ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

Testing of Semiconductor Devices and Sensors

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Testing Diodes
- Diode Temperature Sensor
- Diode Light Sensor
- Diode Light Source

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- BJT
- MOSFET

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INTRODUCTION

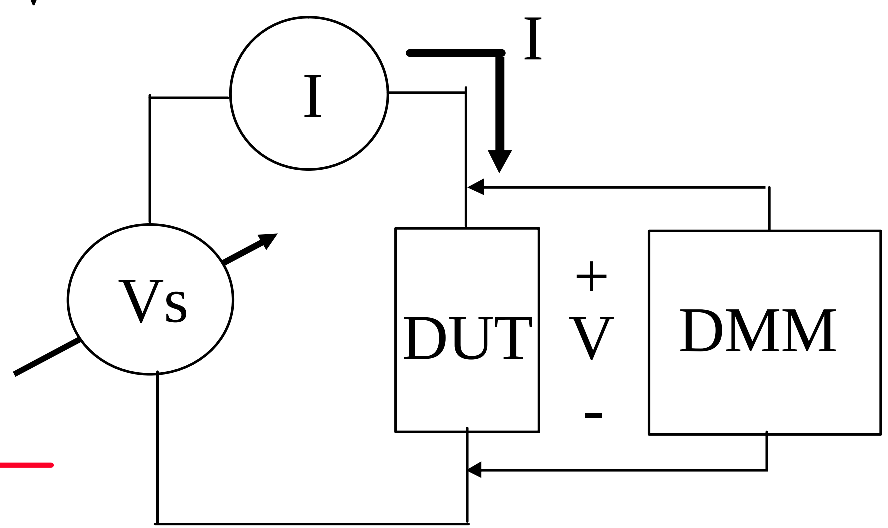
This is a laboratory guide that will introduce the reader to testing of semiconductor devices and sensors. Most devices are tested by measuring voltages across a device and the resulting current through a device. This can be done manually with variable voltage sources, voltmeters and current meters. A programmable test instrument called "Semiconductor Parameter Analyzer" could also be used and can provide equivalent results with easier and more flexible setup.

DEFINITION OF TERMS

DUT - Device Under Test
Ohm's Law – Fundamental Relationship between current through and voltage across a resistor.
Charge – created by the presence or absence of electrons
Current – movement of charge
Voltage – potential to move charge
Resistor – opposition to the movement of charge
LED – Light Emitting Diode
Diode – device that allows current to flow in one direction only
BJT – Bipolar Junction Transistor
MOSFET – Metal Oxide Semiconductor Field Effect Transistor

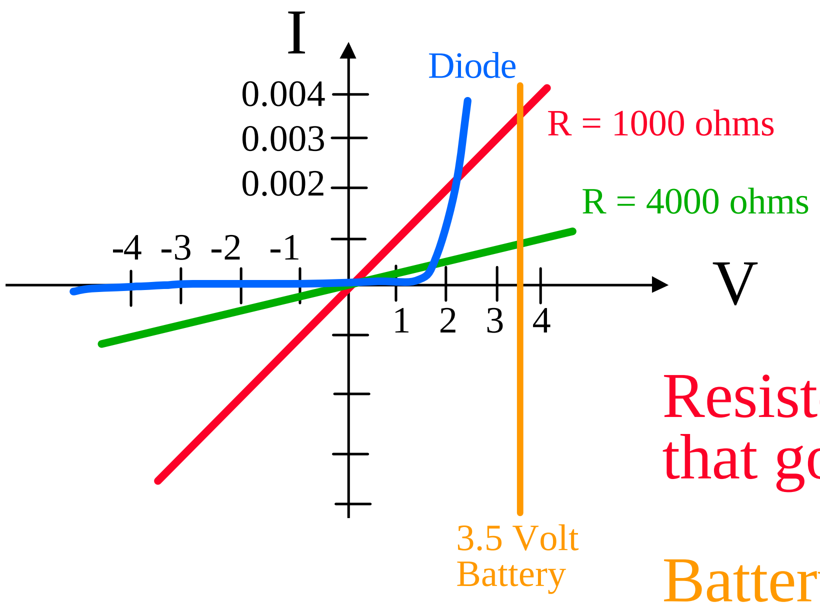
CHARACTERIZATION OF ELECTRONIC DEVICES

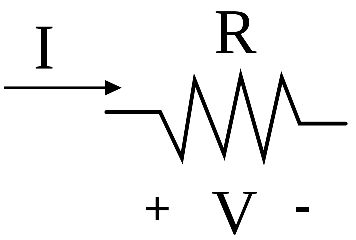
Electronic devices are classified by their current-voltage (I-V) characteristics. The I-V characteristics could be measured experimentally or derived theoretically. The experimental approach would involve applying several voltages and measuring the corresponding current. The current vs. voltage is plotted and compared with known classifications. For example: a variable voltage supply Vs is used to apply different voltages to the Device Under Test (DUT) while a current meter (I) and Digital Multimeter (DMM) is used to measure I and V



Data is collected for I and V
(shown on the next page)

DEVICE CLASSIFICATIONS



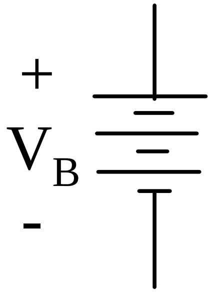


Resistor Symbol

Resistors have linear I-V characteristics that go through the origin.

Battery has linear I-V characteristics with constant voltage at any current

Diode has exponentially increasing current in the first quadrant and ~ zero current in the third quadrant (until breakdown).

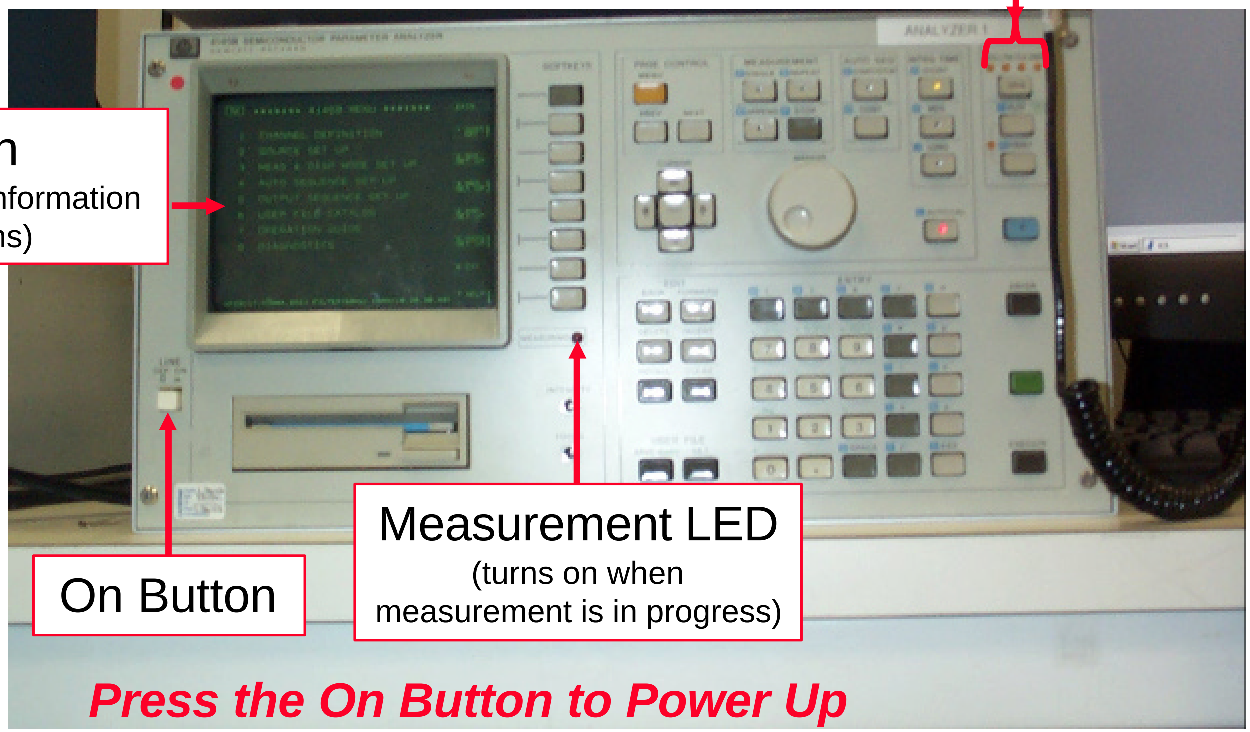


Battery Symbol

HP4145 – SEMICONDUCTOR PARAMETER ANALYZER

Data Transfer & Standby LED's

Screen
(Displays useful information and options)



