TUNNELING CURRENT PROBE FOR NONCONTACT WAFER-LEVEL PHOTODIODE ARRAY TESTING

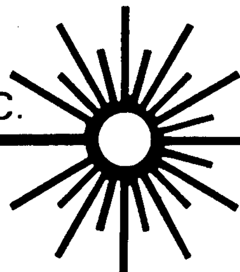
Phase III

Final Report

December 31, 1999

20000419 119

FIBERTEK, INC.



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
December 1999

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Tunneling Current Probe for Noncontract Wafer-Level Photo diode Array Testing - Phase II&III

5. FUNDING NUMBERS
$1,577,707 C
(Includes Phase I)

6. AUTHOR(S)
Dr..Horacio Verdun
Mr. Bruce McIntosh

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
FIBERTEK, INC.
510 Herndon Parkway
Herndon, VA 20170

8. PERFORMING ORGANIZATION REPORT NUMBER
2 -Final
3 -Final

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Commander U.S. Army
CECOM ACQUISITION CENTER
AMSEL-ACCC-A-CE
FORT MONMOUTH, NJ 07703-5008

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
FIBERTEK, Inc. Phone: (703) 471-7671
Fax: (703) 471-5306
Website: www.fibertek.com

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unrestricted

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

ABSTRACT

The Tunneling Current Probe (TCP) is an automated picometer-sensitive proximity sensor and current measurement system which measures the current through a photodiode detector array element by establishing a tunneling current between a metallic probe tip and the detector element contact pad. The non-contact performance evaluation of infrared photodiode detector arrays at the wafer-level entails the measurement of the current versus voltage (I-V) characteristic of each detector element at several illuminations. From this data the zero bias resistance, R_0, and the responsivity, R_λ, of each element at a known temperature, T. are obtained. These parameters are used to predict each element's performance or theoretical detectivity, D^*. Mechanical cryoprobe measurements performed on witness devices can be replaced with the high throughput TCP nondestructive evaluation of photodiode arrays at the wafer level. This will yield a cost effective solution to the problem of collecting the necessary data to detect both materials imperfections and processing flaws prior to dicing and hybridization to readout circuits. Further application of this or other probes based on picometer-sensitive proximity sensors to other detector structures, and to the broad range of semiconductor devices and measures. may lead to a nondestructive quantitative alternative to mechanical probe and electron beam measurements.

14. SUBJECT TERMS
Tunneling Current Probe, non-contact Wafer-Level photodiode array testing

15. NUMBER OF PAGES
Phase II-17, Phase III-30

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

TUNNELING CURRENT PROBE
FOR NONCONTACT WAFER-LEVEL
PHOTODIODE ARRAY TESTING

Phase III

Final Report

December 31, 1999

Prepared under contract No. DAAB07-87-C-F096 for
Center for Night Vision and Electro-Optics
Fort Belvoir, Virginia 22060-5677

FIBERTEK, Inc.
510 Herndon Parkway
Herndon, VA 22070

Table of Contents

1. Introduction 4

2. Probe Description 6

3. Upgrades 10

4. Measurement Procedure 12

5. Photodiode Measurement and Characterization 22

6. Results 25

7. Conclusions 30

List of Figures

Figure 1: Piezoelectric Control Loop 4

Figure 2: The Tunneling Process 5

Figure 3: TCP System 8

Figure 4: Time Requirements 10

Figure 5: Probe Tip and Shield 11

Figure 6: Tungsten Tip 12

Figure 7: Reference Layout 18

Figure 8: Array Setup 19

Figure 9: Element Setup 20

Figure 10: I-V characteristics of tunneling current probe and hardwire measurements of a) an MWIR diode, and b) an LWIR diode. 26

Figure 11: R_0 data for 14 elements of the 128×128 two color array 27

Figure 12: Diode dynamic difference resistance plotted against $(1/f/\#)^2$ 27

Figure 13: Area tested by tunneling current probe of TWS production wafer. 28

Figure 14: R_0 values measured by the tunneling current probe from a TWS array on a production wafer before hybridization. 29

1. INTRODUCTION

This final report prepared under contract DAAB07-87-C-F096 documents the results of FIBERTEK's Phase III research on a program entitled "Application of the Scanning Tunneling Microscope for Non-contact Testing of HgCdTe Diodes". In this program, FIBERTEK further developed, fabricated and tested a Photodiode Array Tester capable of performing automatic wafer-level MWIR and LWIR photodiode array testing. Upgrades included: incorporating a cold shield around the tip and improving the sample holder to reduce thermal background; adding a long distance microscope for improved viewing; and improving the XY stages with linear encoders. Other improvements were made in the software which included software for array testing and data reduction.

The heart of the Photodiode Array Tester is the Tunneling Current Probe (TCP) which consists of a metallic tip, a piezoelectric actuator, and the electronic servo control system. This basic configuration is illustrated in Figure 1.

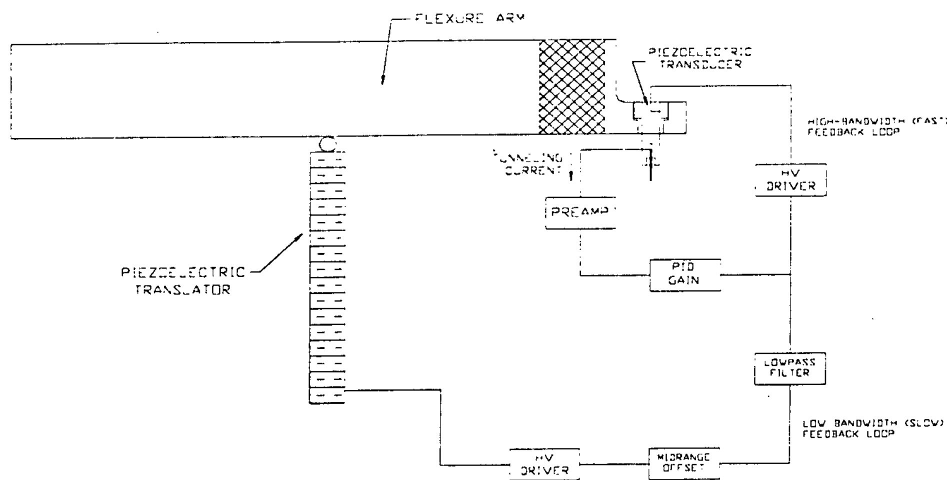


FIGURE 1: Piezoelectric Control Loop

A metallic tip mounted on a piezoelectric actuator can be electrically positioned at a constant separation of a few angstroms from an electrically conductive surface, a point at which a tunnel junction can be established. Specifically, it may be positioned at a separation of a few angstroms from the indium bump, or metal pad, which is built on each photodiode of an infrared focal plane array for electrical contact. This is shown in Figure 2. If the electrical potential difference between electrodes of the tunnel junction is smaller than the work functions, the tunneling is directly into the solid-state electronic states of the electrode with the highest electrical potential. This tunneling current is very sensitive to the tip-to-pad spacing and it is used as the position sensing device for a servo loop controlling the piezoelectric actuator, which is designed to keep a constant tunneling current.

