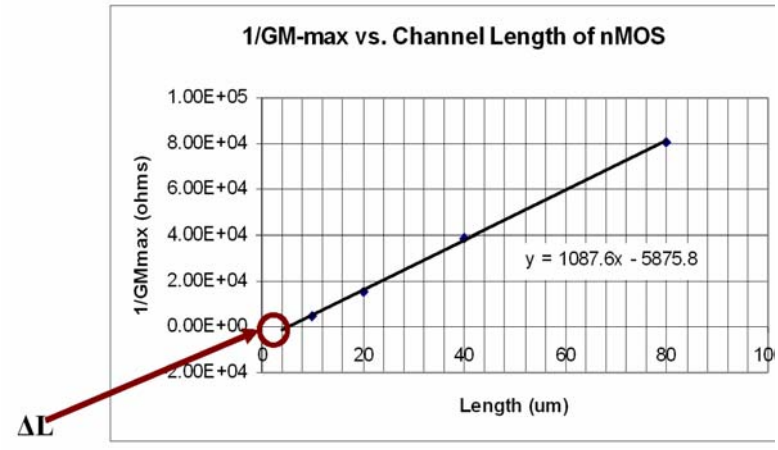


Figure 27: 1/Gm(max) vs. Length Graph for four same width transistors in the same cell

$$L_{eff} = L - \Delta L \qquad \text{Equation (1)}$$

4. Threshold Voltage (Vt) from ID, GM vs. VG Graph:

1. Go to the ICS window and click down the scroll bar, shown in Figure 28. Then select GM.

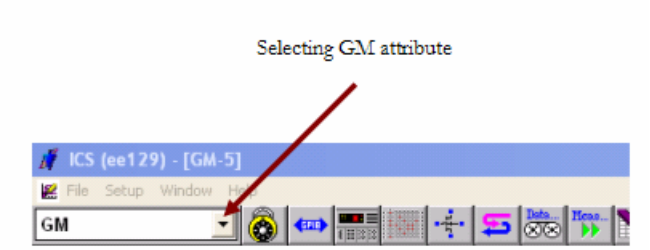


Figure 28: Selecting GM attribute from ICS window

2. Click on the Measure icon, shown in Figure 29. The Measure window should pop-up. Make sure GM is also selected in the Measure window, then click on Single to plot GM graph.

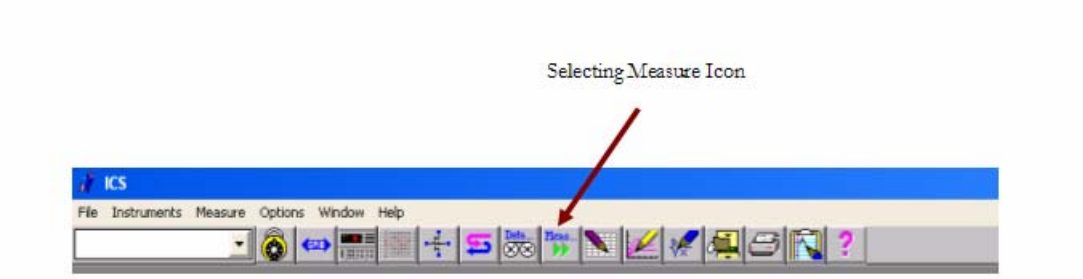


Figure 29: Selecting Measure icon from ICS Window

3. A GM graph should pop-up with two curves, like Figure 30

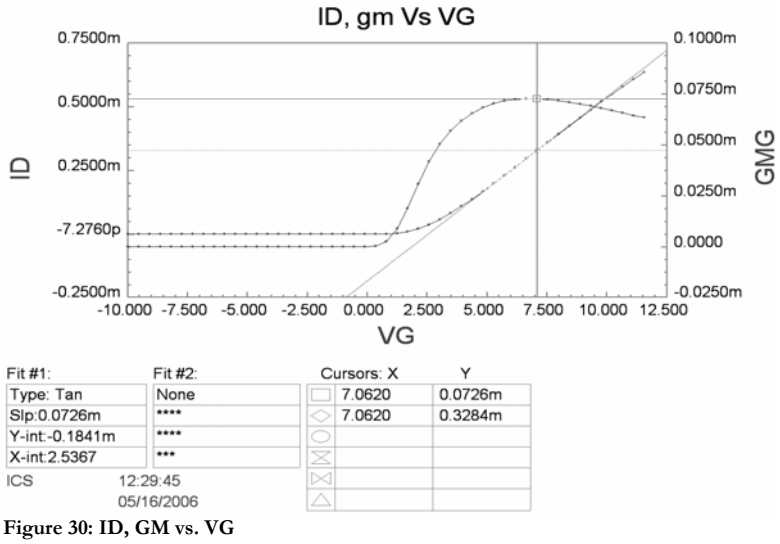


Figure 30: ID, GM vs. VG

4. If the GM graph window does not pop up, click on Setup Plot View icon, see Figure 31. Two windows should pop up, a GM graph and the Setup Plot View window; see Figure 32 and Figure 33.

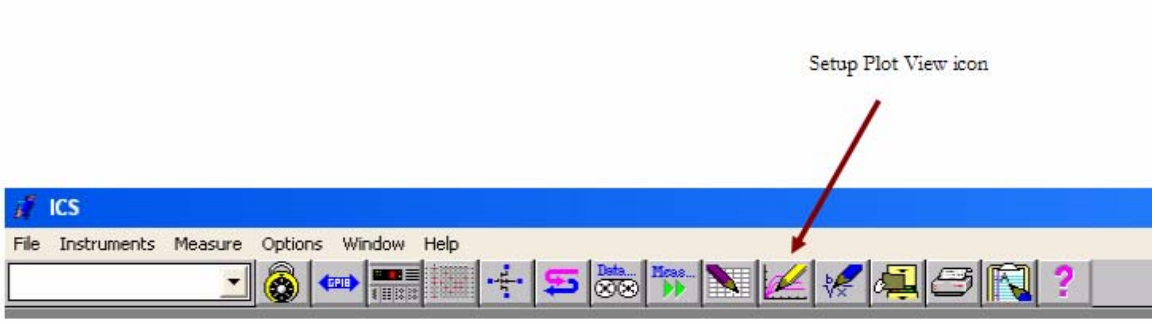


Figure 31: Selecting Setup Plot View icon from ICS toolbar

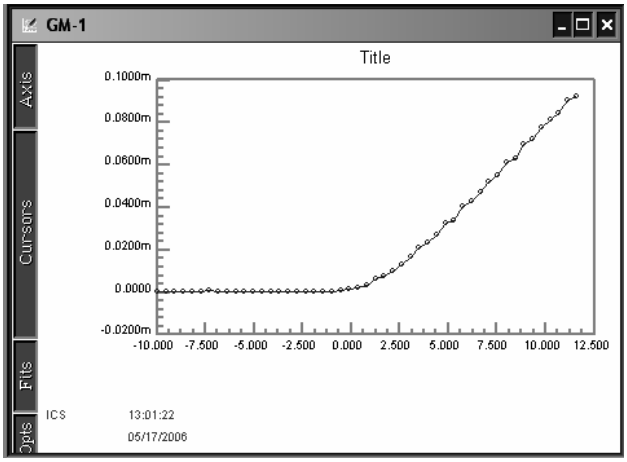


Figure 32: GM Plot (ID vs. VG is only shown)

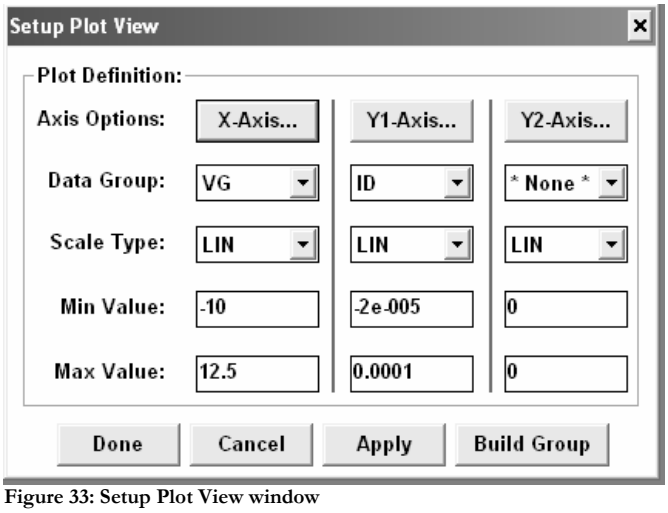


Figure 33: Setup Plot View window

5. Click on the Data Group of Y2-Axis…, see Figure 34. Select GMG(*), click Apply and Done.

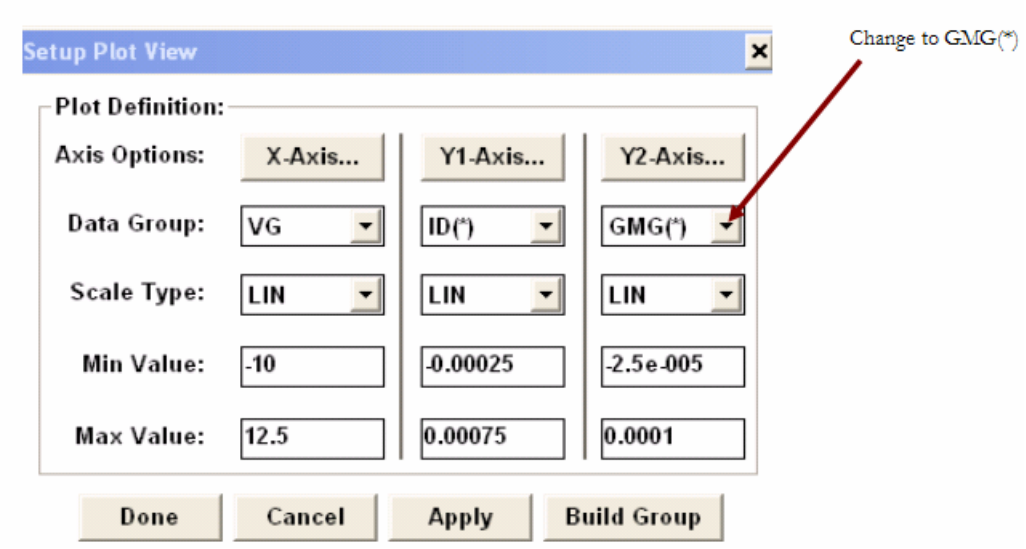


Figure 34: Setup Plot View window

6. A graph similar to Figure 30 should pop up. When putting a title on the graph, click on Opts on the left side of the GM graph, see Figure 35.