On Button

Measurement LED
(turns on when measurement is in progress)

Press the On Button to Power Up

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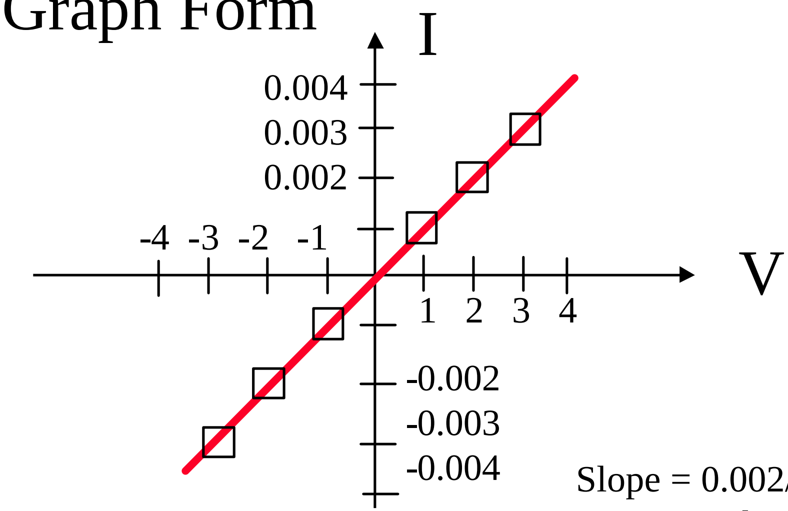
RESISTOR TEST DATA

Data in Table Form

I (amps)	V (volts)
-0.003	-3
-0.002	-2
-0.001	-1
0	0
0.001	1
0.002	2
0.003	3

Data in Graph Form



Slope = 0.002/2
R = 1000 ohms

Y = mX + B (B → 0)