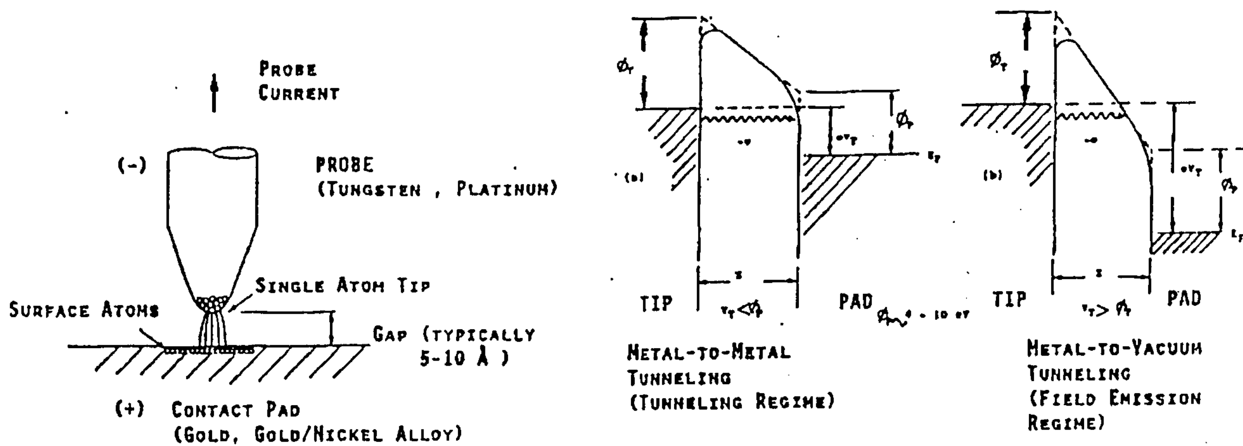


FIGURE 2: The Tunneling Process

The non-contact nature of this probe permits testing of individual photodiodes on a wafer through their deposited conductive pads. Its use avoids mechanical damage and surface contamination which are deleterious to both diode performance and characterization process. The nature of this probe is truly non-destructive as it avoids both mechanical

contact and the use of energetic electron beams or radiation. Its tunneling current arises from only low energy, a few eV, non-ionizing electrons which do not alter the original pad surface through processes such as absorption, desorption, or radiation damage. This permits testing in medium vacuums (such as those normally used to prevent condensation and to achieve thermal isolation) and avoids the need for ultra high vacuum clean surfaces.

The intended use of the TCP is for non-destructive determination of the essential photodiode performance parameters such as quantum efficiency and zero bias dynamic resistance at the detector's ideal cutoff wavelength, i.e., at lambda peak. These determinations are conducted at those reduced temperatures and backgrounds which still allow the detector to exhibit the diffusion limited behavior expected for the greater background illuminations experienced in actual applications. The information depicting each array's performance will be available in numerical form, graphic histograms and I-V characteristics, and in two dimensional fixed patterns for the evaluation of all the arrays in an entire wafer and prior to further processing. Therefore, bad arrays can be screened out before proceeding with the next manufacturing step such as attachment to the CCD chip. Savings achieved by avoiding this operation on bad arrays are very significant. This constitutes the main rationale for the development of the instrument described here.

2. PROBE DESCRIPTION

The main challenge in the practical implementation of the probe is the stabilization of the tip-to-pad distance. It is required that this distance be stable within a picometer

during the time of the measurement. This requirement is made even more difficult to satisfy when it is compounded with the need to have a fairly open structure to allow the positioning of the tip within a 75 mm square area. A diagram of the whole system is shown in Figure 3. The tip is a piece of electrolytically sharpened tungsten wire, which is mounted on a piezotranslator consisting of a cylindrical piece of piezoelectric ceramic with an outside diameter of 6.2 mm, a length of 25 mm and a thickness of 0.5 mm. One electrode covers most of the external surface and the other most of the internal one. The lowest oscillating mode of this translator is 15 kHz. At room temperature, it produces a translation of 13 μm per kV. This fast actuator is controlled by a servo-loop, using, as a position sensor signal, the tunneling junction current. The tip and fast actuator are mounted on a horizontal arm attached to a pedestal through a steel plate that works as a flexure joint. The vertical position of this beam is controlled by a piezo-stack capable of providing a tip position adjustment within a range of about 200 μm. This adjustment is used to pull the tip up, at the end of a characterization cycle, to give a safe standoff distance when moving from one array element to the next. It is also used to provide a compensation for thermal drift during the time of preparation of the tunnel junction prior to the I-V characteristic determination. This is accomplished by making the piezo-stack part of a compensating servo loop that uses the voltage applied to the fast actuator as the position signal. This servo loop acts to maintain this voltage close to zero. The lowest vibration frequency of the whole assembly is about 500Hz.

The wafer is mounted on a copper sample-holder attached to an XYZ translation stage through a thermally insulating plate. This holder is surrounded by reflective

insulation to reduce the thermal radiation level impinging on most of its area, and consequently reduce, as much as possible, the absorption of thermal radiation. The holder is thermally connected to the bottom of a liquid nitrogen container through a bellows with sufficient length to allow the adjustment of the position of the stage within a 75 mm range in both the X and Y directions. With liquid nitrogen, a temperature of 77.8° K can be obtained at the holder. A coarse vertical adjustment is provided by the Z translator which, like the X and Y translators, is driven by a stepping motor. This translator provides a vertical position adjustment within a range of 4 mm.