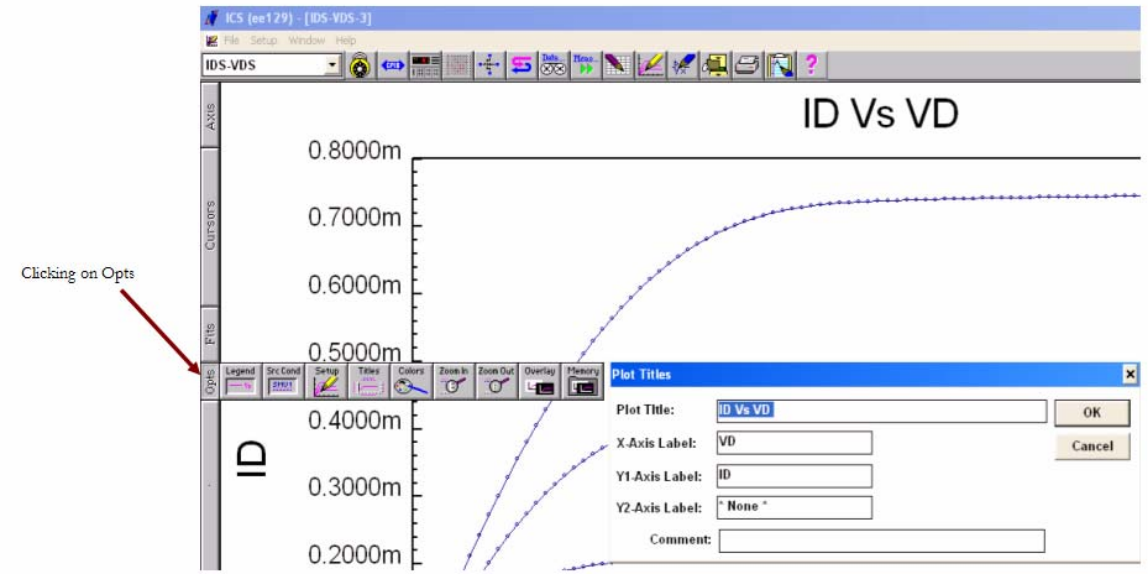


Figure 35: Plot Titles window

7. The following menu should pop up like in Figure 36. Click on Titles, the Plot Titles window should pop-up like in Figure 35.

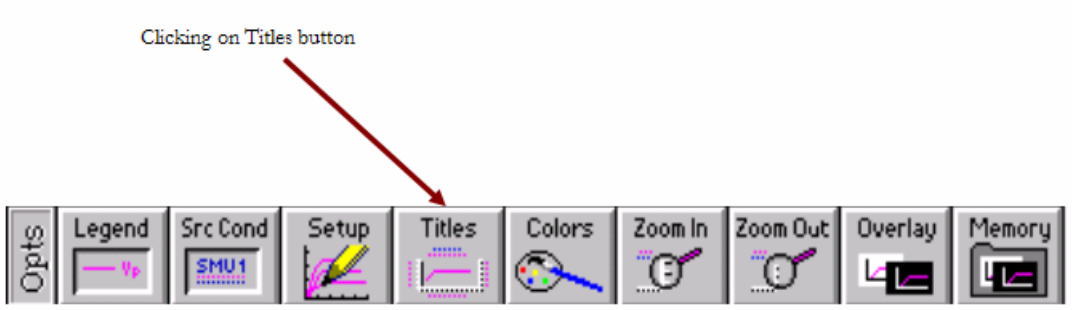


Figure 36: Opts window

8. After having the following graph like in Figure 30, we are ready to measure Vt. To obtain GMmax, click on Cursors on the left side of the GM graph, see Figure 37.

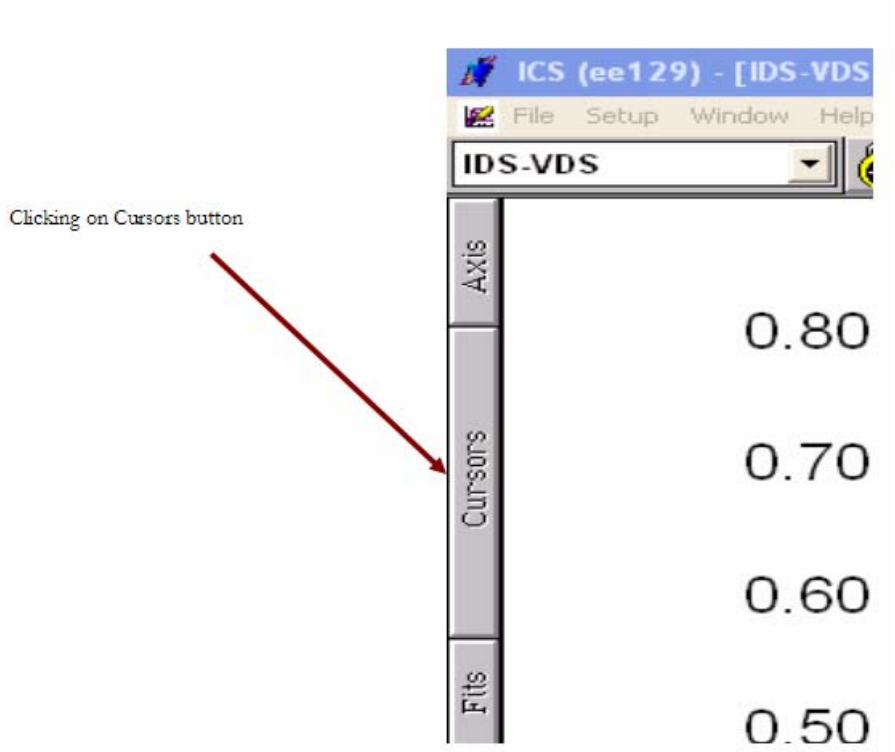


Figure 37: Cursor button (left side of ICS window)

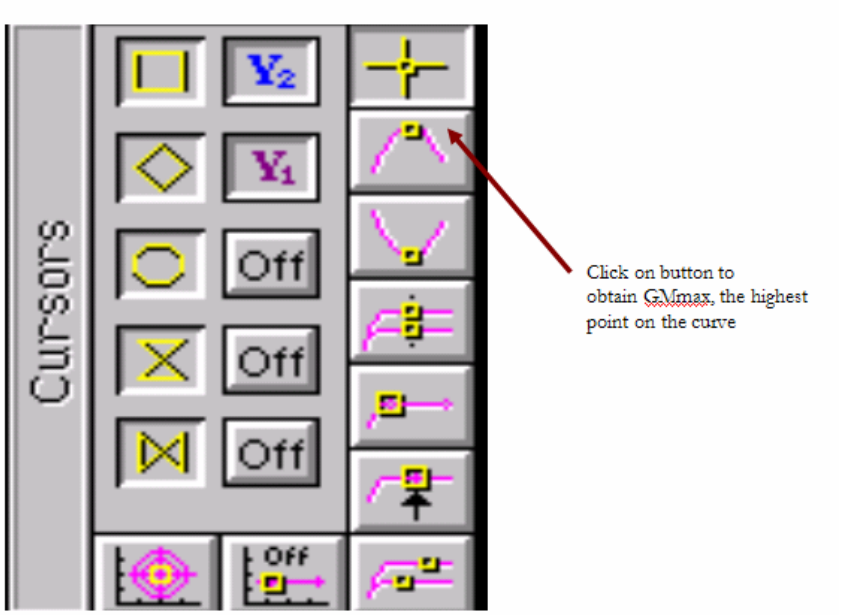


Figure 38: Cursors window (obtaining GMmax)

9. The following menu should pop-up like in Figure 38. Choose a shape, for example the square and click on the OFF button on the right side. Click the OFF button twice to put the cursor on Y2 (GMG curve). To obtain the highest point on this graph (GMmax), click on the button in Figure 38.

10. To obtain IDmax and VGmax, select another shape from Figure 38. For example select the diamond, click the OFF button once to choose Y1. Then click the X-Y cursors shown in Figure 39.

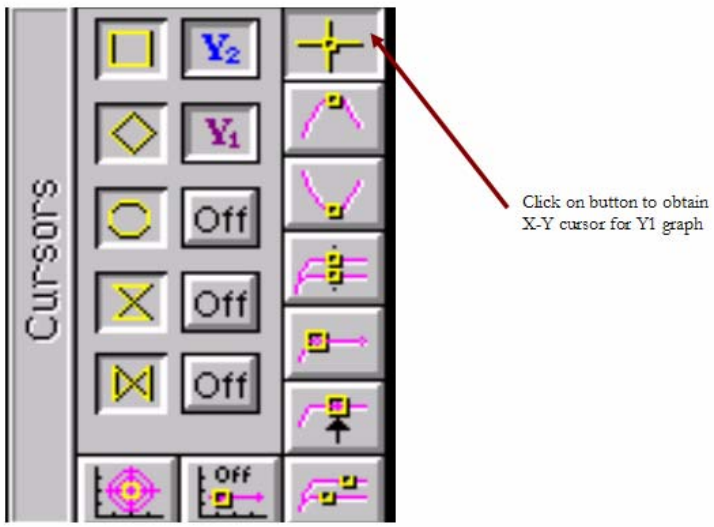


Figure 39: Cursors window (obtaining IDmax & VGmax)

11. Once the cursors are applied to Y1 (ID vs. VG curve), move the cursor to be aligned with the vertical axis of the GMmax, like in Figure 30.

12. To obtain a tangent line on ID vs. VG curve, click on Fits on the left side of the graph, see Figure 40.

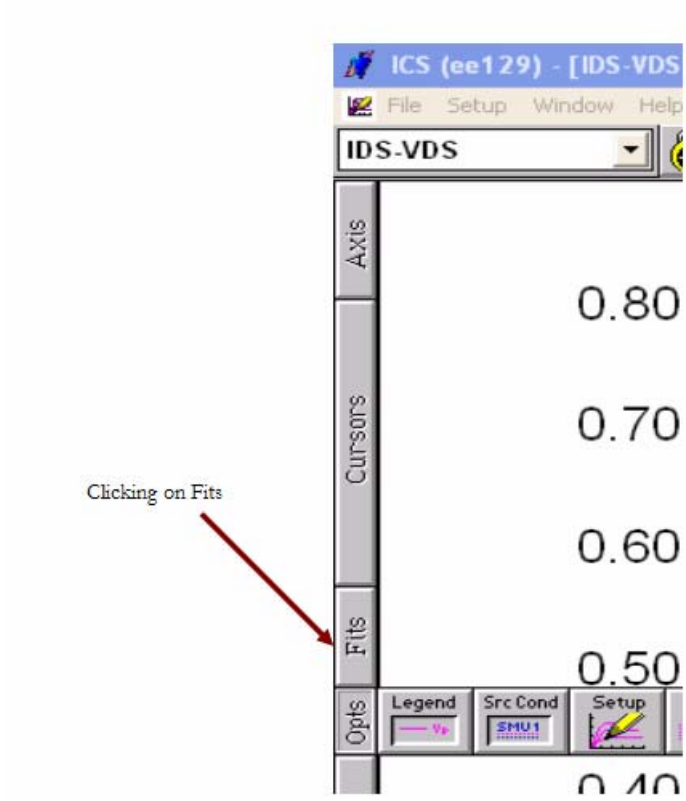


Figure 40: Fits button on left side of ICS window

13. The following menu should pop-up like Figure 41. Click on the Fit #1 button and the diamond shape, to identify which graph the tangent line will be drawn. Click the Tangent Line button to obtain the tangent line onto the ID vs. VG curve, see Figure 41.

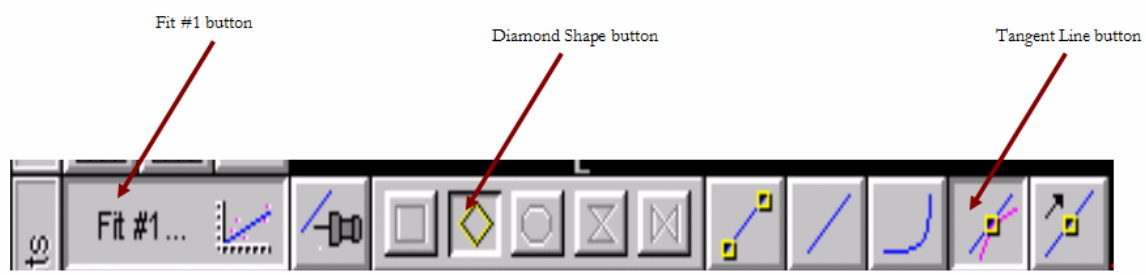


Figure 41: Fits window

14. After GMmax, VGmax, and IDmax have been identified from the graph, Vt can be calculated by the following formula;

$$V_T = -\frac{ID_{\max} - gm_{\max} \times VG_{\max}}{gm_{\max}} \qquad \textbf{Equation (2)}$$

15. Vt can also be measured by observation of the following, see Figure 42. Vt is where the tangent line crosses the x-axis and also shown in the table below.