I = slope V + 0

I = (1/R) V Ohm's Law

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TESTING RESISTORS

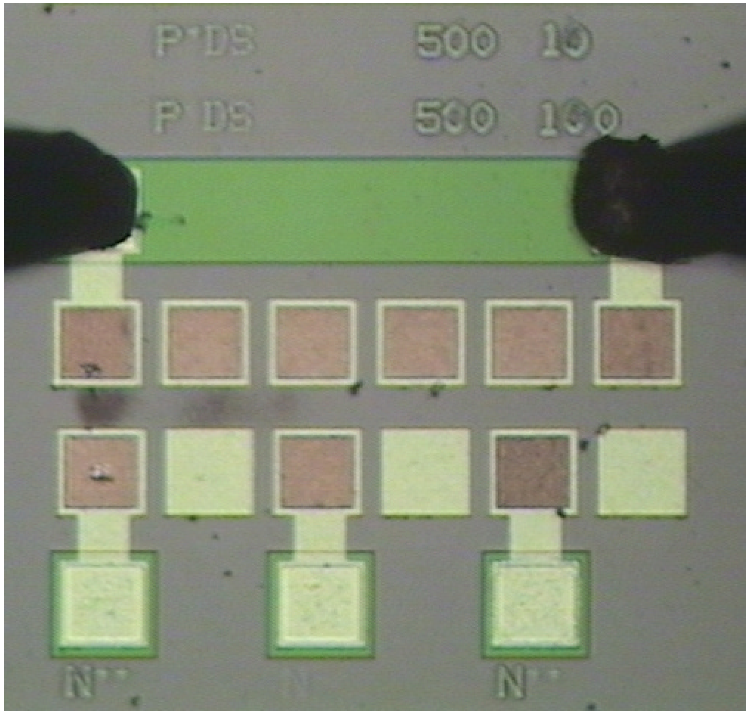
Resistor I-V Characteristics

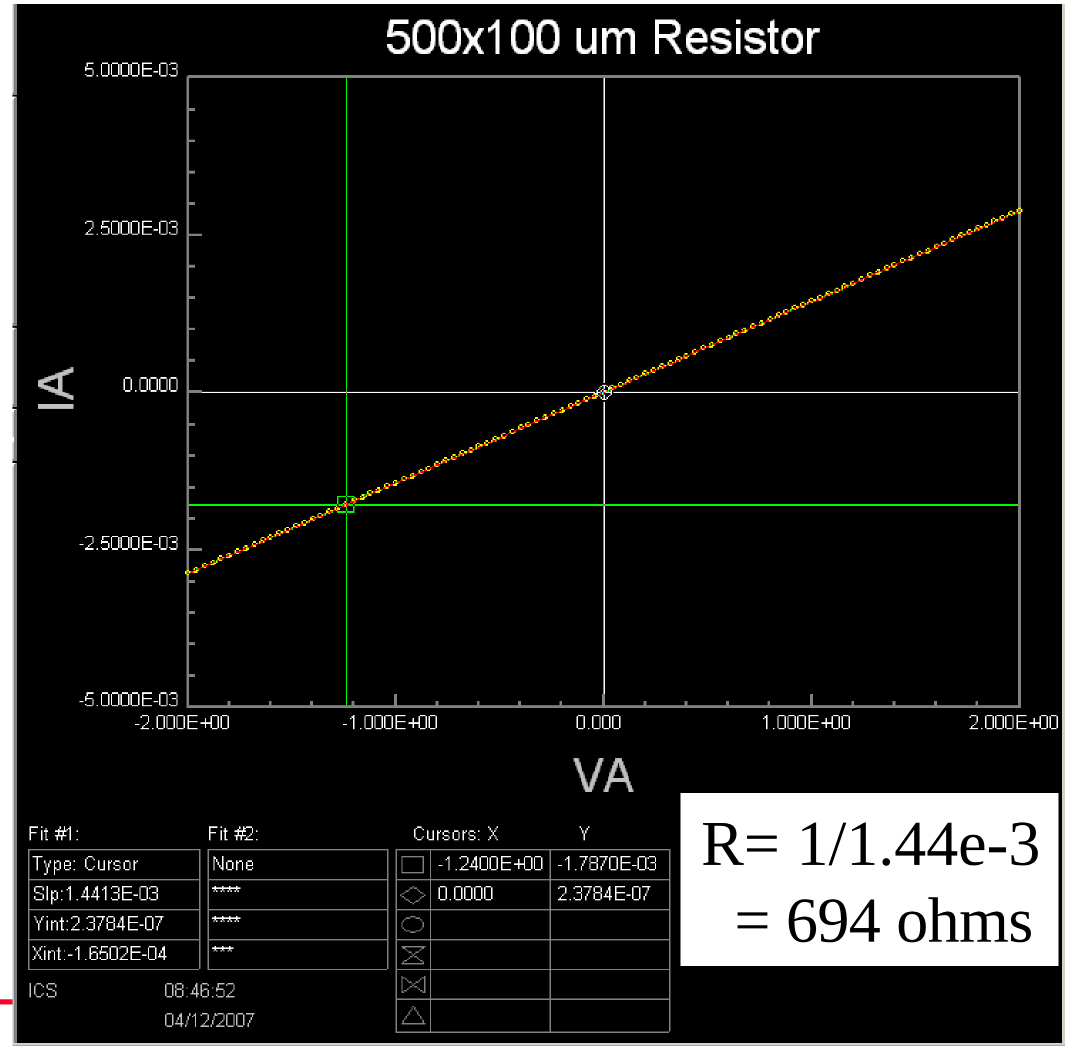
Resistor as a Light Sensor

Resistor as a Temperature Sensor

Testing of a Resistive Chemical Sensor

RESISTOR I-V CHARACTERISTICS





R = 1/1.44e-3
= 694 ohms

R = Rhos L/W

find Rhos

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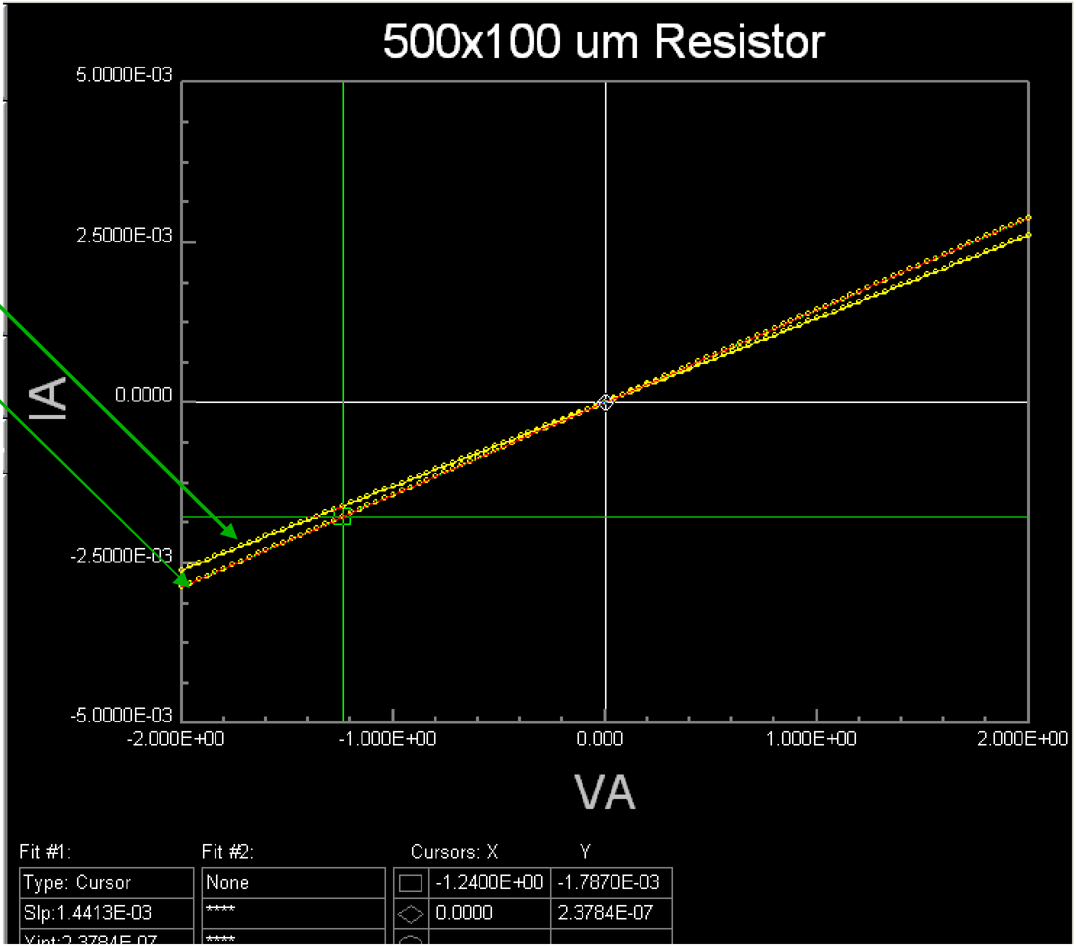
RESISTOR LIGHT RESPONSE

No light

Full light

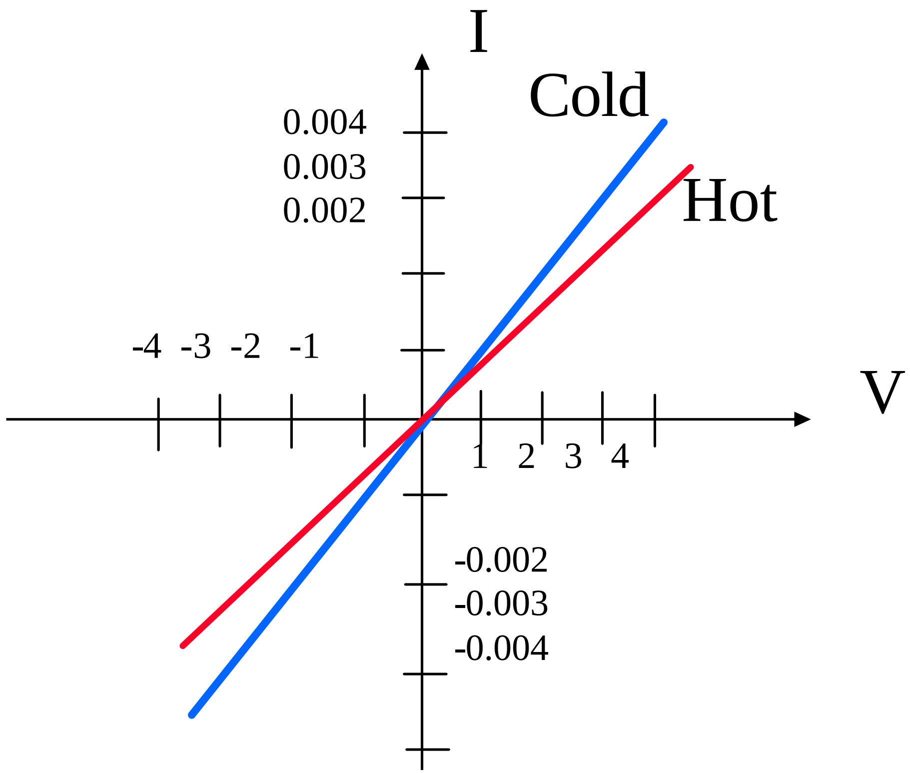


$R = \rho\, L/(W\, x_j)$ ohms

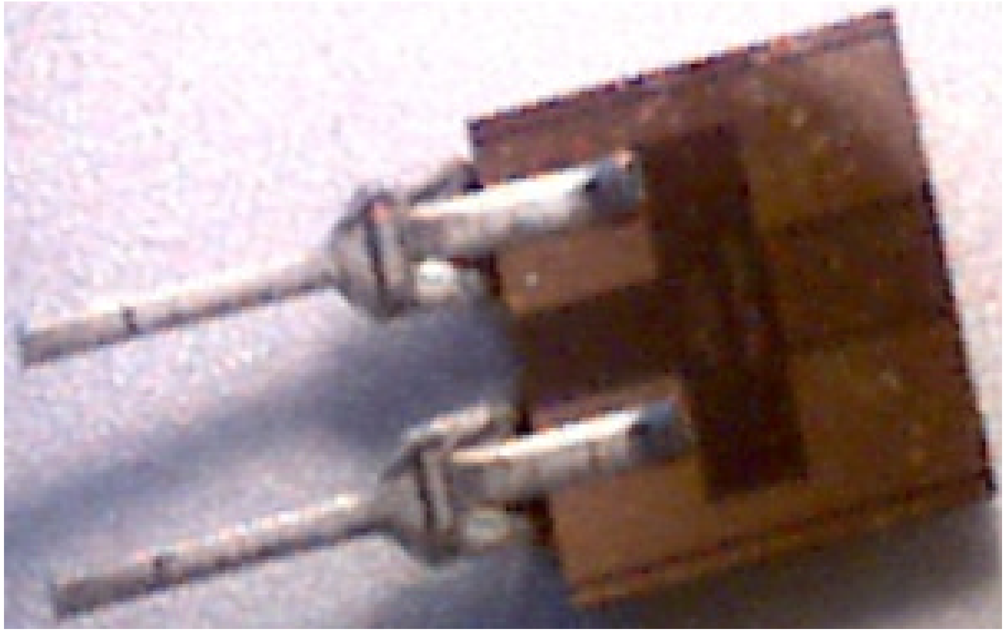
$\rho = 1/(q\mu_n n + q\mu_p p)$

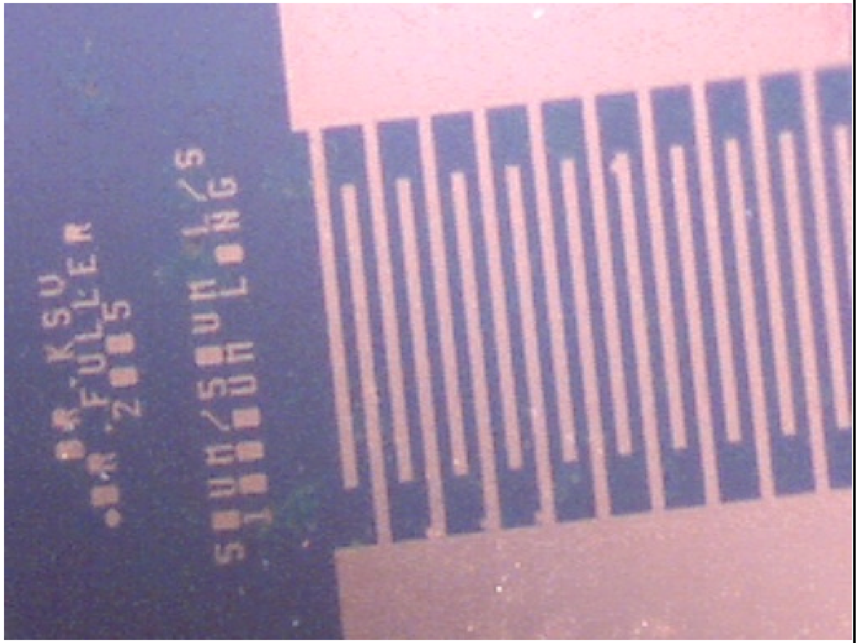
L,W,xj do not change with light, µn and µp does not change with light but can change with temperature, n and p does not change much in heavy doped semiconductors (that is, n and p is determined by doping)