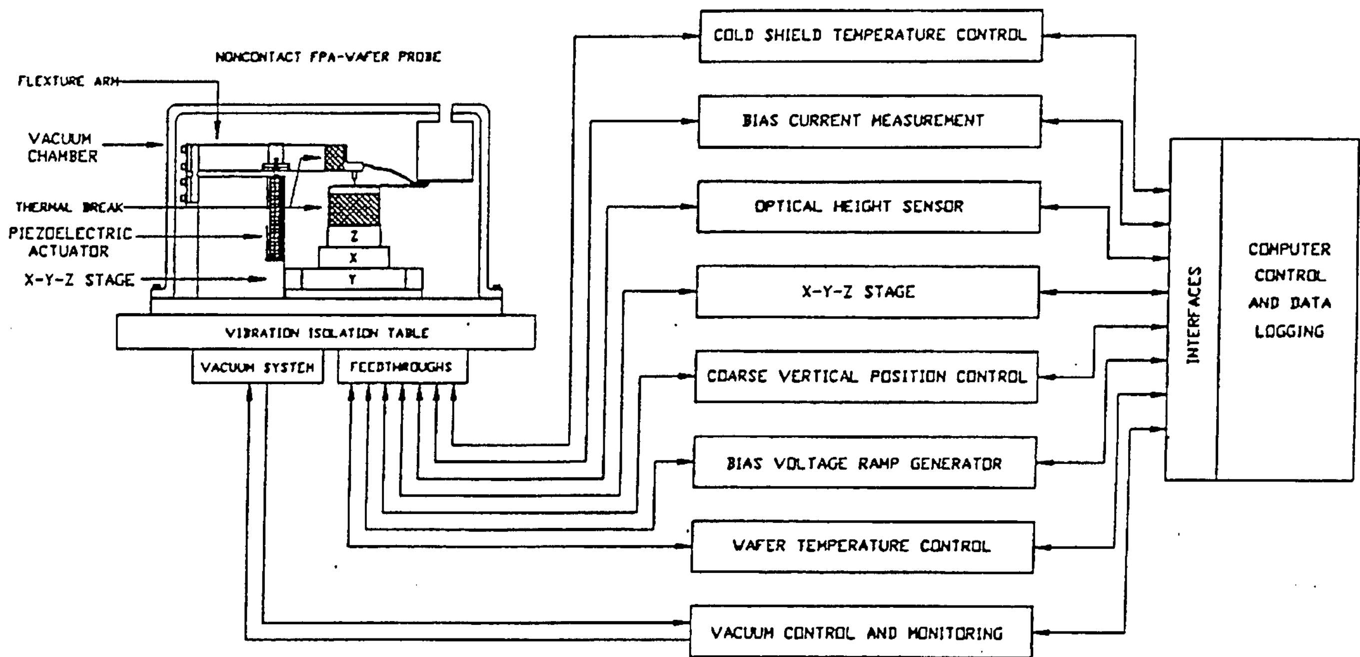


FIGURE 3: TCP System

The whole assembly is enclosed in a vacuum chamber. The vacuum is established by using a turbomolecular pump to bring the pressure at the chamber below 10^{-5} Torr. At

this point the valve connecting this pump to the chamber is closed, the turbomolecular pump is turned off and an ion pump is turned on to improve the vacuum within the chamber and keep it at a level below 10^{-6} Torr. Therefore, the vacuum can be maintained at a level sufficient to produce good thermal isolation while keeping the system vibration free.

The whole system is controlled through a personal computer, which also performs the tasks of data acquisition, logging, processing and display. The I-V characteristics are determined by taking 500 data points in each direction of the bias voltage sweep for a total of 1000 points. Each data point is taken in intervals of 10 μs. Therefore, the whole I-V characteristic is determined in a measurement interval of only 10 milliseconds. Shorter scan times are preferable to minimize the probability of having a perturbation of the tip-to-pad spacing due to thermal drift, vibration or actuator voltage noise that could significantly alter the tunnel junction resistance during the measurement cycle.

A diagram containing all the operations required for the complete characterization of an array or complete wafer is shown in Figure 4. The current throughput is two photodiodes per second. As can be noticed in this chart, the time required to slowly and safely lower the tip on the contact pad without crashing on it is much longer than desired and is at this moment the operation controlling most of the realizable throughput. Work is continuing to reduce this time.

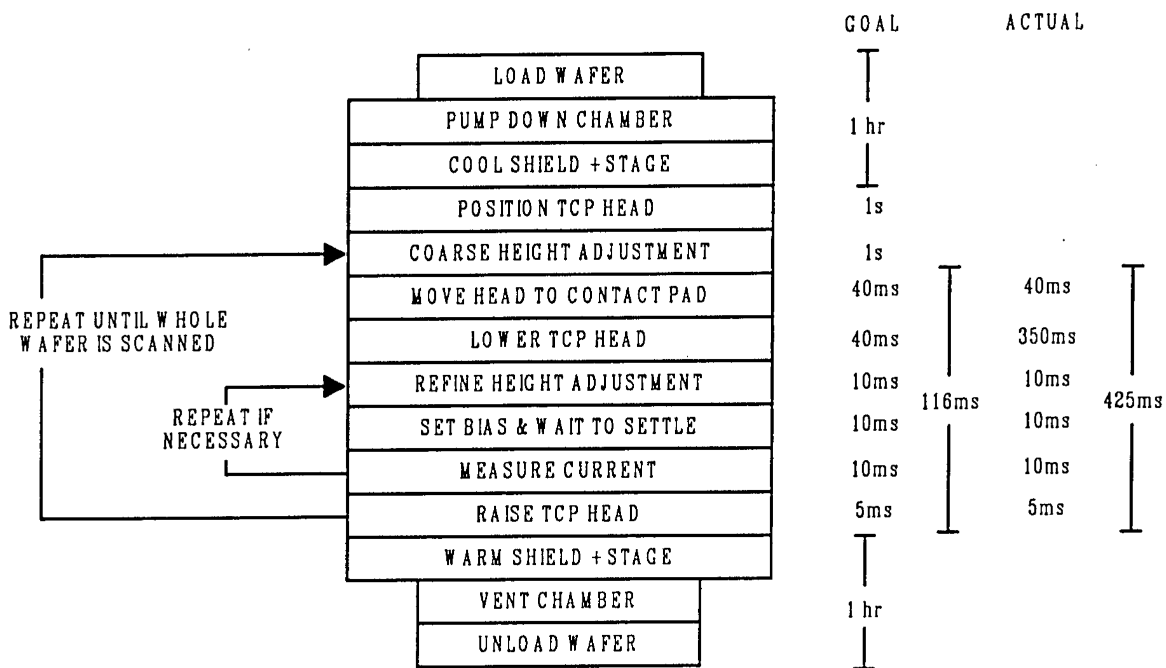


FIGURE 4: Time Requirements

3. UPGRADES

Several features of the tunneling current probe were upgraded from the previous prototype. A cooling shroud was added around the tip, as shown in Figure 5, to suppress the background radiation during testing of LWIR sensors. This shroud was cooled by attaching a copper strap to a cooling block, which was then cooled with continuous feed liquid nitrogen. A temperature of approximately 150° K was achieved at the shroud. This significantly reduced the effect of background radiation on the sample.