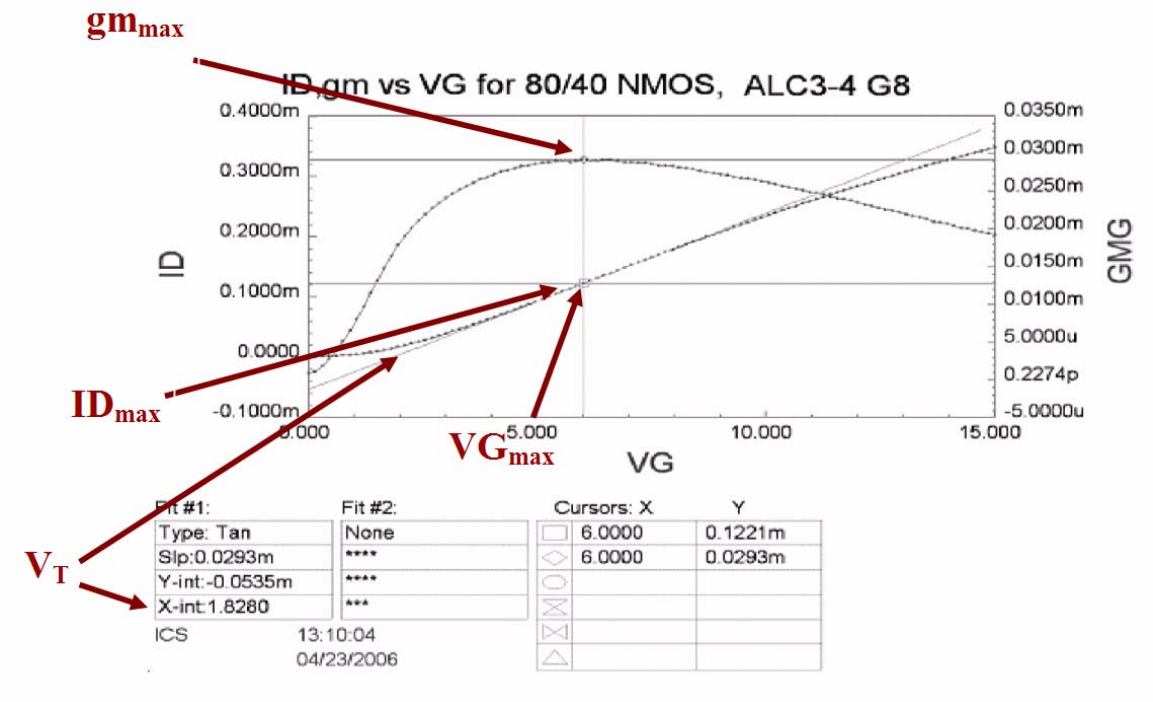


Figure 42: Measuring Vt by observation

Diode Testing:

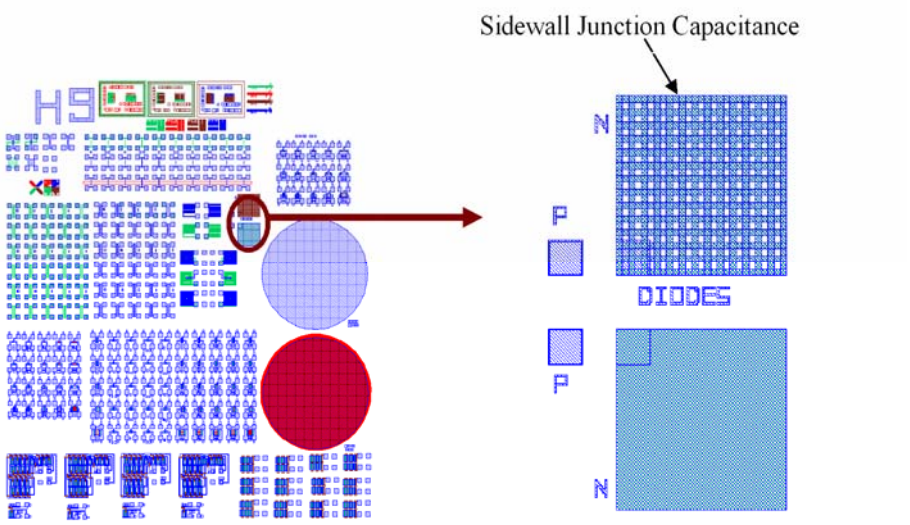


Figure 43: Diode from a cell

1. A diode in a cell is shown in Figure 43
2. In this case, sidewall junction capacitance is considered, see Figure 43
3. Sweep the Voltage from P to N
4. Select Diode from the Menu bar.
5. Click on  icon to see the probe configuration on the diode
6. Probe configuration connection is shown in Figure 44

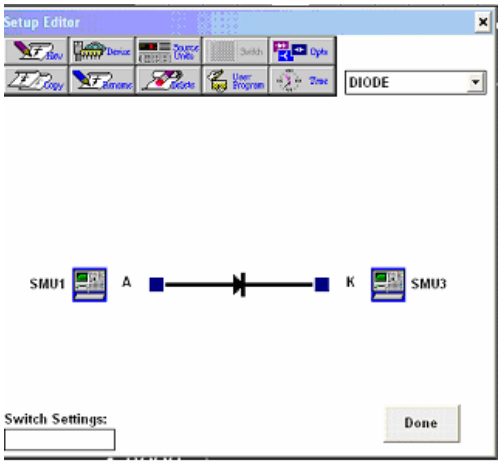


Figure 44: Setup Editor for diode

7. Setup for SMU1 and SMU3 should look like as shown in Figure 45 and 46.
8. After setting up both SMU1 and SMU3, click OK and then click Single in the Measure window.
9. The I-V characteristic of diode will look something like Figure 47.

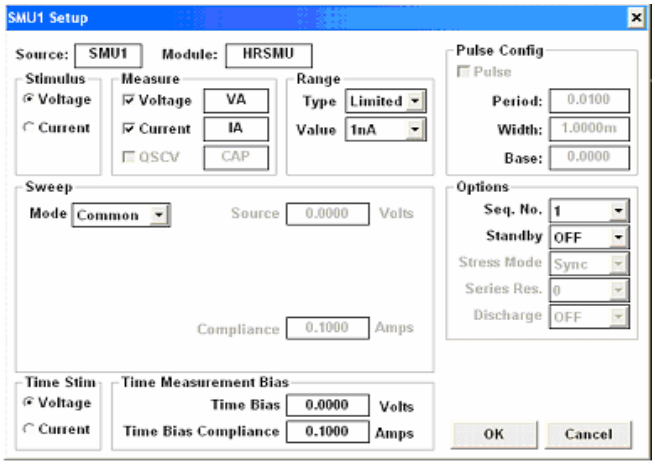


Figure 45: SMU1 setup

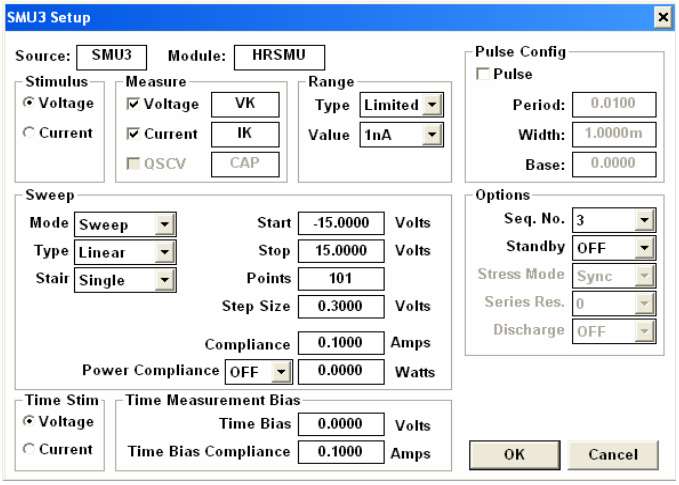


Figure 46: SMU3 setup

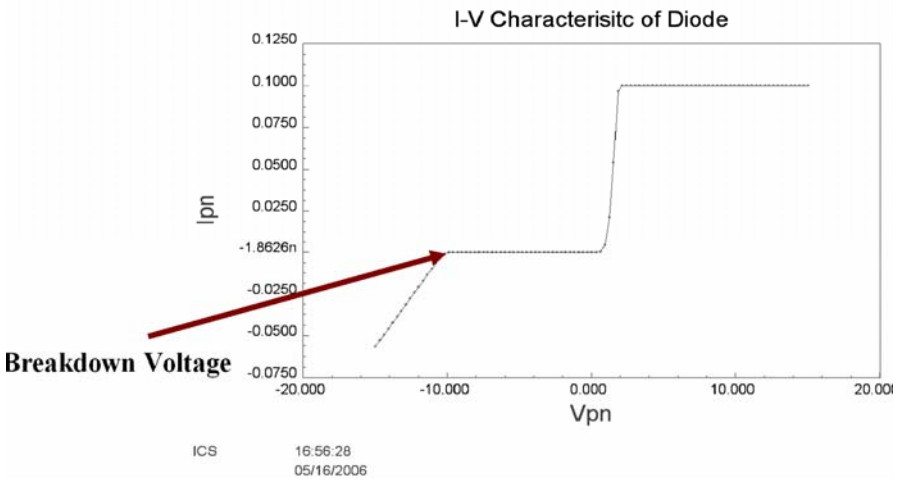


Figure 47: I-V characteristic of Diode

MOS Caps Testing:

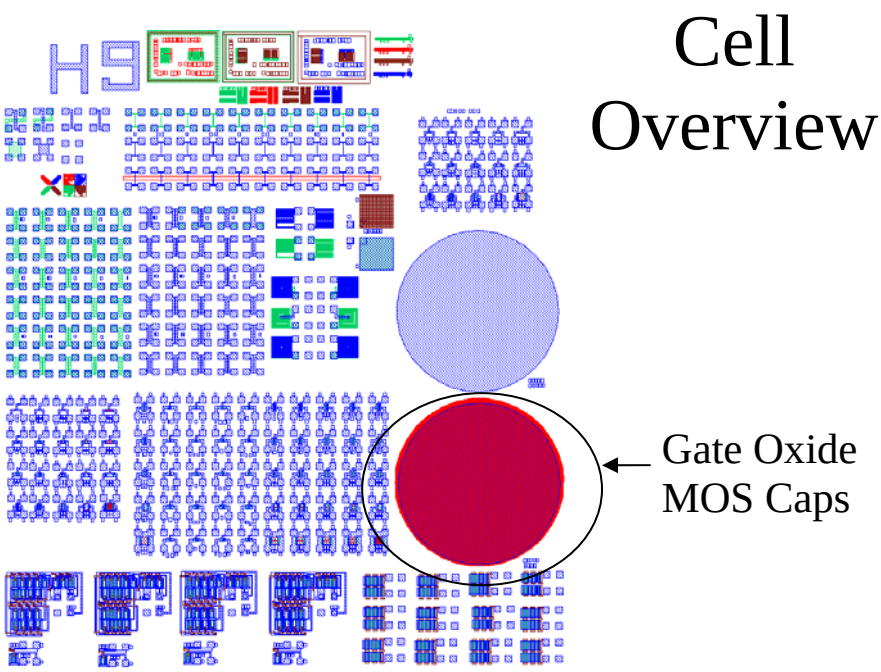


Figure 48: MOS Cap cell overview

1. Pull the pins on the Gate Oxide MOS Caps on the wafer as shown in Figure 49.

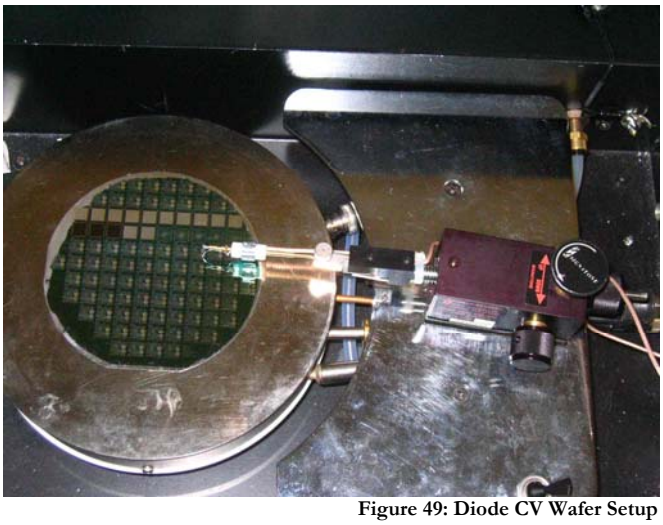


Figure 49: Diode CV Wafer Setup

2. In the ICS window select Diode CV
3. Click on Measure Button from the menu bar.
4. To see the arrangement of the probe connections, go to set up editor in the menu bar. Click Up or Dn to select1MHz for high frequency. Set up editor should look like figure 50.