RESISTOR TEMPERATURE RESPONSE



TESTING RESISTOR CHEMICAL SENSORS

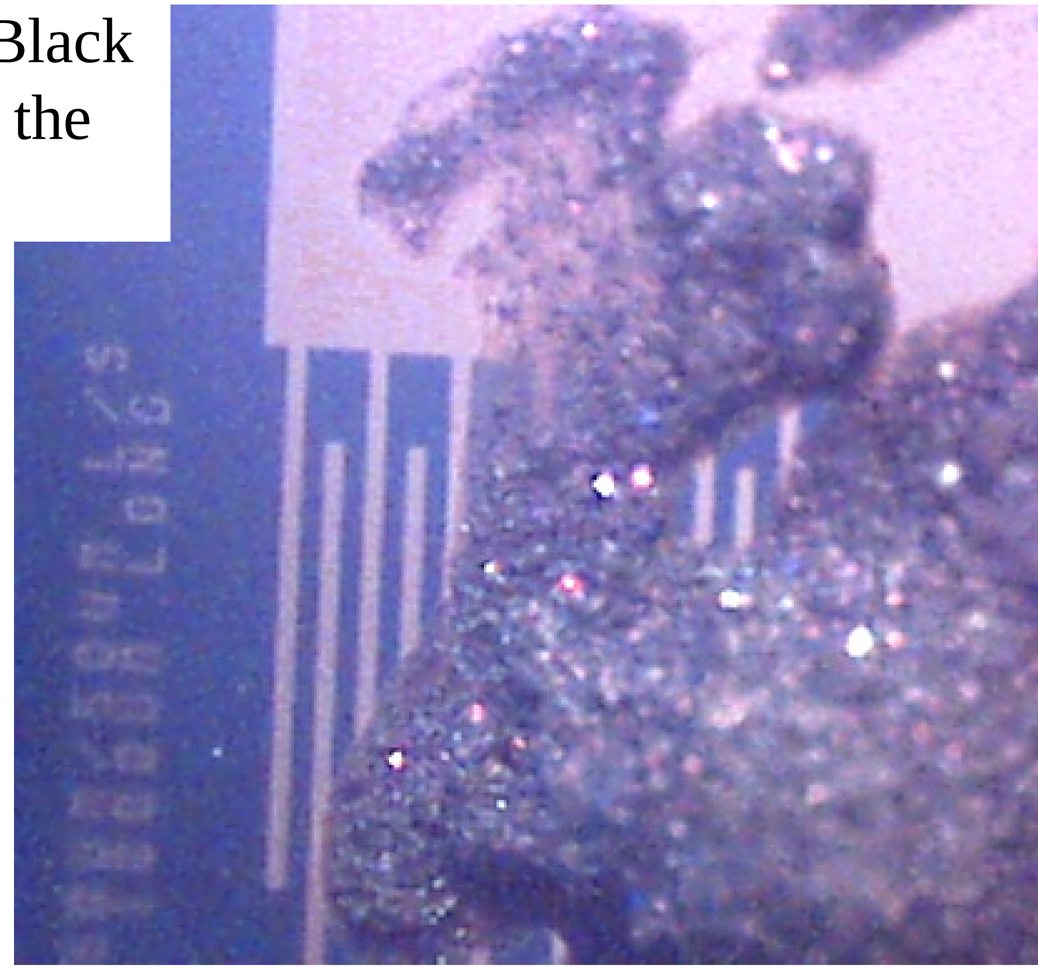




Upper Left: Finished Sensor with chip pins
Upper Right: Close up of interdigitated gold fingers

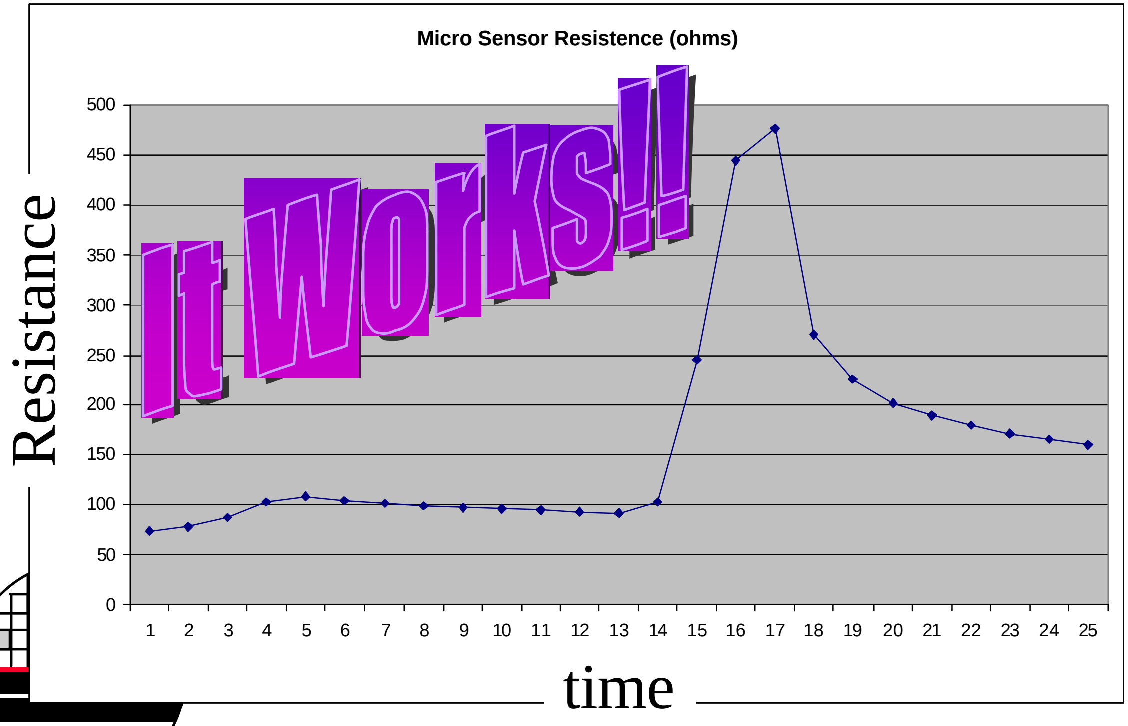
COMPLETED POLYMER/CARBON BLACK RESISTORS

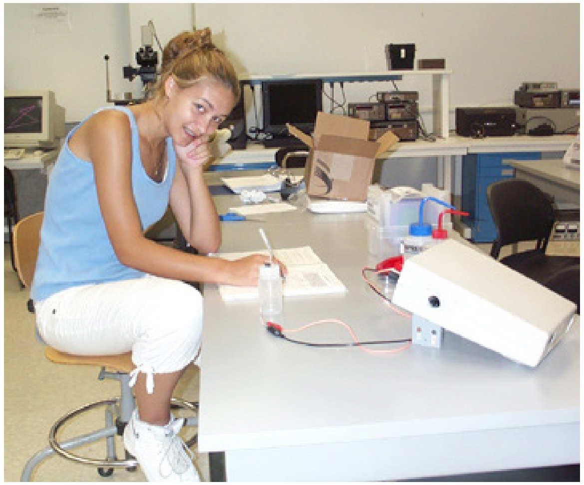
Mix a polymer with Carbon Black and apply a thin coating over the interdigitated gold fingers.