The sample holder was also improved by replacing the previous copper strap cooling method with a direct cooled copper sample-holder. This reduced the sample temperature

from about 110° K to 77.8° K. A heating unit was also added to control the sample temperature at a set level.

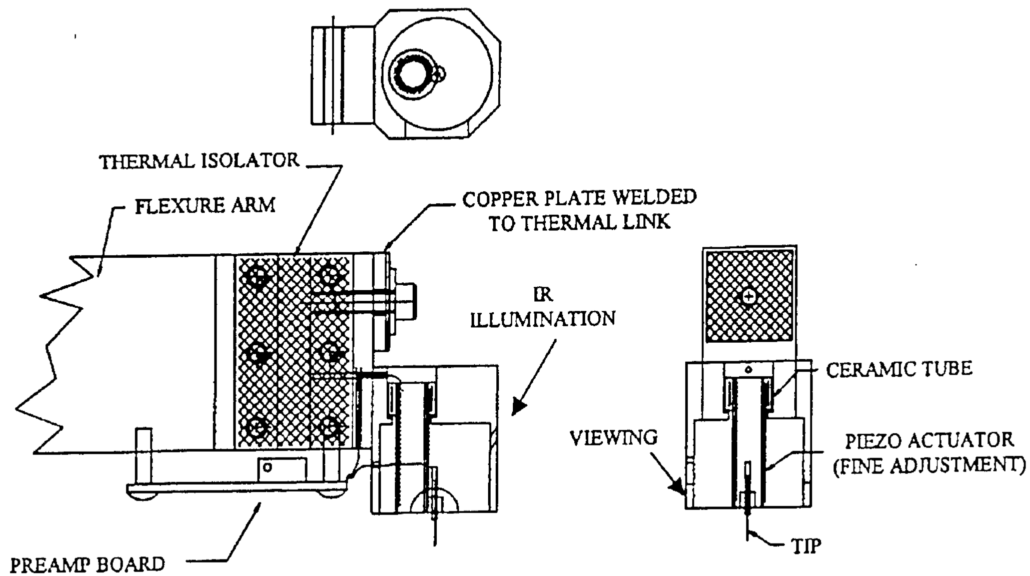


FIGURE 5: Probe Tip and Shield

X-Y stages were upgraded with encoders to give feedback for locating diodes and setting references. A long distance microscope was also added to improve sample imaging.

The platform for testing was changed to Windows NT to allow for multitasking. Software was upgraded so automatic testing of wafers could be done. Also, software was written to do data reduction and graphically map the wafer relating diode quality to a color code.

4. MEASUREMENT PROCEDURE

A. POWER-UP

Turn on the computer. Turn on the Granville-Phillips Ion Gauge Controller. Start the Newport Motion Controller. Turn on the power strip on the side of the vibration table. Float the table at 80 psi.

B. INSTALLING TIP

Using the keys on the Newport Motion Controller, move the sample holder all the way down. Position the X and Y stages so that the tip is positioned over the hole in the right front of the sample holder. Select a new, sharp tip, cut in half and bend the end basically as shown in Figure 6. Using tweezers, push the tip into the small stainless tube glued to the piezo. Bend should be so that tip fits snug, but not so much as to cause the tip to be hard to press in.

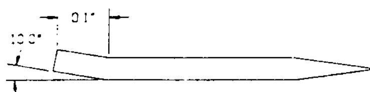


Figure 6: Tungsten Tip

Once the tip has been installed, the microscope needs to be focused on it. Twist the flashlight on the top of the microscope to turn on the finder light. Turn the switch on the back of the microscope to vertical. Turn off all other lights. Adjust the micrometers on the microscope mount to point the light onto the ceramic holding the tip. Focus some on the ceramic using the focusing knob on the back of the microscope. Next move the light down to the needle and focus on

it until you get a sharp pinpoint of light. Rotate the switch on the back of the microscope to horizontal and turn on the sample light. You should see a dark image on the monitor now. If not try tuning the horizontal micrometer left and right a little. If you still can't see anything, go back and try refocusing on the needle. Repeat micrometer adjustments and focusing until you see a dark image on the monitor. Focus better on it and move down the side of it until you reach the tip. Align the tip at the top, center of the monitor about an inch down. Remember to turn off the finder light!

C. PUMP-DOWN

1. Manual

a. From Atmosphere

Go to Tests/Pump Down. If the ion pump is on, leave the large valve closed! (If the ion pump is off and the chamber is at atmosphere, open the large valve unless you know the pump is evacuated some. If it is already pumped down some, open the large valve when the pressure is about 10^{-1} Torr). Open the small valve. Turn on the turbo pump. Press on the door some and watch for the pressure to start coming down. When the pressure is around 10^{-2} Torr, the sample holder can be cooled with liquid nitrogen, as described in COOLING. This will also trap water to the side of the dewar and aid in pump-down. At the bottom of the 10^{-4} scale, the ion gauge should start. If it

doesn't start, then push the IG1 button on the Ion Gauge Controller. Once to the lower 10^{-5} Torr range there are two options depending on whether the ion pump is running or not.

1. If the ion pump is off (large valve should be open at this point), press the "Power" button on the Digitel 500 and then the "HV Enable" button, to turn the ion pump on. (If you see a blue glow in the chamber, turn off "HV Enable" quickly. This indicates the pressure is still too high and can damage the pump). Watch for the three red lights on the front panel of the Digitel 500 to go out. If they do, then the pump has started. If the HV enable light flashes, then the pressure is still too high for the ion pump to start. Press the HV Enable switch off and wait for the pressure to come back down. When it has, press HV Enable on again to try to restart the pump. Don't try this more than a couple of times. If it still won't start, then wait for the pressure to drop lower and try HV Enable again.