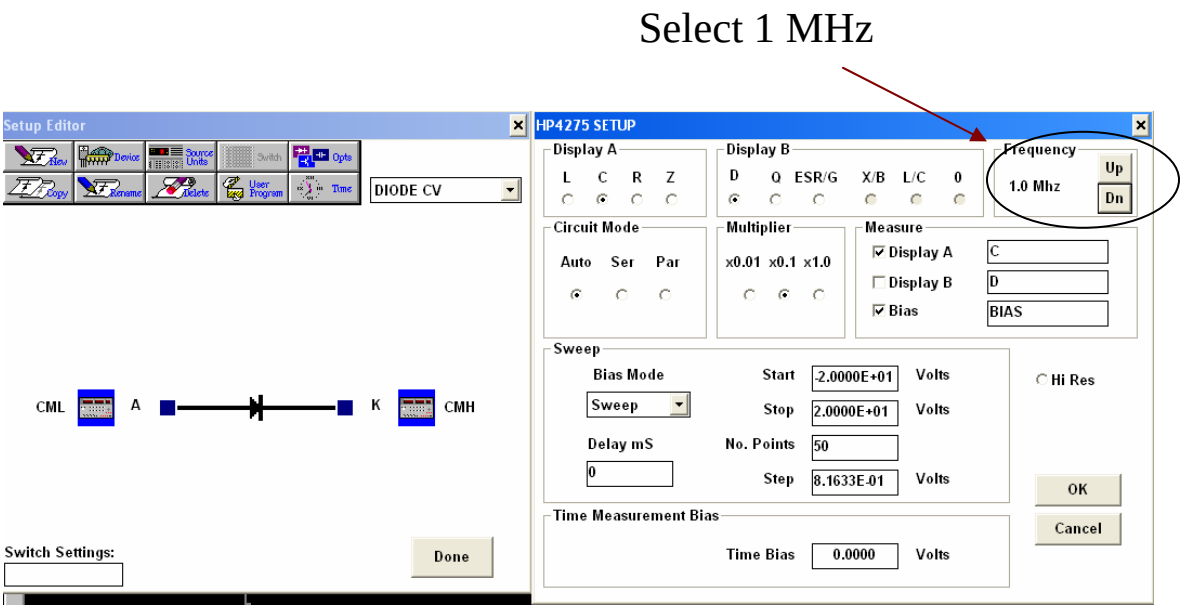


Figure 50: Diode CV set up editor

.

5. To sweep the value of voltage click on SMU3 on the setup editor as shown in figure 51

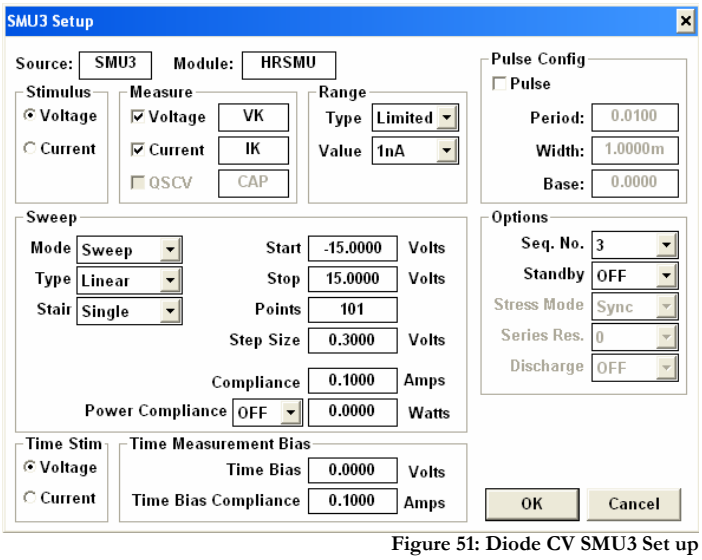


Figure 51: Diode CV SMU3 Set up

6. To see the CV graph, go to menu bar and click on setup plot view.

7. Click apply and then click done.
8. Figure 52 is showing the ultimate graph of the C vs. V in high frequency.

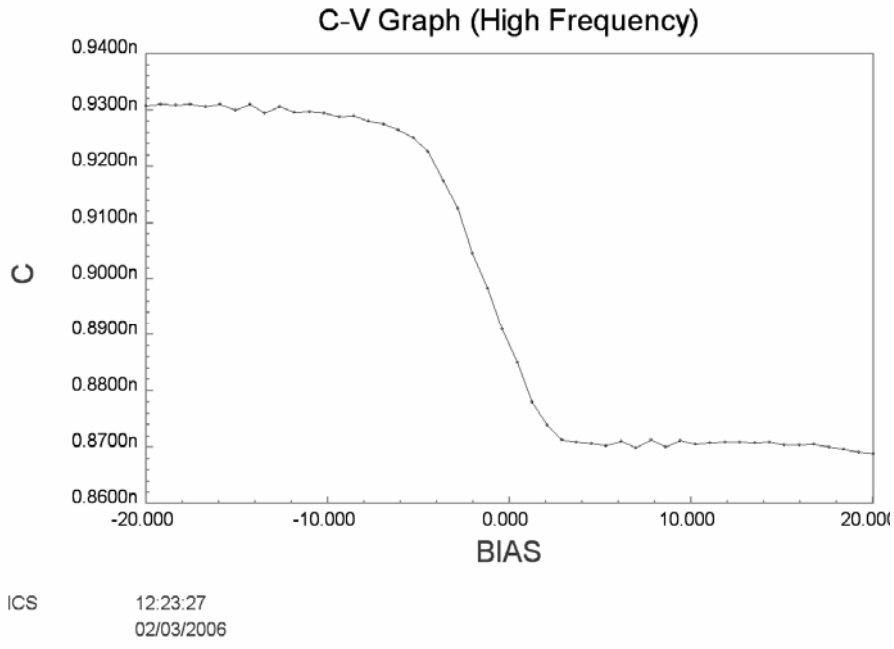


Figure 52: C-V Curve (High Frequency)

Sheet Resistance Testing:

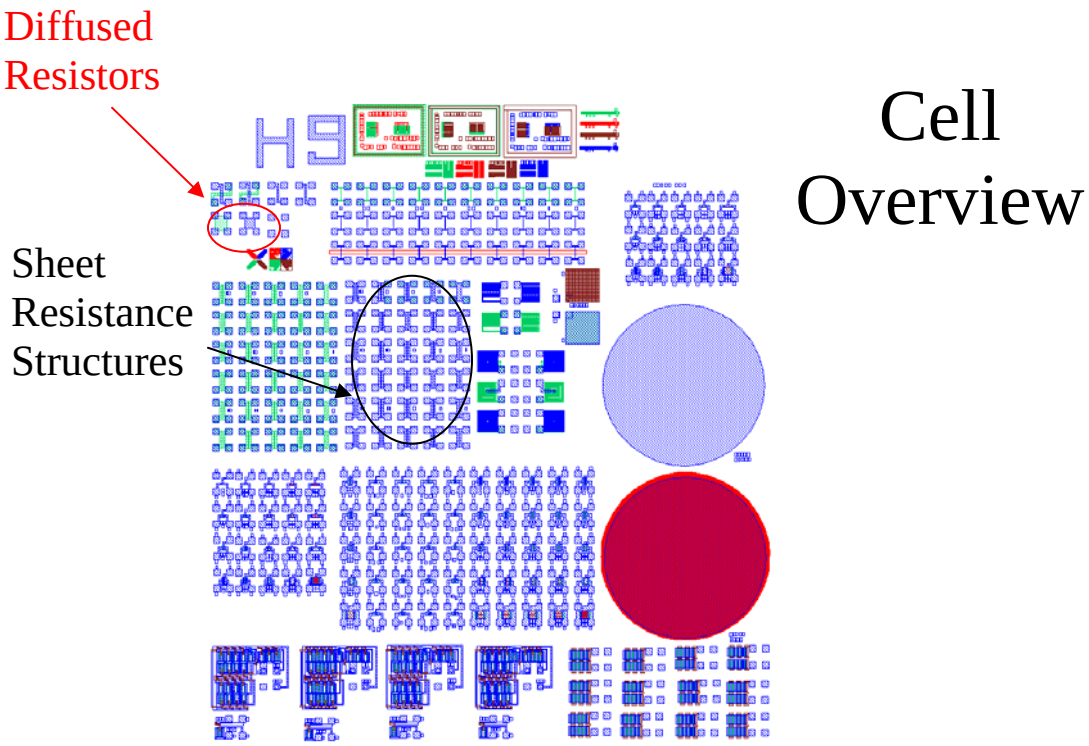


Figure 53: Resistor cell overview

When testing the diffused resistors devices on the wafer the following measurements can be obtained:

- I-V characteristic
- Resistance

1 Pull the pins on the 4 contacts on the wafer as shown in Figure 54.

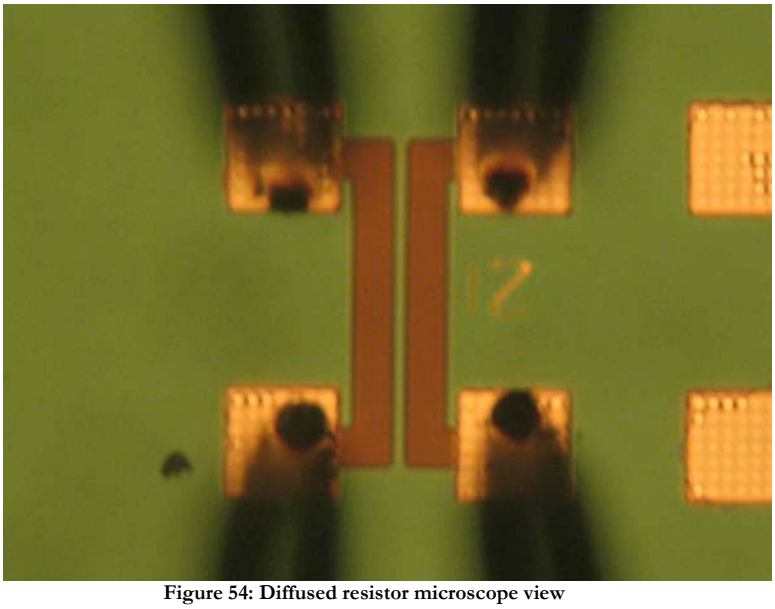


Figure 54: Diffused resistor microscope view

2 In the ICS window select R TEST
3 Click on Measure Button from the menu bar.
4 To see the arrangement of the probe connections, go to set up editor in the menu bar. Set up editor should look like figure 55.