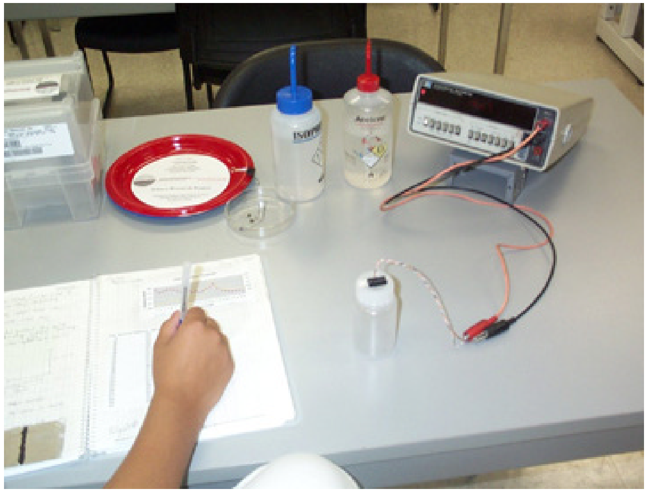


MANUAL TESTING

The resistance is measured using an ohmmeter. Measurements are taken every 15 seconds. Chemical fumes are presented to the sensor after 60 seconds causing an increase in resistance

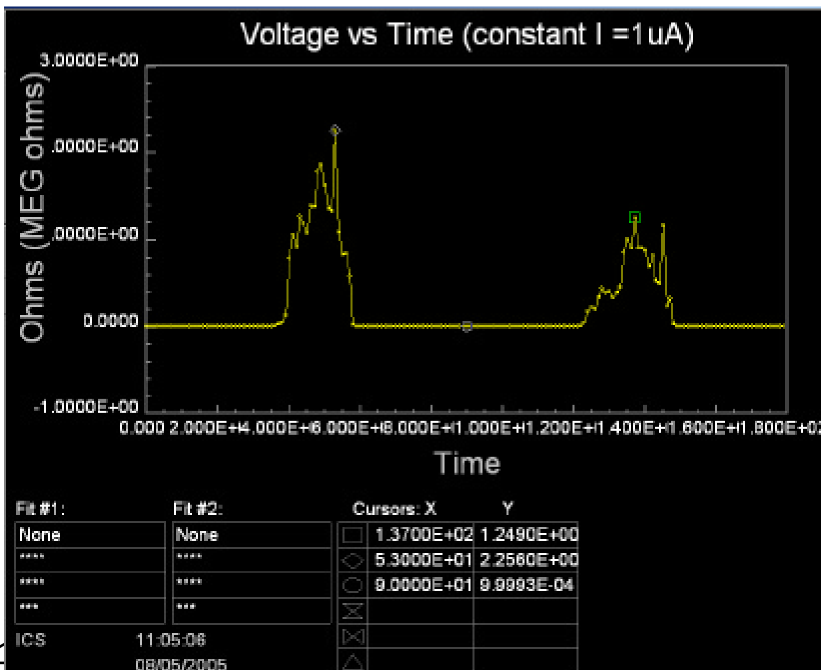






AUTOMATED TESTING

Computer controlled ohmmeter measures resistance every second for 3 min. Output is plotted versus time.

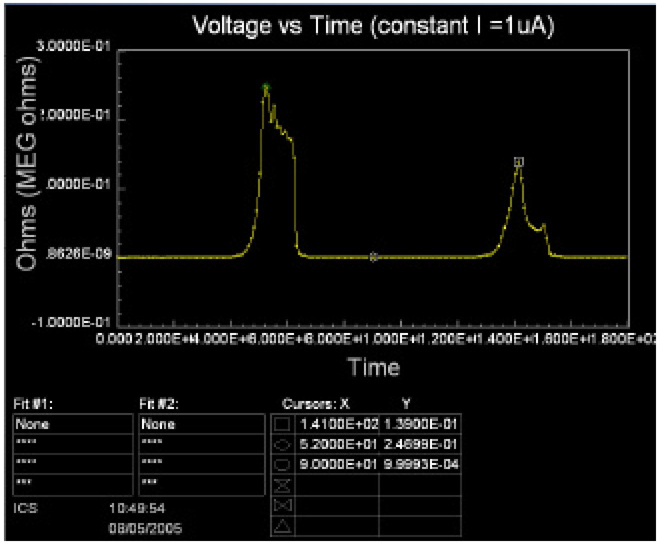


30s off, 30s on, 60s off, 30s on, 30s off

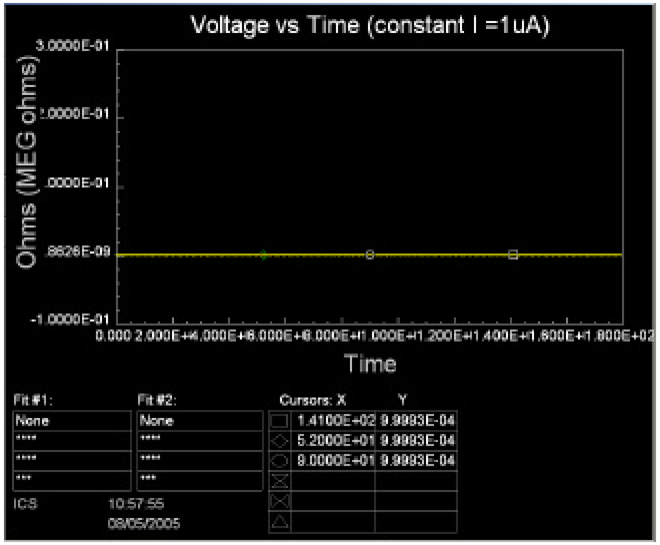
Off means no chemical vapors
On means chemical vapor exists

MORE CHEMICAL SENSOR TEST RESULTS

30s off, 30s on, 60s off, 30s on, 30s off
0.5 ml Acetone/ 125 ml bottle = 4000 ppm
Resistance goes from ~100 ohms (no vapor) to ~ 100,000 ohms (with vapor)

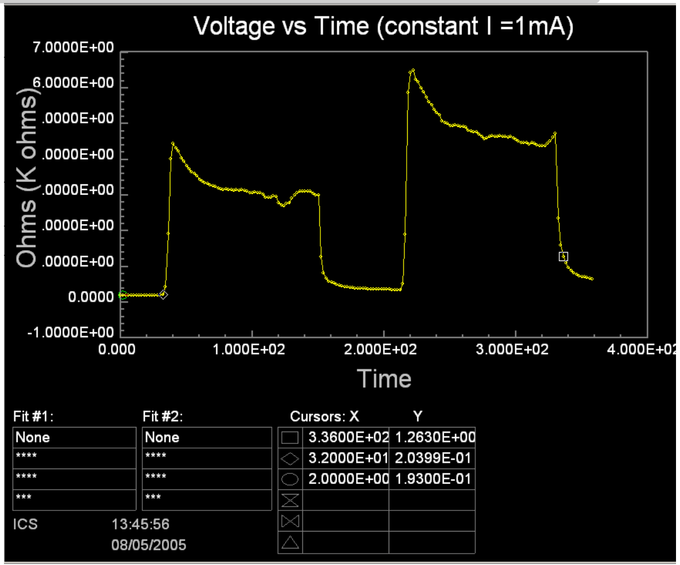


30s off, 30s on, 60s off, 30s on, 30s off
Isopropanol ~ 10,000 ppm
No Response

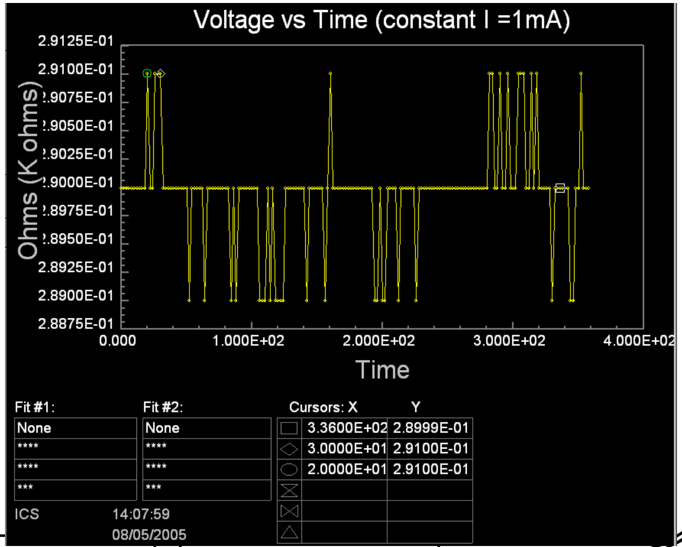


MORE CHEMICAL SENSOR TEST RESULTS

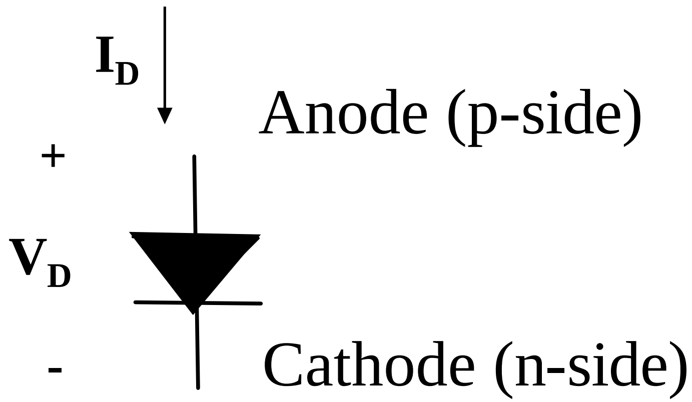
30s off, 120s on, 60s off, 120s on, 30s off
0.1 ml Acetone/ 125 ml bottle = 800 ppm
Resistance goes from ~100 ohms (no vapor) to ~ 4,000 ohms (with vapor)