2. If the ion pump is on, open the large valve. Watch for the three red lights on the front panel of the Digitel 500 to go out. If they do, then the pump has started. If the HV enable light flashes, then the pressure is too high for the ion pump to start. Press the HV Enable switch off and wait for the pressure to come back down. When it has, press HV Enable on again to try to

restart the pump. Don't try this more than a couple of times. If it still won't start, then wait for the pressure to drop lower and try HV Enable again.

Once the ion pump has started, run both pumps together until the ion pump seems to be stable and then close the small valve. If the ion pump holds the pressure by itself for several minutes, then turn off the turbo pump. At this point, once the sample holder has cooled down, the system is ready for testing.

b. From Below Atmosphere

Go to Tests/Pump Down. The small and large valves should be closed with the chamber pumped down some and the ion pump should be on. (If not, pump down as in Part 1). Turn on the turbo pump and wait for about five minutes until the half speed rotation light goes green. Open the small valve. Pressure might jump up, but should then come back down. When the pressure is around 10^{-2} Torr, the sample holder can be cooled with liquid nitrogen, as described below. This will also trap water to the side of the dewar and aid in pump-down. At the bottom of the 10^{-4} scale, the ion gauge should start. If it doesn't start, then push the IG1 button on the Ion Gauge Controller. Once to the lower 10^{-5} Torr range, open the large valve. The pressure on the Digitel 500 should come up and gradually the three red lights should

go off. Run both pumps together until the ion pump seems to be stable and then close the small valve. If the ion pump holds the pressure by itself for several minutes, then turn off the turbo pump. At this point, once the sample holder has cooled down, the system is ready for testing.

2. Automatic

Go to Tests/Pump Down. Press "Automatic" button. Unit will go through pump-down sequence. (This choice is presently disabled).

D. COOLING

When the pressure is around 10^{-2} Torr, fill the liquid nitrogen dewar with a hand held dewar or directly from a LN_2 tank. Fill slowly at first to allow for venting from boil-off. Watch for temperature to drop to about 77.6° K on the sample holder. Set heater control to desired temperature.

E. SET REFERENCES

Unit should be pumped down and the sample holder should be cooled before setting references. Make sure the table is floating to 80 psi.

1. Load Old Reference Points

   File/Open/References

2. Create New Reference Points

Test/Reference Points

Program will prompt you to center the stages. Select Yes for setting references and No if you are just testing points. Go to Tunneling. Set the Safely Go To Voltage Level value to zero and click Go. Voltage level should drop to zero so Physik Instrumente supply can be turned on. Make sure the tip is not close to the wafer before turning power to piezo's on. This is because the tip jumps some. Turn on power to the Fibertek control box, the Trek HV Power Supply, and the Physik Instrumente (PI) supply. Set the voltage level to about 3 V and click Go. Tip should rise up. Readjust the telescope to position tip at the top of the screen. DO NOT CUT POWER TO THE STACK AND BE CAREFUL WHAT VOLTAGE YOU SET AFTER THIS POINT! Use the Z-stage manual button on the Newport Motion Controller to raise the stage until you can focus some on the wafer. You will see a reflection of the tip moving up to the actual tip. Don't let them touch. If you need to adjust the X and Y position, select Close and move X and Y from the program, <u>NOT</u> the manual panel. If you move from the manual panel it will affect the home position. Set X and Y step sizes and move around to find the first reference point. Go to Tunneling and set 2 nA, 50% threshold, and Range 1. Click Set. Go to IV Parameters and adjust values. Click Set. Set the Adjust Stack Voltage By field to about 0.1 and click the down arrow beside it until the tip nears the element. Click Close and adjust the position as necessary to center the tip. When the tip is near to the element, turn off

the light and wait a couple of minutes. Temperature should be at set point before testing. Continue lowering in small steps (0.01 or 0.001) until 50% is achieved. At this point, adjust the bias voltage until tunneling is steady. Record the voltage level of the stack to use in the Low Limit Voltage field during array testing. Go to Close and set Origin. Go back to Tunneling and raise the stack up some. Press Close and move along the X-axis and find the second reference point (farthest point which you would like to test on array). Tunnel it if necessary, as described above, to verify location. Set B for it. Go back to origin and then up the Y-axis to find the third reference point. Tunnel it if necessary to verify its location. Set A for it. Go back to the Origin. Set OA and OB. These are the defined lengths between element centers. References are actual locations and take tilt of wafer into account. Should have:

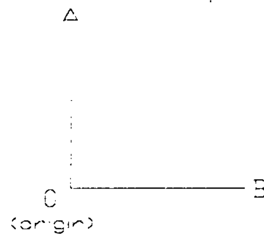


Figure 7: Reference Layout

Click OK. Save reference points to a file with extension *.ref.

F. WAFER SETUP

1. If a wafer has been previously defined and saved, then open it with File/Open/Wafer.

2. If a wafer has not been defined then go to Edit/Wafer. The first screen sets up the layout of arrays on the wafer. Select matrix or non-matrix type wafer, rows and columns of arrays, wafer size and array offsets. Wafer size is origin of lower left array to farthest element on lower right array (W(X)) and from origin to farthest element on upper left array (L(Y). Array offset is array origin to adjacent array origin. See Figure 8.

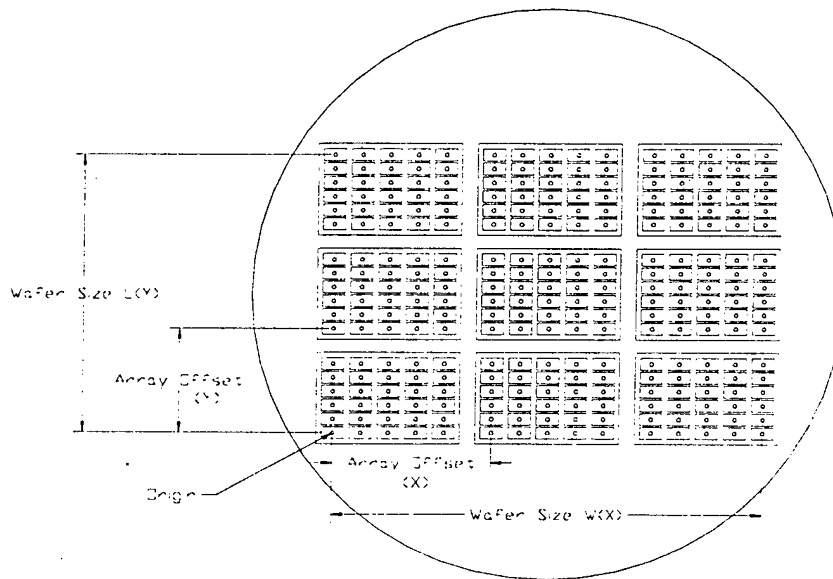


Figure 8: Array Setup

After arrays have been defined, go to Edit Arrays. Click the array you want to define and then Edit. This screen sets up how elements are positioned on each array. Set number of rows and columns, W(X) and L(Y). See Figure 9.