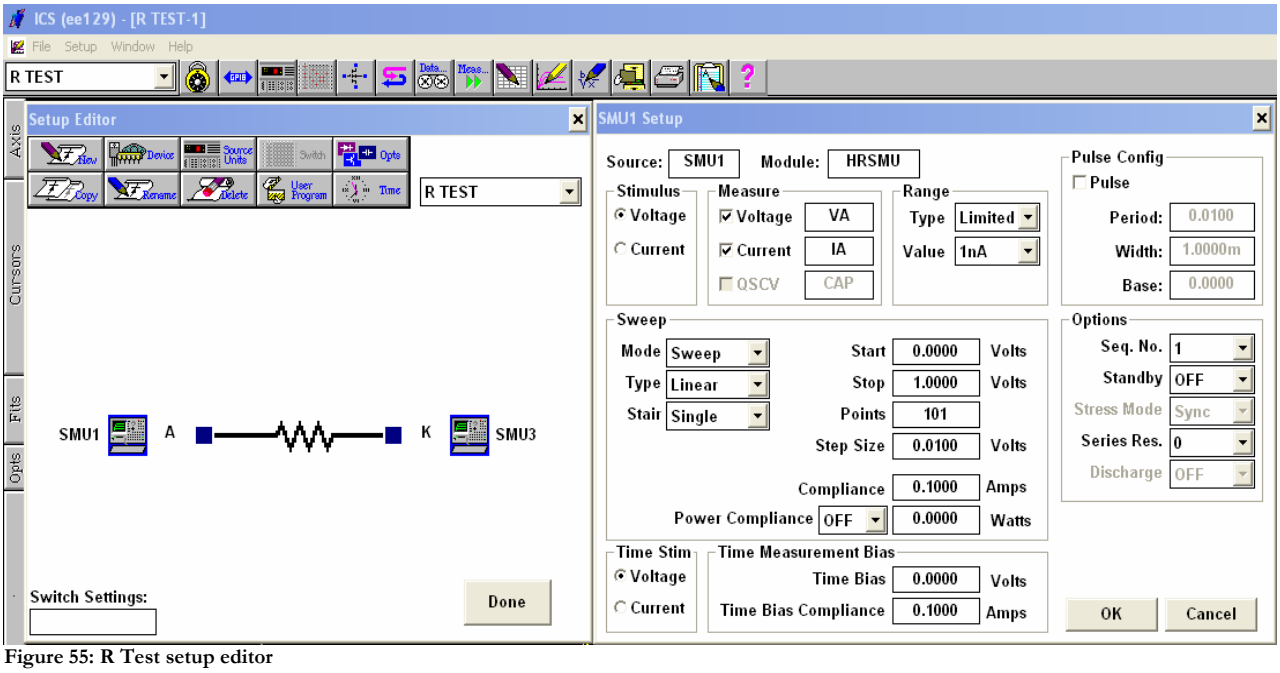


Figure 55: R Test setup editor

5 To sweep the value of voltage click on SMU3 on the setup editor as shown in figure 56.

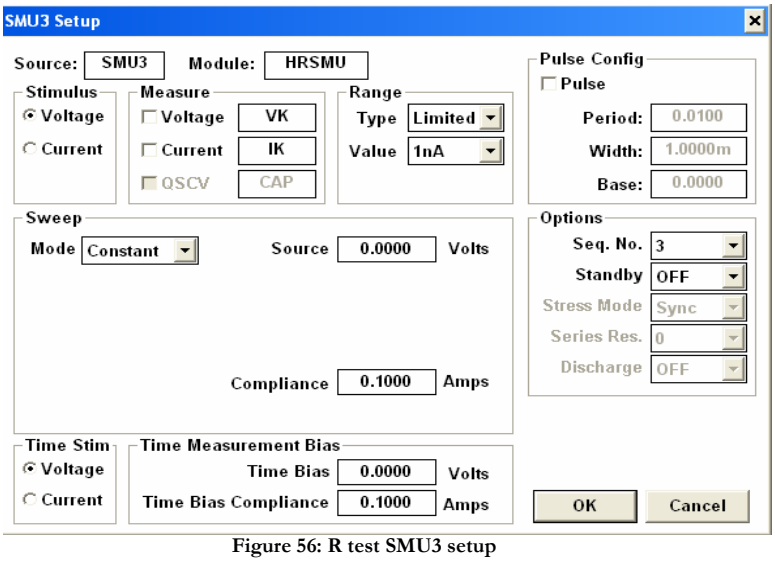


Figure 56: R test SMU3 setup

6 To see the graph of ID vs. VD, go to menu bar and click on setup plot view.
7 Click apply and then click done.
8 Figure 57 is showing the ultimate graph of the ID vs. VD

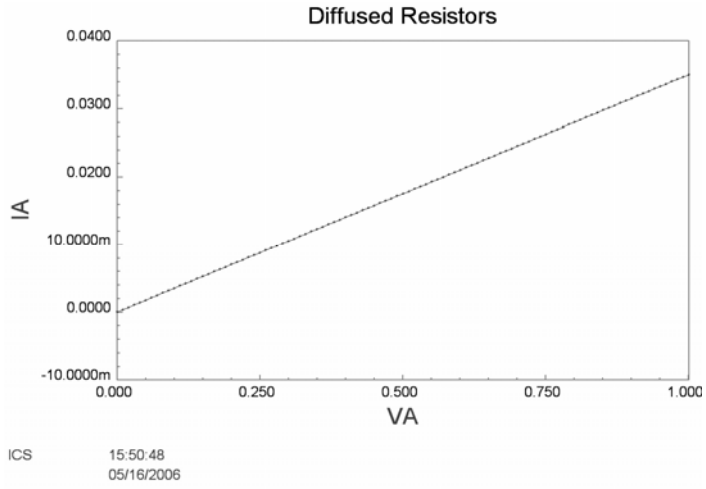


Figure 57: Sheet resistance IV curve

9 Resistance can be extracted from the slope of the graph.

$$R_s = 4.54\frac{V_D - V_C}{I_{AB}}$$ **Equation (3)**

where Rs is the sheet resistance, 4.54 is the resistivity, (VB-VC) is the voltage and IAD is the current. The voltage and current sources were from the laboratory set-up.

$$R_s = slope = \frac{0.75 - 0.25}{0.022 - 0.001} = 41.6(\Omega / square)$$

Contact Resistance 1C Testing:

1. Pull the pins on the 4 contacts on the wafer as shown in Figure 58.

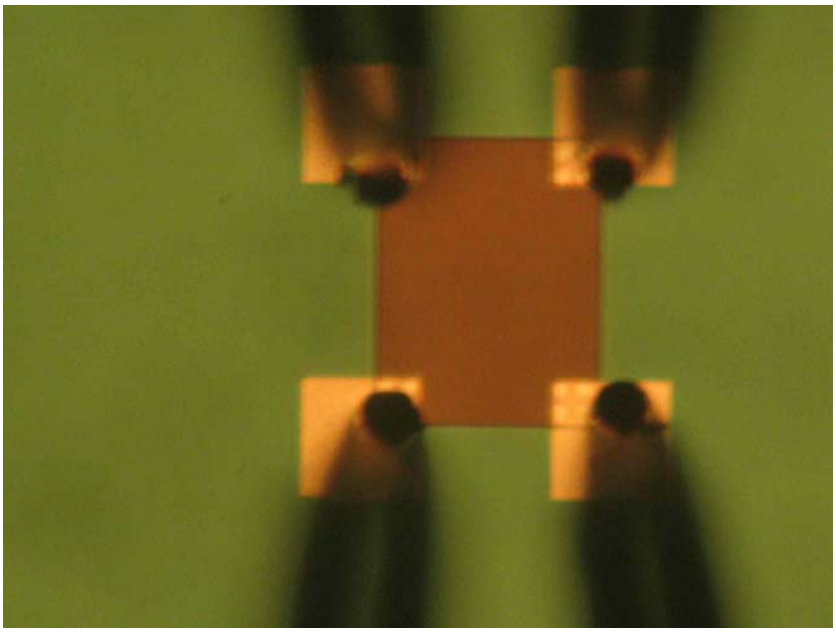


Figure 58: Diffused resistor microscope view

2. In the ICS window select RES_AL.
3. Click on Measure Button from the menu bar.
4. To see the arrangement of the probe connections, go to set up editor in the menu bar. Set up editor should look like figure 59.