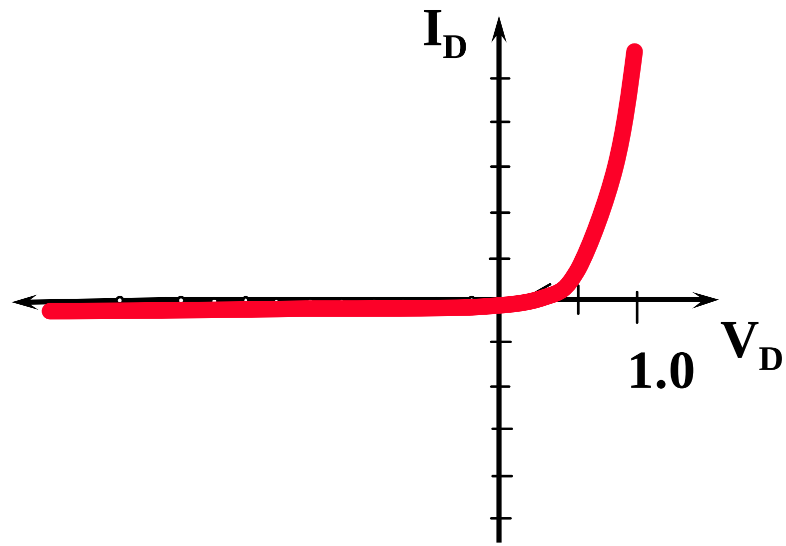
Sensor shows no response to 1 ppm acetone (just measurement noise)



DIODES - THEORY



SYMBOL



Diodes are like check valves. Current only flows in one direction (as shown by arrow in the symbol)

$$I_D = Io\,[EXP^{(-VD/Vth)}\ -1\ ]$$

Ideal Diode Equation

Io is a constant eg 1E-9 Amps
Vth is ~ 0.026 at room temperture

TESTING DIODES

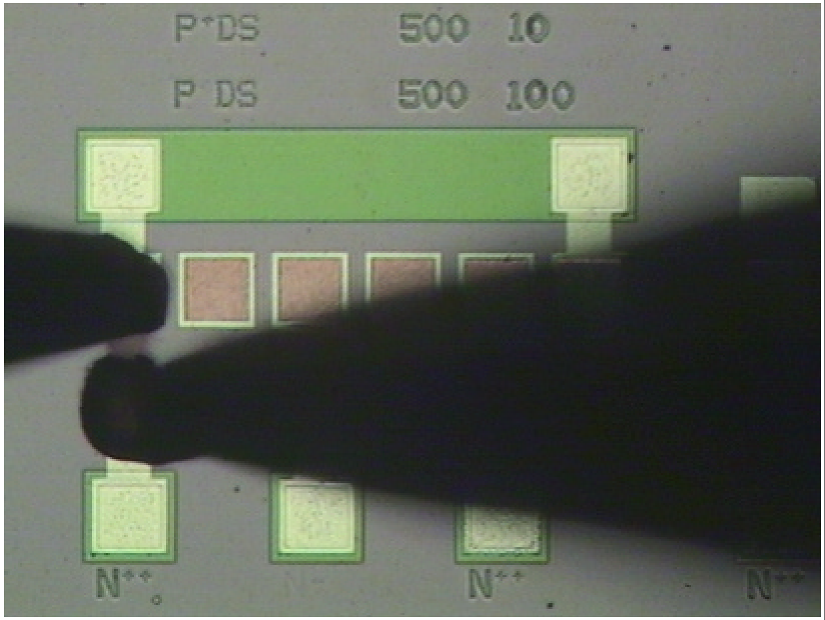
Diode I-V Characteristics

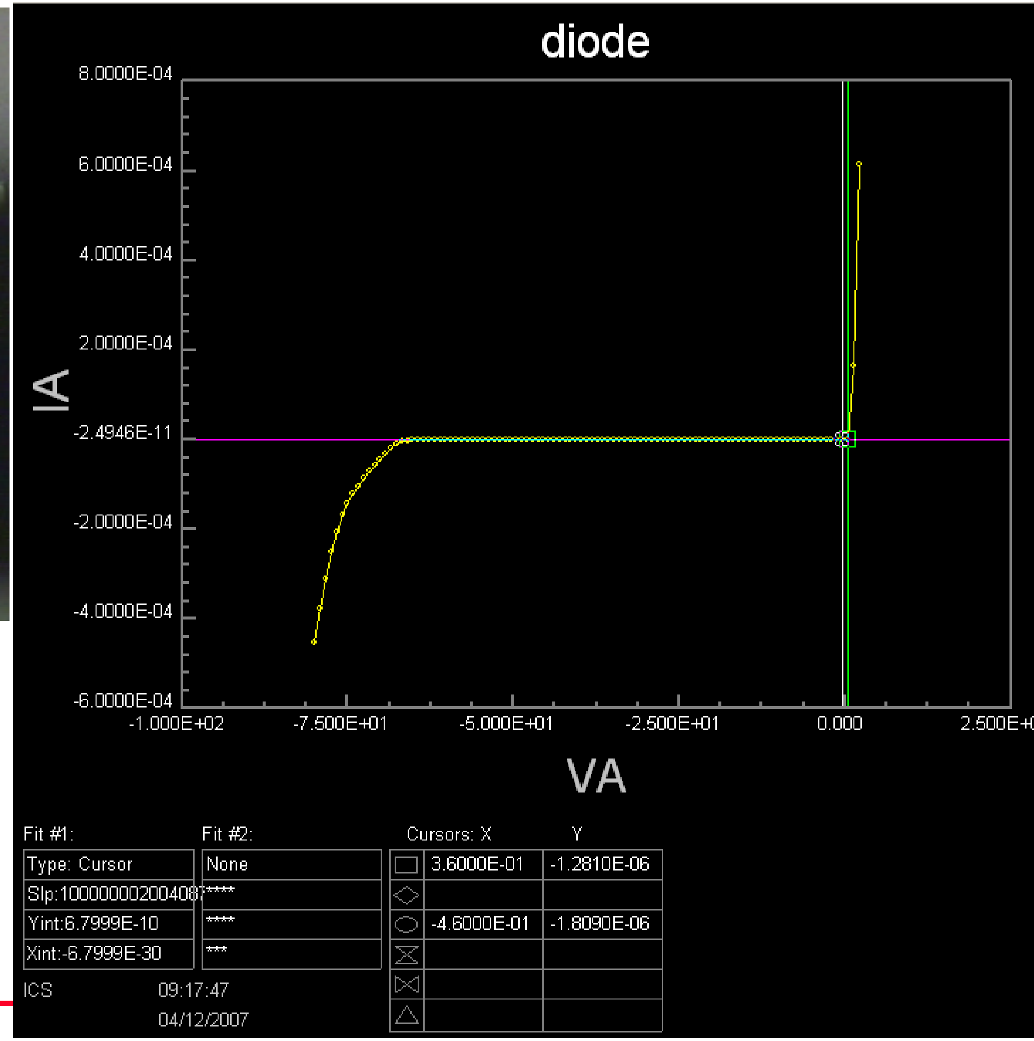
Testing a Diode as a Temperature Sensor

Testing a Diode as a Light Sensor

Testing a Diode as a Light Source (LED)

DIODE I-V CHARACTERISTICS





Nearby N++ contact to n type substrate allows us to use the resistor as a photo diode