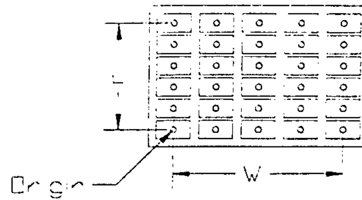


Figure 9: Element Setup

When all settings are complete, save wafer with *.wmf extension.

G. TESTING

Once the unit is pumped down and cooled, testing can be done on individual elements or by testing a matrix of elements.

1. Individual Elements

Make sure the table is floating.

Test/Reference Points.

This is done exactly like above in the Set References section. Program will prompt you to center the stages. Select No. Go to Tunneling. Set the Safely Go To Voltage Level value to zero and click Go. Voltage level should drop to zero so Physik Instrumente supply can be turned on. Make sure the tip is not close to the wafer before turning power to piezos on. This is because the tip jumps some. Turn on power to the Fibertek control box, the Trek HV Power Supply, and the Physik Instrumente (PI) supply. Set the voltage level to about 3 V and click Go. Tip should rise up. Readjust the telescope to position tip at top of screen. DO NOT CUT

POWER TO THE STACK AND BE CAREFUL WHAT VOLTAGE YOU SET AFTER THIS POINT! Use the Z-stage manual button on the Newport Motion Controller to raise the stage until you can focus some on the wafer. You will see a reflection of the tip moving up to the actual tip. Don't let them touch. If you need to adjust the X and Y position, Select Close and move X and Y from the program. Set X and Y step sizes and move around to find an element. Go to Tunneling and set 2 nA, 50% threshold, and Range 1. Click Set. Go to IV Parameters and adjust values. Click Set. Set the Adjust Stack Voltage By field to about 0.1 and click the down arrow beside it until the tip nears the element. Click Close and adjust the position as necessary to center the tip. When the tip is near to the element, turn off the light and wait a couple of minutes. Temperature should be at set point before testing. Continue lowering in small steps (0.01 or 0.001) until 50% is achieved. At this point, adjust the bias voltage until tunneling is steady. Record the voltage of the stack to use in the Low Limit Voltage field during array testing, if necessary. Click Collect IV to sweep an IV curve. Results can be viewed with IV Graph.

2. Testing a Matrix

A wafer and references should be defined at this point as described above in WAFER SETUP and SET REFERENCES.

Make sure the table is floating.

Test/Wafer.

Set a lower voltage limit. This should be below the value recorded in the SET REFERENCES section. Name the file and fill in the description. Set to Locate only if not sure the wafer is defined correctly. Click Test and make sure the stages move through the array correctly. Next click Locate and Test. Turn off lights and click test. Results can be viewed in IVGraph.

H. SYSTEM SHUTDOWN

After testing is complete, lower the stage to its lower limit with the manual button on the Newport Motion Controller. Turn off the Trek and Physik Instrumente supplies. Shut the large valve. Turn off the Fibertek control box, motion controller, ion gauge supply, temperature controller, the sample light and the power strip on the table. Close the bottle supplying the table pressure.

5. PHOTODIODE MEASUREMENT AND CHARACTERIZATION

The measurement procedure consists of establishing a tunnel junction with a resistance of approximately 10^6 ohms. This is accomplished by selecting an adequate bias voltage and tunneling current. The tip is then lowered until the servo loop takes control. Next, the bias voltage is swept to determine the zero current point. The bias voltage is then set approximately 10 mV from the zero current point. After a few milliseconds for tip stabilization, the voltages controlling the piezoelectric actuators are frozen and the servo loop deactivated. This freezes the tip to pad distance for the I-V measurement. Short scan times are needed to minimize the probability of a change in the

tip-to-pad spacing due to thermal drift, vibration, or actuator voltage noise. Changes in the tip to pad spacing would significantly alter the tunnel junction resistance during the measurement. The I-V characteristic is determined by ramping the bias voltage about the zero current point. 500 data points in each direction of the bias voltage sweep are taken. This measurement takes approximately 10 ms, and supplies two determinations of the I-V characteristic. After the I-V determination, the servo control loops are reactivated. The results for the two sweep directions are compared, and if they vary by more than a pre-selected value, the measurement is repeated. This procedure allows the rejection of spurious data.

The tunneling current probe system is controlled through a personal computer, which performs the tasks of data acquisition, logging, processing and display. The information depicting the performance of each diode array is available in numerical or graphic histogram form. The I-V and R-V characteristics of each individual diode are also available for evaluation. This allows bad arrays to be screened before proceeding with the next manufacturing step: hybridization to the CCD chip. Savings achieved by avoiding this operation on bad arrays are very significant, and constitute the main rationale for the development of the tunneling current probe.

The tunneling current probe is intended to non-destructively determine the photodiode performance parameter of zero bias dynamic resistance (R_0). R_0 determines the fraction of the generated photocurrent that can be sensed by a preamplifier in the read out circuit. R_0 is also representative of the amount of noise generated in the photodiode.

The maximum photodiode performance is achieved when R_0 has the maximum possible value.