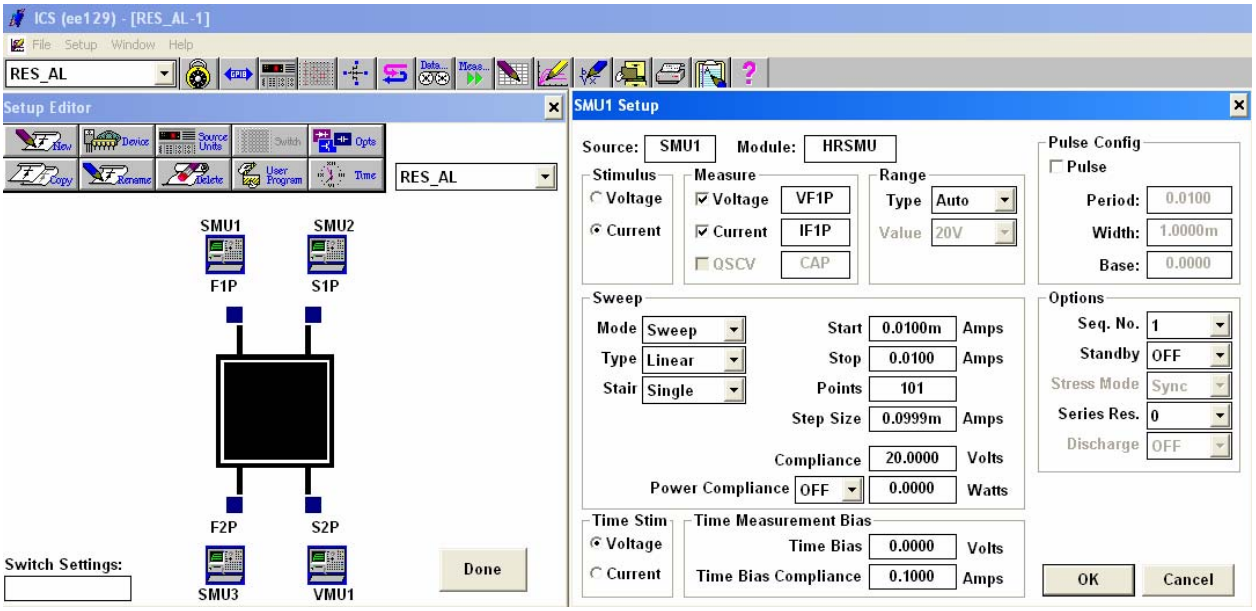


Figure 59: RES_AL setup

5. To force the current through A and D click on SMU2 and SMU3 on the setup editor as shown in Figure 60 and Figure 61.

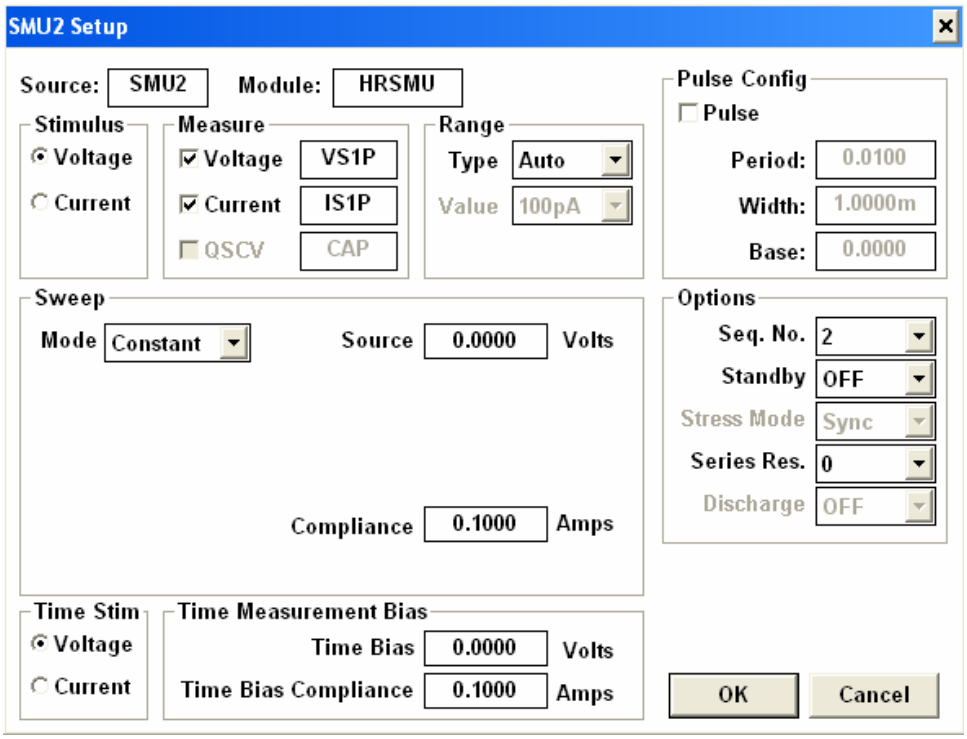


Figure 60: RES_AL setup for force current through A to D

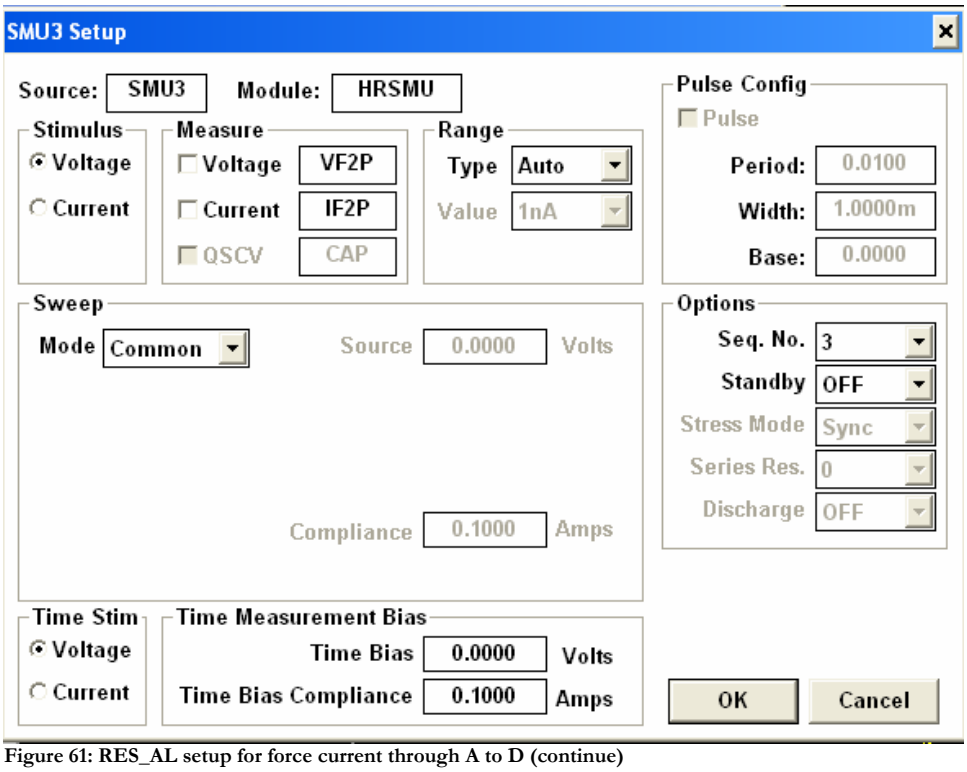


Figure 61: RES_AL setup for force current through A to D (continue)

6. To measure the voltage difference from B to C click on SMU1 setup editor as shown in Figure 62.

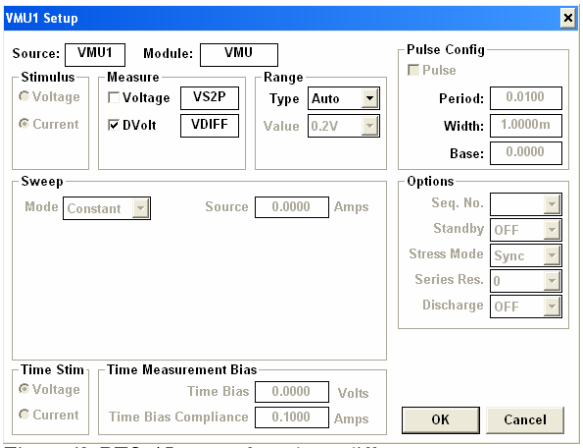


Figure 62: RES_AL set up for voltage difference

7. To see the graph of ID vs. VD, go to menu bar and click on setup plot view.
8. Click apply and then click done.
9. Figure 63 is showing the ultimate graph of the ID vs. VD

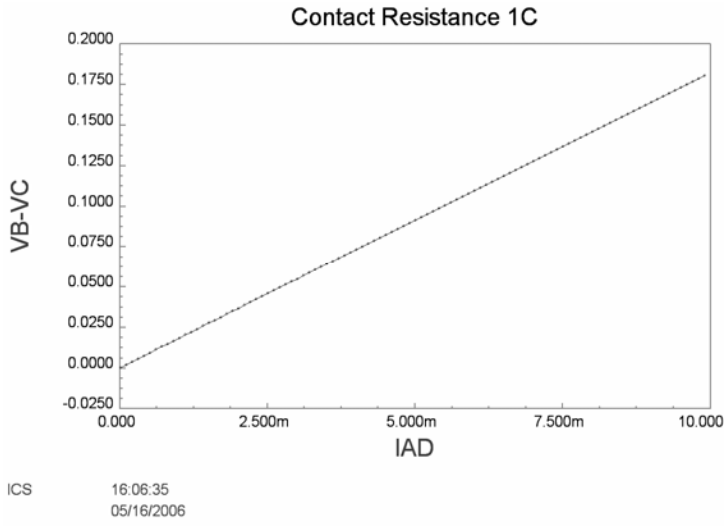


Figure 63: Diffused resistor IV curve

10. Resistance can be extracted from the slope.

$$R_s = 4.54\frac{V_B - V_C}{I_{AD}} \quad \textbf{Equation (4)}$$

where Rs is the sheet resistance, 4.54 is the resistivity, (VB-VC) is the voltage and IAD is the current. The voltage and current sources were from the laboratory set-up.

$$R_s = slope = \frac{0.130 - 0.027}{7.5m - 2.5m} = 20.6(\Omega / square)$$

Appendix

A

Appendix A: SnagIt

Introduction to SnagIt

SnagIt is a powerful tool for image capture on computer screen. By using SnagIt, you can select and capture anything on your screen, then easily add text, arrows, or effects, and save the capture to a file. One advantage of using SnagIt is that captured images are clearer than using Print Screen function on the keyboard. This tutorial will focus on capturing ICS Graph and some basic editing skills.

Getting Started:

1. Go to Start
2. Click on the SnagIt tool

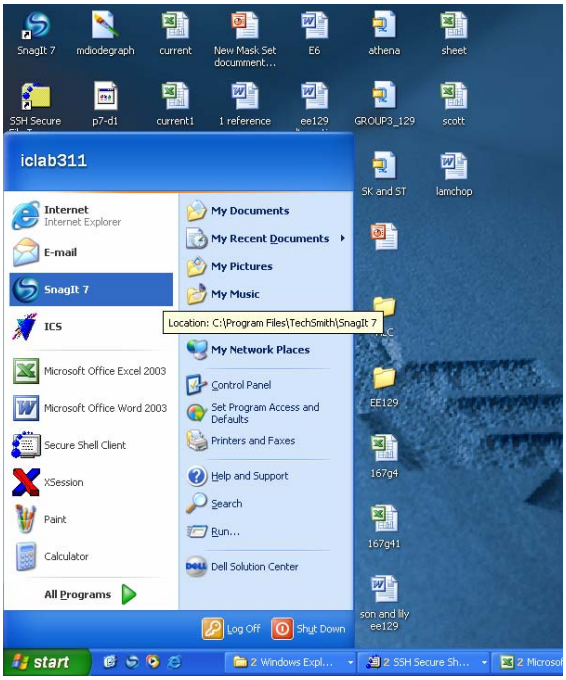


Figure 64: Opening SnagIt

3. After opening the SnagIt, the window should look like Figure 65.

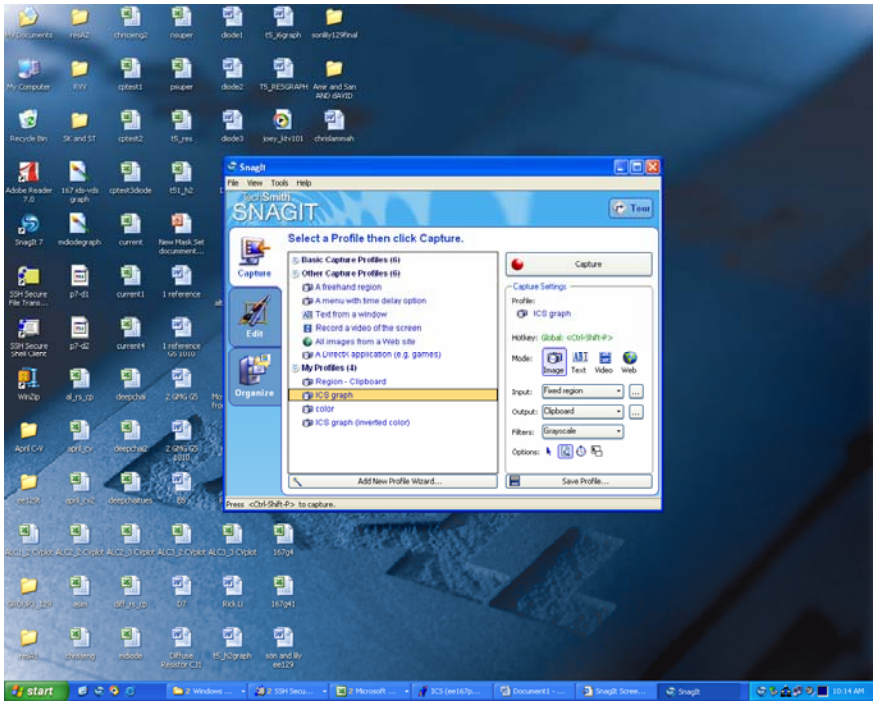


Figure 65: SnagIt Window

Testing EE/MatE 129 device wafer

Choosing ICS Graph Profile:

1. In the SnagIt Window in Figure 65, choose a profile on the list.
2. Choose ICS graph (Inverted color), seen in Figure 66. This is chosen because we want white background and solid lines for our graphs.
3. After clicking on the profile, you can minimize the window.
4. SnagIt is ready to be used.