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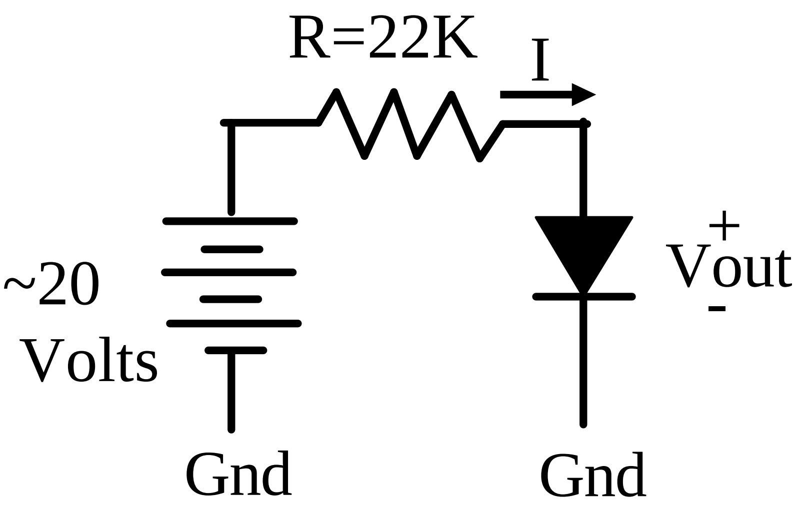
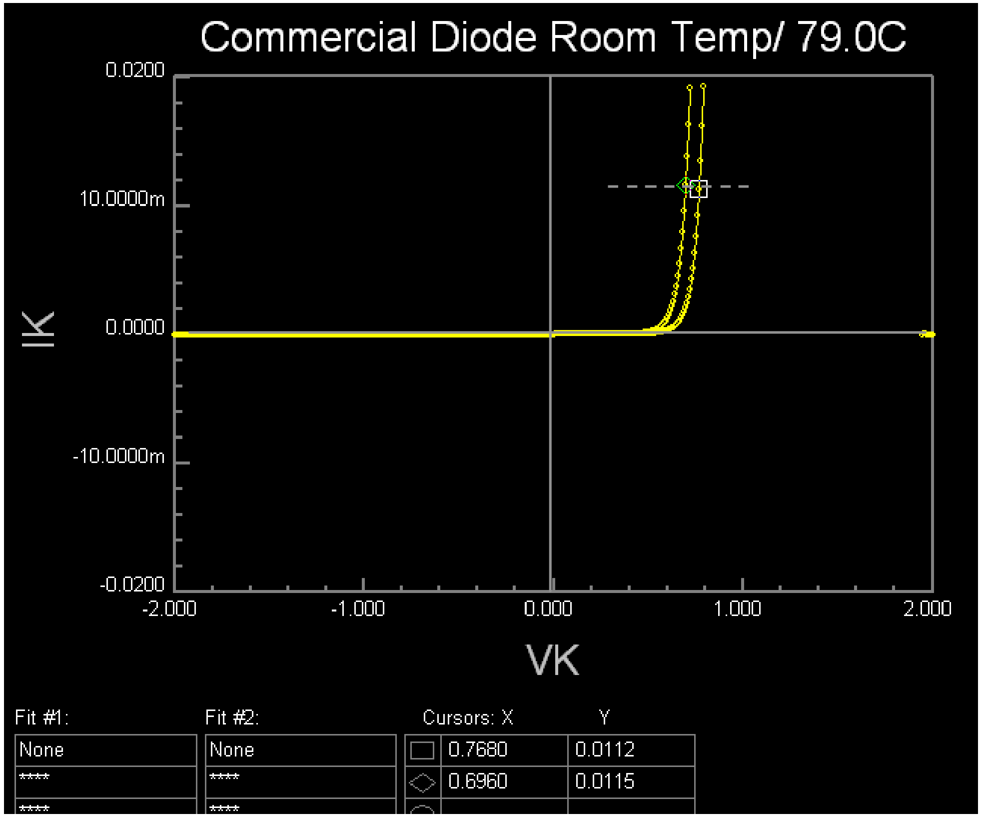
DIODE TEMPERATURE SENSOR

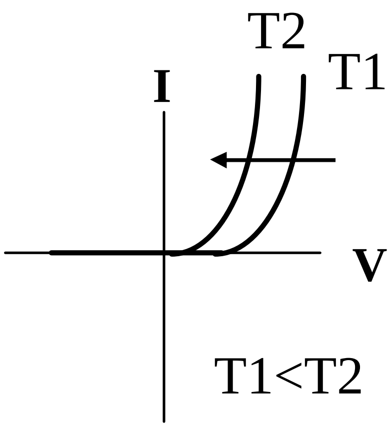


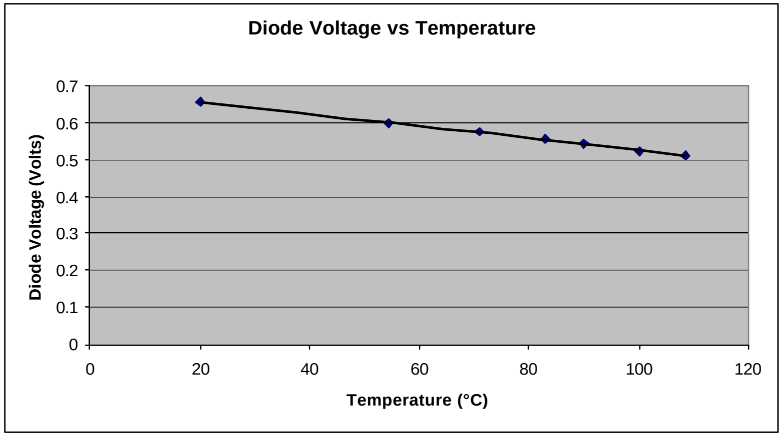


Idea is to keep the current constant and measure Vout vs T

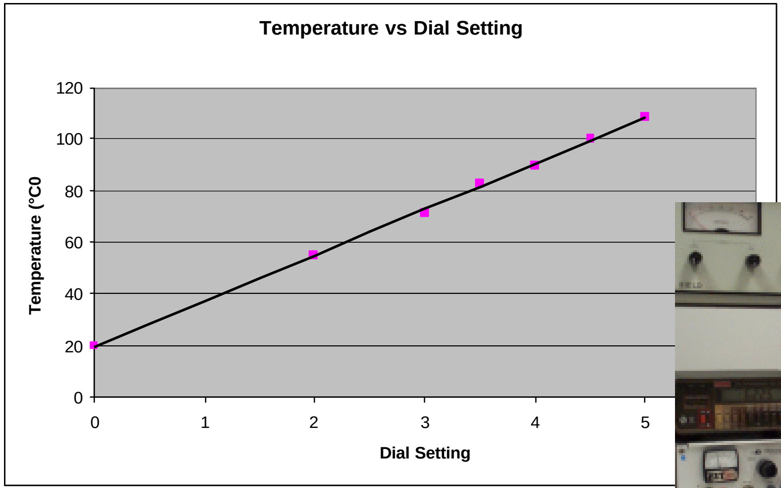
Compare with theoretical -2.2mV/°C

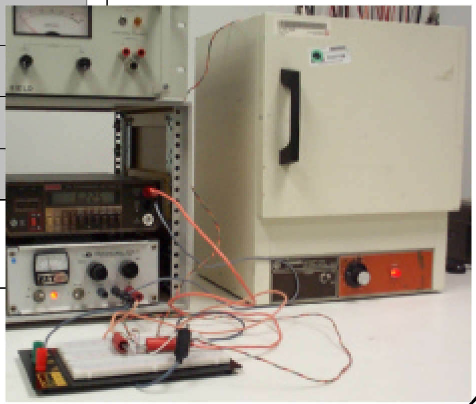
DIODE TEMPERATURE TEST DATA





Dial	Vdiode	Temp
0	0.6539	20
0.5		
1		
1.5		
2	0.601	54.5
2.5		
3	0.5747	71
3.5	0.556	83
4	0.543	90
4.5	0.5246	100
5	0.51	108.5