The diode dynamic resistance (R_D) is found through the following equation:

(1) $$R_D = (dV_D / dI_D)$$

where I_D and V_D are the diode current and voltage respectively. The I-V characteristic measured by the tunneling current probe is the combination of the serially connected tunnel junction and the photodiode. The tunnel junction can be described as a constant series resistance (R_T) independent of voltage. The tunnel junction closely approximates an ohmic resistance because of the limited voltage range (±250mV) over which measurements are obtained. Thus, the diode voltage V_D can be obtained from the applied external voltage V_B (the tunneling current probe voltage) as given by:

(2) $$V_D = V_B - R_T I_D$$

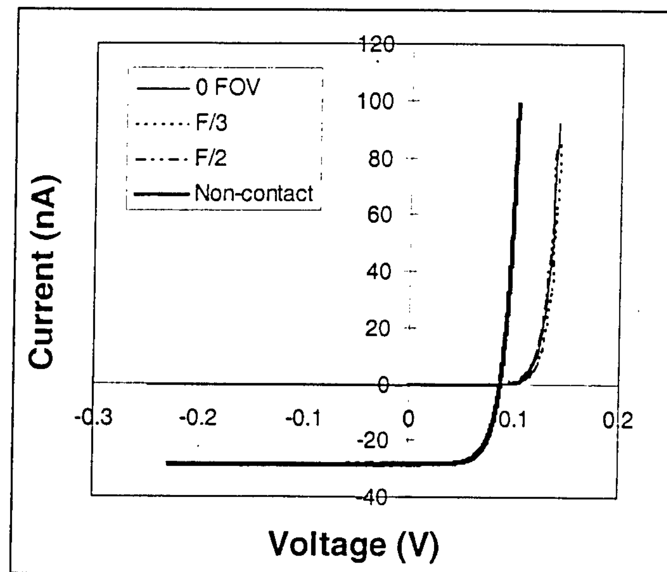
In order to calculate R_D, R_T must be determined for each measurement. The value of the tunnel junction resistance can be found from the intercept obtained from a least squares fit to the line of the total resistance R plotted against inverse current. The value of R is obtained from the Shockly diode equation:

(3) $$R = (mkT/q)[1/(I-I_{rev})] + R_T$$

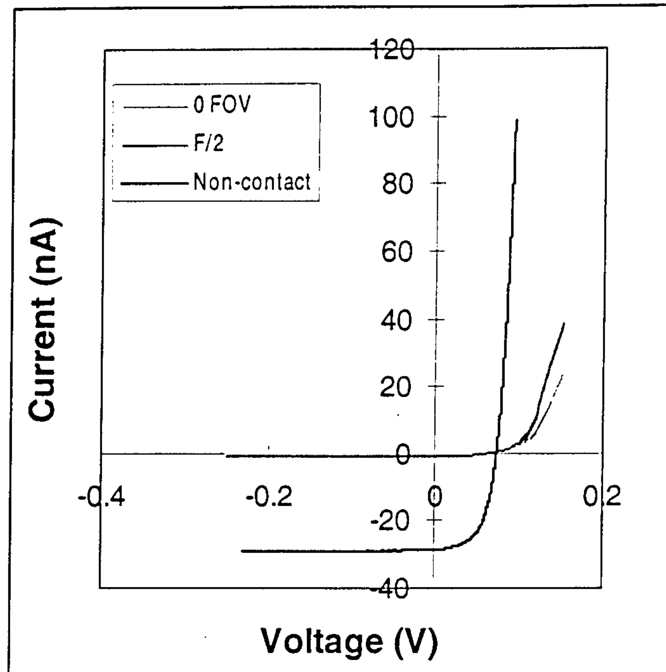
where m is the diode ideality factor, k is Boltzmann's constant, T is the temperature of the detector, q is the electronic charge, and I_{rev} is the diode reverse current limit. Typical values obtained for the tunneling junction resistance are 0.5 MΩ. The R_D value is then determined by taking the numerical derivative (using an 11 point fit) of the modified I-V_D curve.

6. RESULTS

To test the capability of the tunneling current probe, I-V characteristics determined by the tunneling current probe were compared against hardwire measurements. I-V and dynamic resistance measurements were performed on a two color HgCdTe MWIR/LWIR diode array. The128×128 two color array was hybridized to a fanout with 64 elements wired out to a leadless chip carrier (LCC). Thirty-two of the 10 micron cutoff LWIR and thirty-two 4.5 micron cutoff MWIR diodes were tested. The hardwire tests were performed in a continuous flow liquid nitrogen cooled dewar at 80 °K under several illumination levels. The non-contact tunneling probe measurements were performed at the LCC gold bonding pads. The results from Figure 10, show good agreement between the tunneling current probe and hardwire dewar I-V characteristics.



a.



b.

FIGURE 10: I-V characteristics of tunneling current probe and hardwire measurements of a) an MWIR diode, and b) an LWIR diode.

14 diodes of the 128×128 two color array were measured by both the tunneling current probe and the hardwire setup. R_0 values were computed from the I-V_D curves. The results are shown in Figure 11.

To determine the tunneling current probes f/# the dependence of the diode dynamic difference resistance upon the photon flux is plotted. As several authors have demonstrated, the dynamic difference resistance varies inversely with f/#. From Figure 12, an approximate f/# = 0.5 was determined for the tunneling current probe. This result is consistent with the fact that the probe assembly on the tunneling current probe system

is not presently cooled. We expect the f/# to increase once the probe assembly is liquid nitrogen cooled. Nevertheless, the results demonstrate the tunneling current probe provides an accurate measurement of the I-V and R_0 characteristics of a diode array.

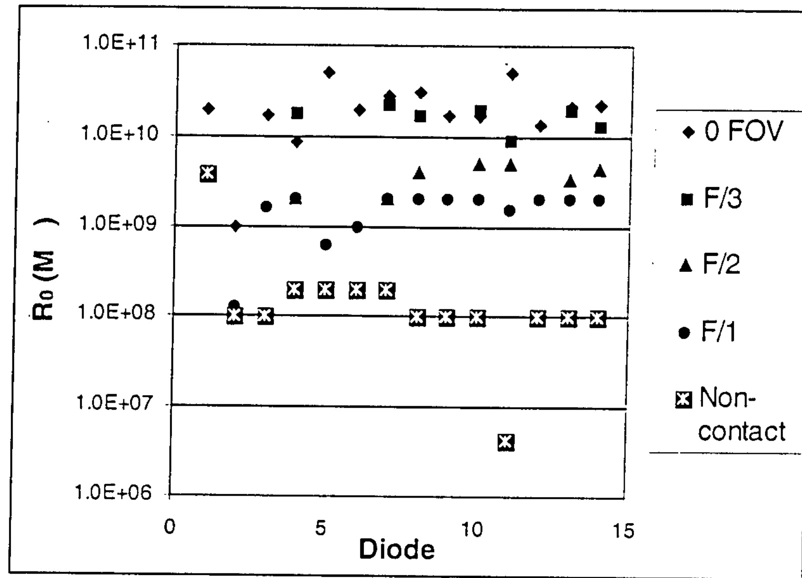


FIGURE 11: R_0 data for 14 elements of the 128×128 two color array.