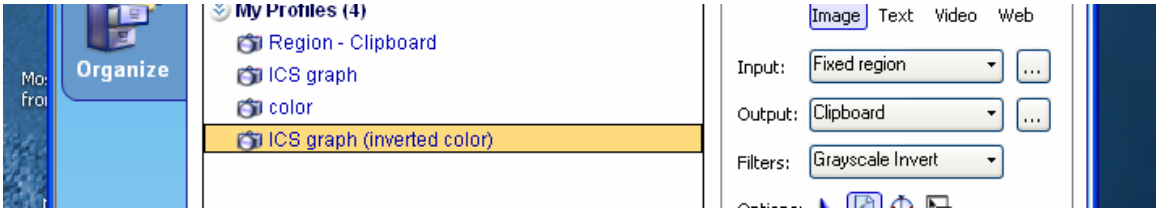


Figure 66: Choosing Profile

Capturing ICS Graph:

1. Figure 67 is a typical ICS graph we want to capture.

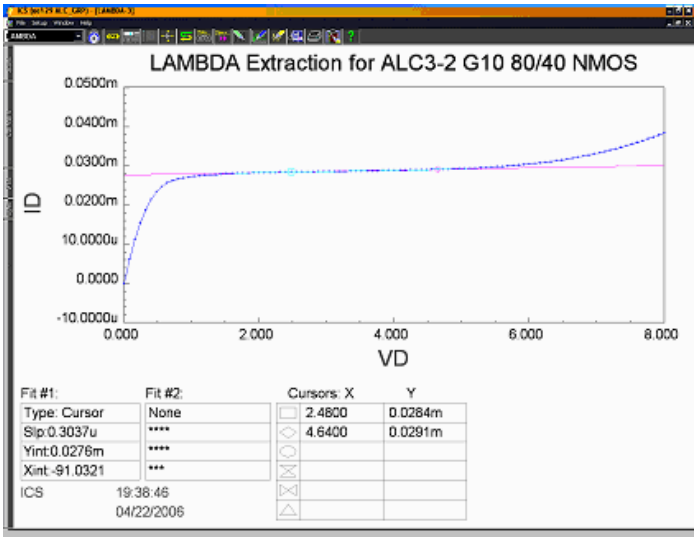


Figure 67: ICS Graph (color has already been inverted)

2. To capture the image, you may call up the window of SnagIt and then click on Capture button, seen in Figure 68.

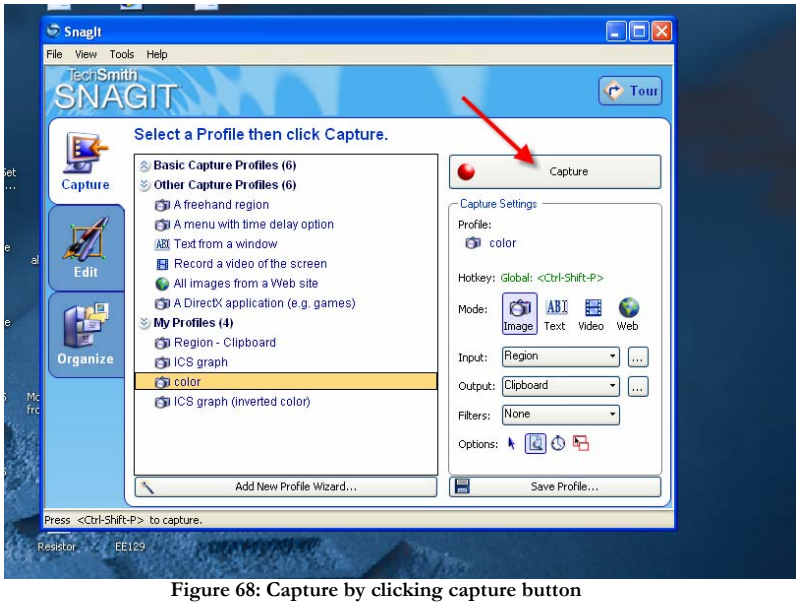


Figure 68: Capture by clicking capture button

3. However, a more convenient way is preferred while you are doing your testing at the same time. You can use the hot key Ctrl + Shift + P instead of clicking the capture button.

4. Following window will pop up as a preview of the image. The graph has a white background and the curve can be easily recognized.

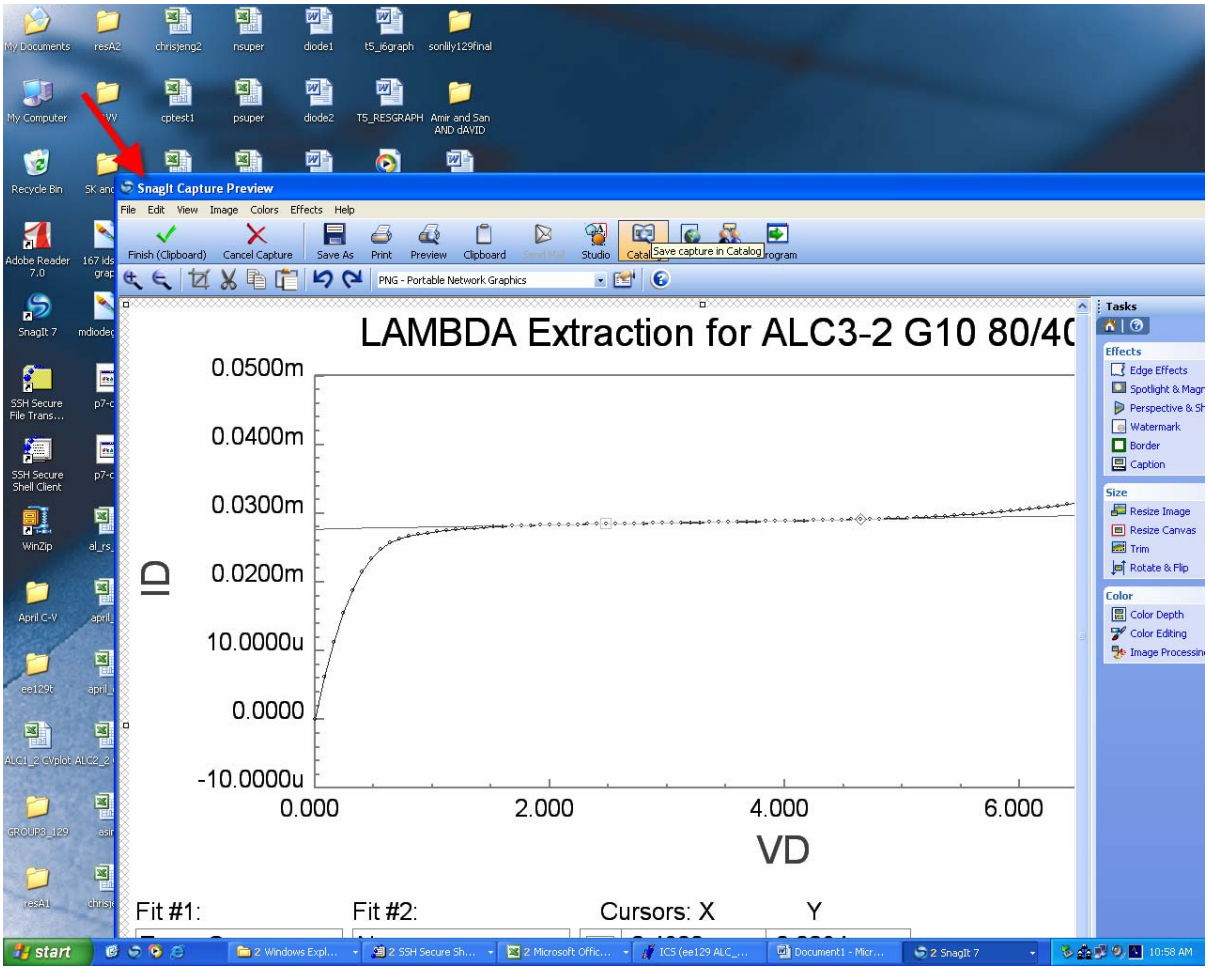


Figure 69: SnagIt image preview

5. You can choose the whole image or part of it on the preview screen.

6. To choose whole image.
   - Activate the preview window
   - Pressing Ctrl + A
   - Pressing Ctrl + C
   - Then you can paste the image on any document

7. To choose a part of the image, you can do the following steps:
   - Activate the preview window
   - Using the cursor to choose the part that you want
   - Pressing Ctrl + X
   - That part of image will be cut off
   - Then you can paste that part of image on any document
   - Following is an example of choosing the title and part of the graph of Figure 67.

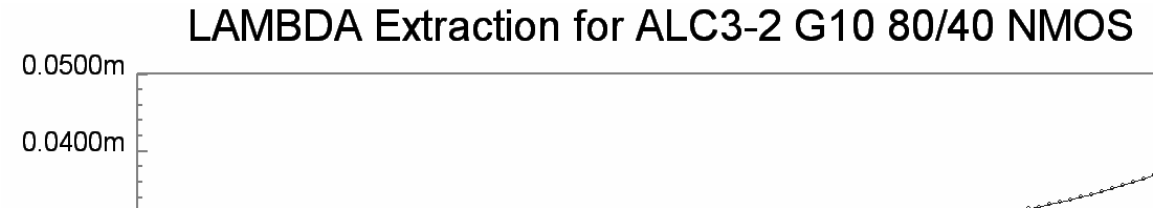


Figure 70: Example of choosing part of an image

Capturing an image is easy to learn. In the following section, Image Editor of SnagIt will be introduced. You can use the software to edit your images.

Image Editing

Sometime you may want to add some comments or indicators on an image. SnagIt has a powerful tool for image editing, which is SnagIt Editor. By using this function, you can add arrows, texts, or circle a part that you want to emphasize.

Getting Started:

1. Call up the SnagIt window

Figure 71: SnagIt Edit Option

2. Choosing "Edit" option on left hand side.
3. Clicking "Open SnagIt Editor"
4. Following Window will pop up, see Figure 72

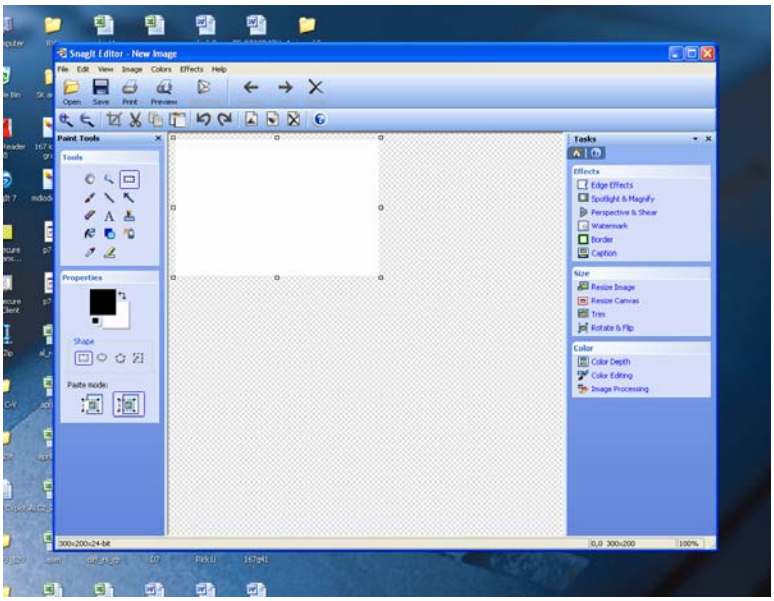


Figure 72: SnagIt Editor

Adding Arrows:

1. Paste the image you have captured on the window, see Figure 73.

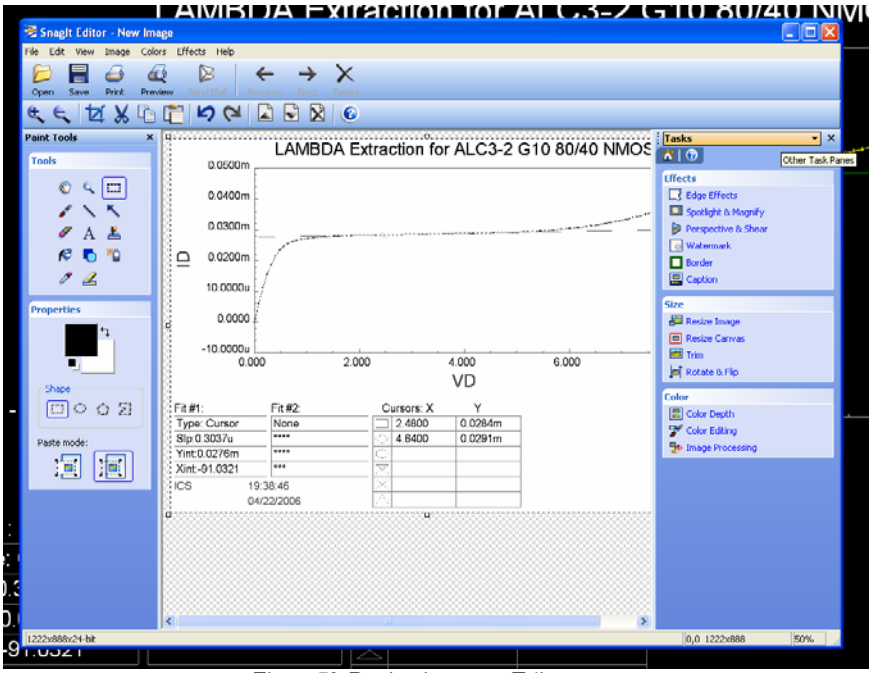


Figure 73: Pasting image on Editor

2. On the left hand side, you could see some small icons. Clicking the arrow shape icon to activate the function.

3. You can choose the style of the arrow in the "Properties" window, see Figure 74.

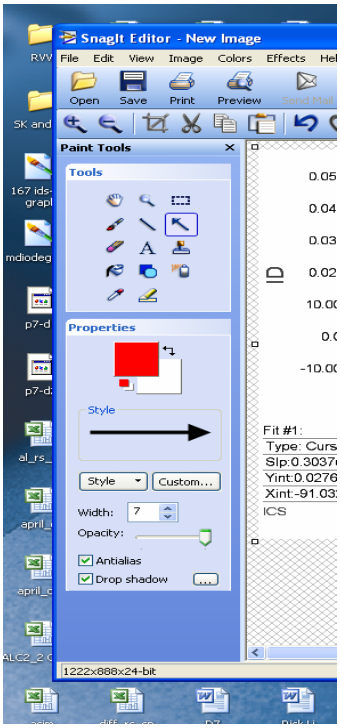


Figure 74: Properties window

4. To add an arrow, firstly you click on the starting point. Then you hold then press and move to the ending point. Figure 75 is an example of pointing to a curve.

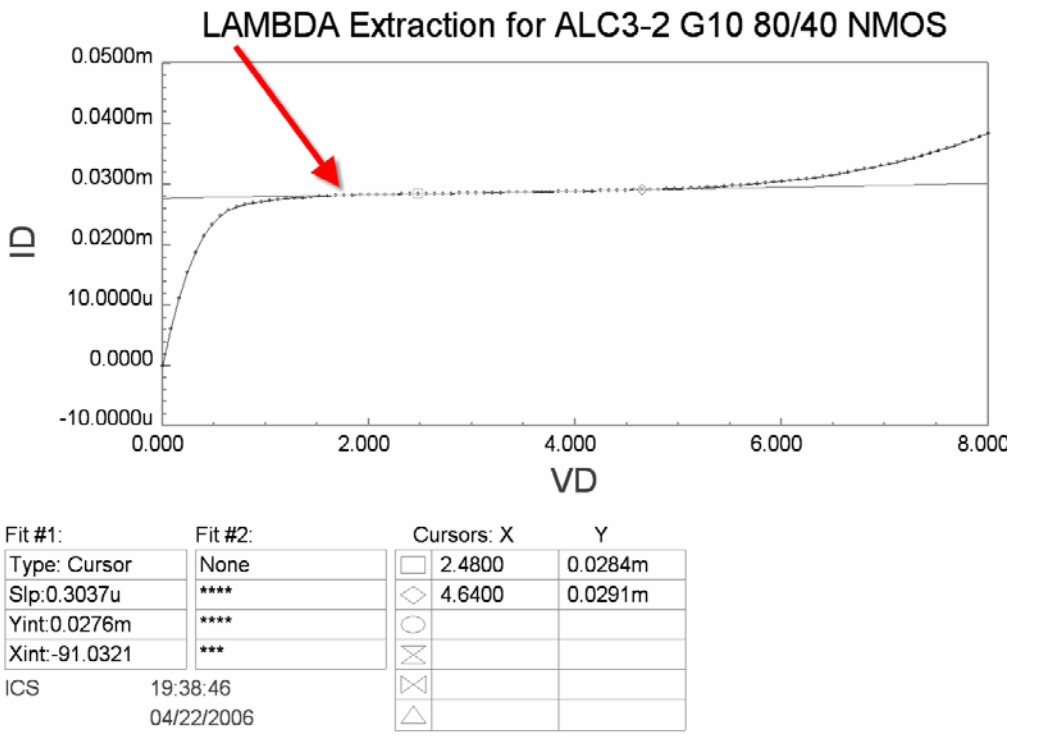


Figure 75: Pointing to a curve

Adding Text:

1. Click on the "A" button to activate adding text function, see Figure 76.

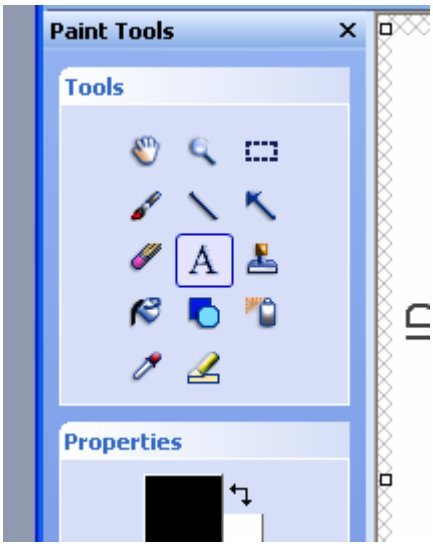


Figure 76: Activate adding text function

2. Use the cursor to create a dialogue box, then a small window will pop-up to edit the text, see Figure 77.

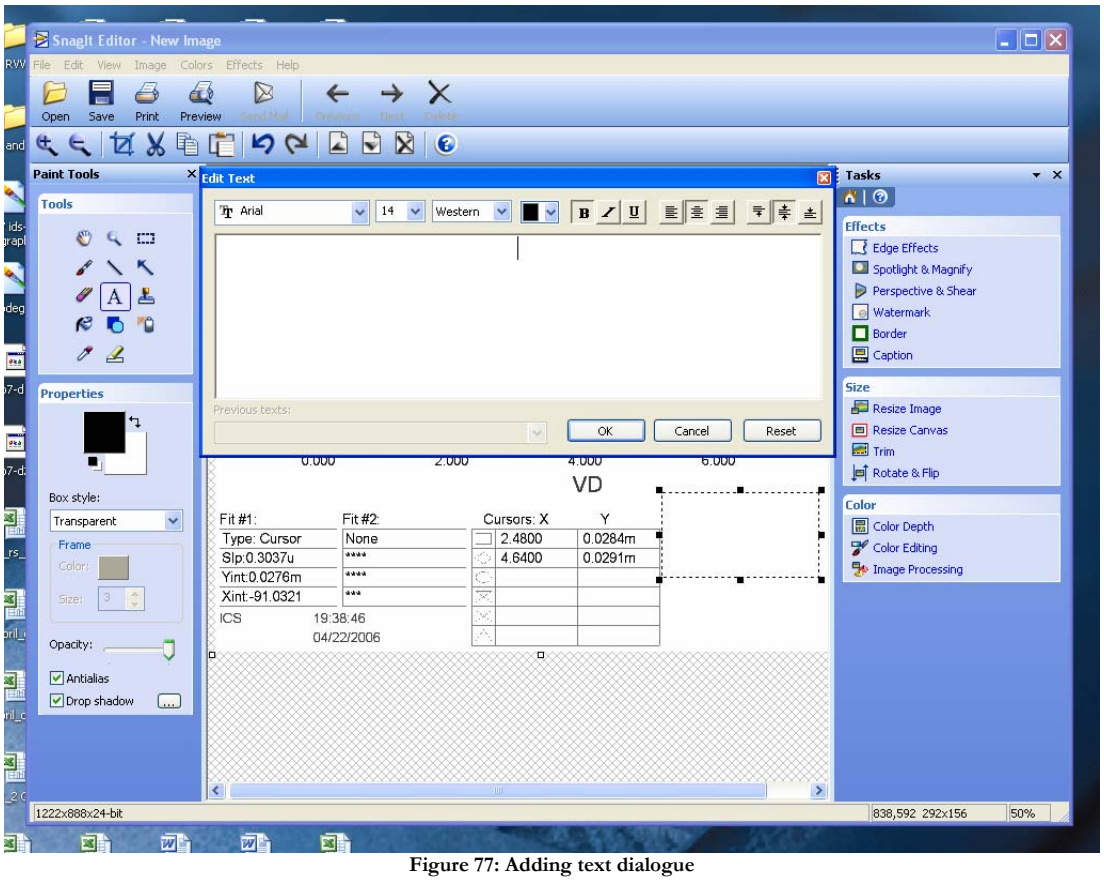


Figure 77: Adding text dialogue

3. After entering the text, press "OK". The text will appear on the image like in Figure 78.

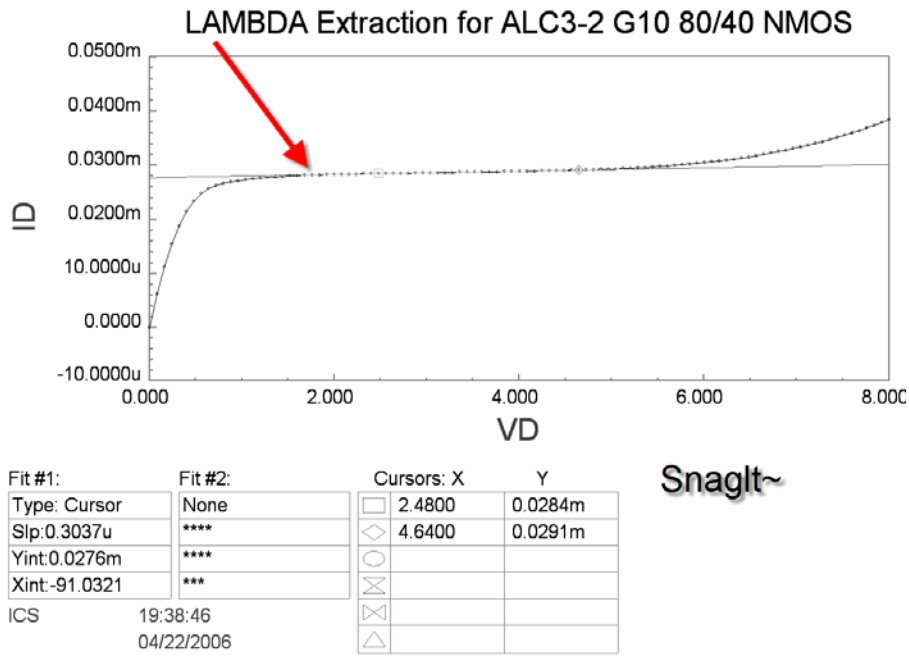


Figure 78: Example of adding text on image

Other functions' operation is similar to above examples. You may want to try to add a line and circle a particular region on an image.