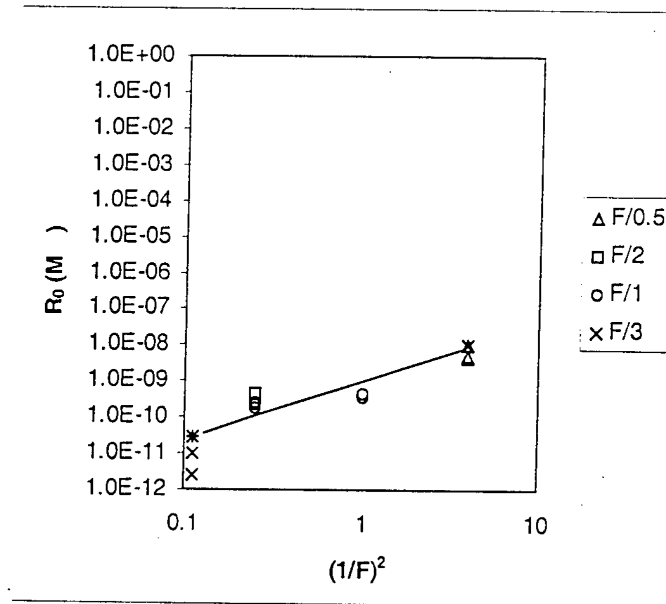


FIGURE 12: Diode dynamic difference resistance plotted against $(1/f/\#)^2$.

The tunneling current probe was also used to analyze a production wafer from the Thermal Weapon Sight (TWS) program. These MWIR HgCdTe 40×16 arrays have a diode dimension of approximately 20×40 microns. The indium pad is approximately 10×10 microns. A diagram of the production TWS wafer is shown in Figure 13 along with the location of the testing area measured by the tunneling current probe.

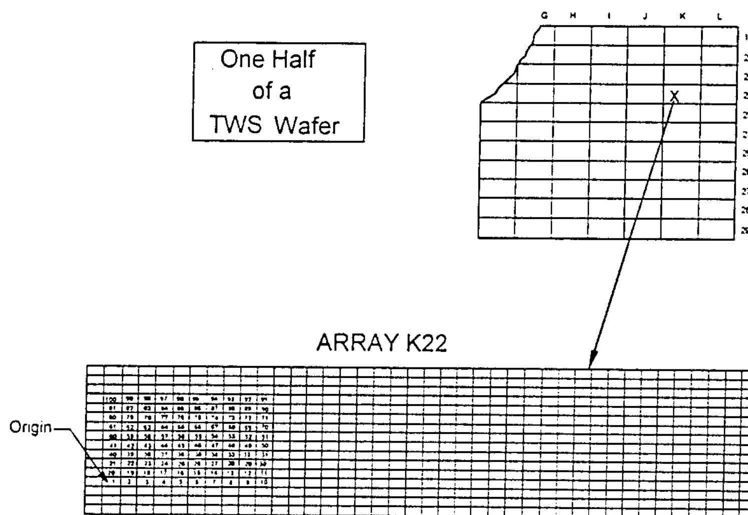
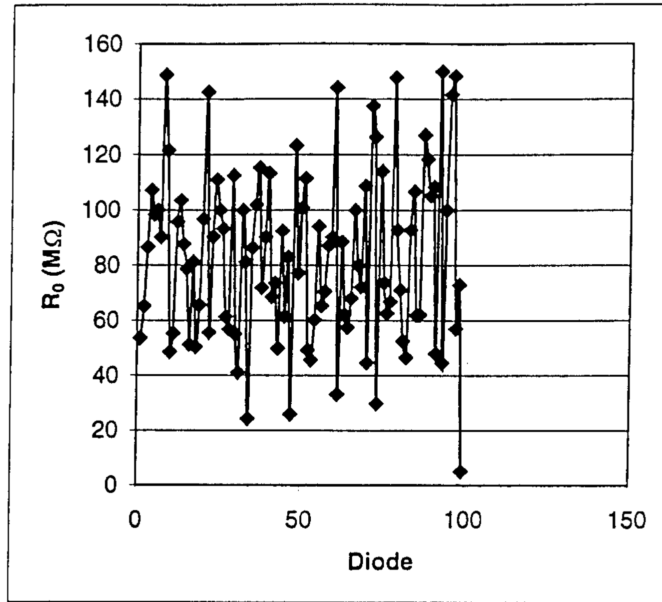
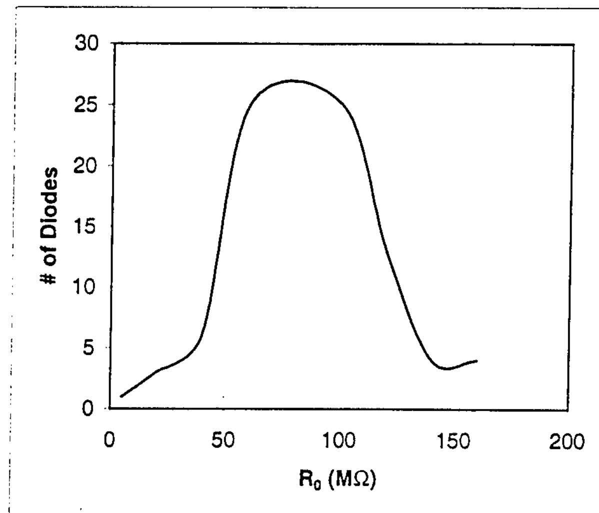


FIGURE 13: Area tested by tunneling current probe of TWS production wafer.

Figure 14 shows the tunneling current probe measurement of R_0 as a function of: a) diode number and b) number distribution of diodes from the area sampled of the TWS array. This data demonstrates the ability of the tunneling current probe to test a production wafer before hybridization to a ROIC. This type of data can be used to determine which of the arrays on the production wafer should be further processed. This determination is made by the direct knowledge of the I-V and R_0 characteristics of the diode elements within a TWS array.



a).



b).

FIGURE 14: R_0 values measured by the tunneling current probe from a TWS array on a production wafer before hybridization.

7. CONCLUSIONS

A non-contact tunneling probe system was described. I-V and dynamic resistance measurements have been successfully obtained from both MWIR and LWIR diodes. A comparison with hardwire dewar tested measurements shows excellent agreement with the tunneling current probe results. These measurements indicate that the tunneling current probe has an approximate f# of 0.5. An array from a thermal weapons sight (TWS) production wafer was also tested by the tunneling current probe. The data demonstrates the ability of the tunneling current probe to test a production wafer before hybridization to a ROIC.