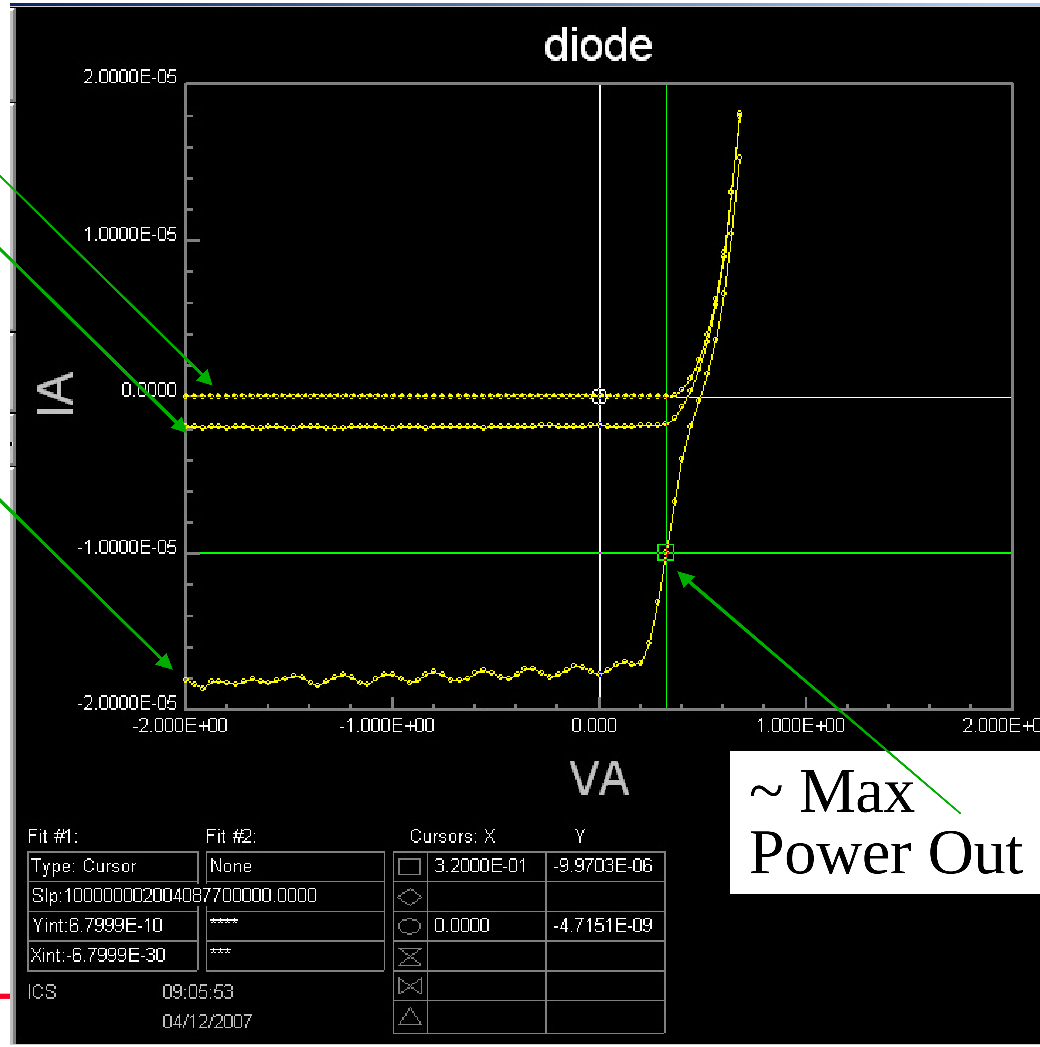


DIODE RESPONSE TO LIGHT

No light

Medium light

Full light



~ Max Power Out

P=IV = (9.97e-6)(0.32)

=3.19µwatts

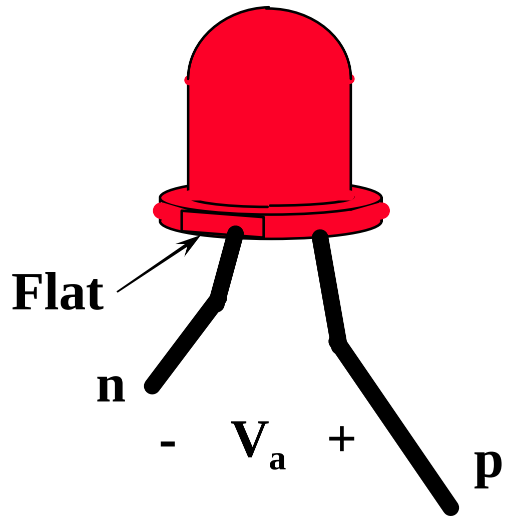
P/unit area =

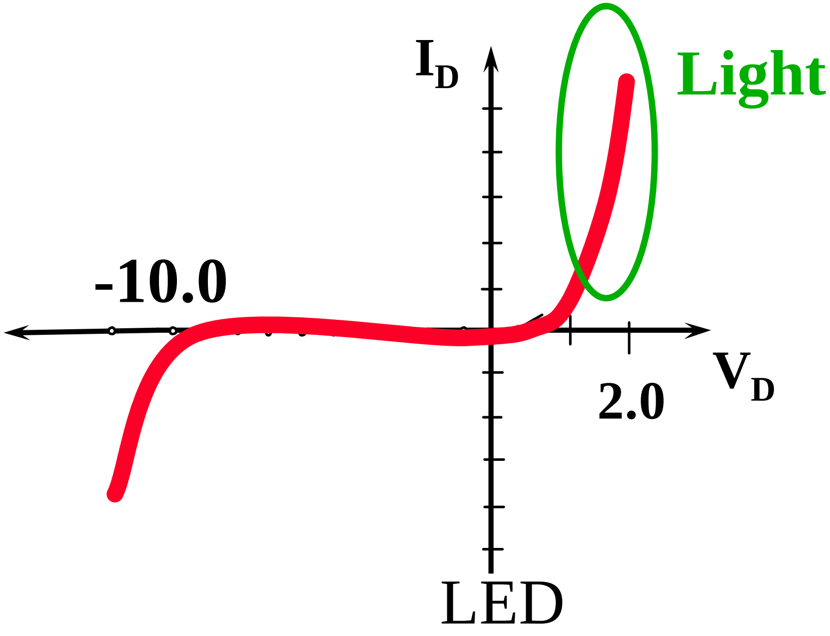
3.18e-6/500e-6/100e-6

= 63.8watt/m^2

TESTING LIGHT EMITTING DIODES

Light Emitting Diode -LED





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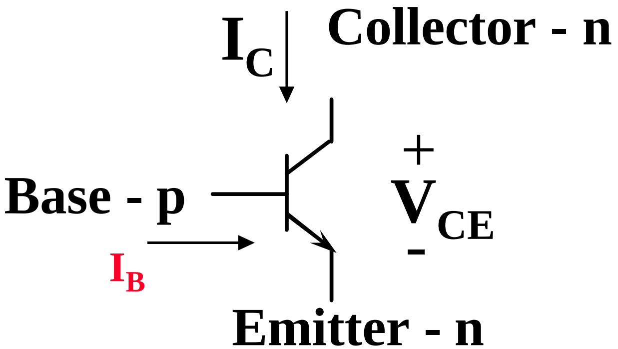
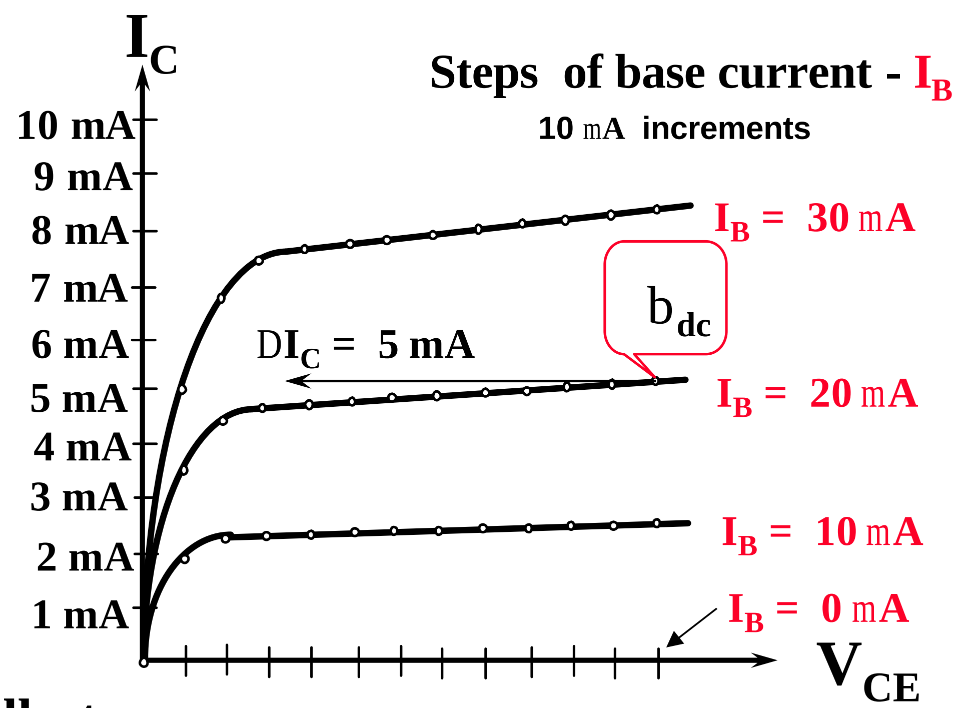
TESTING TRANSISTORS

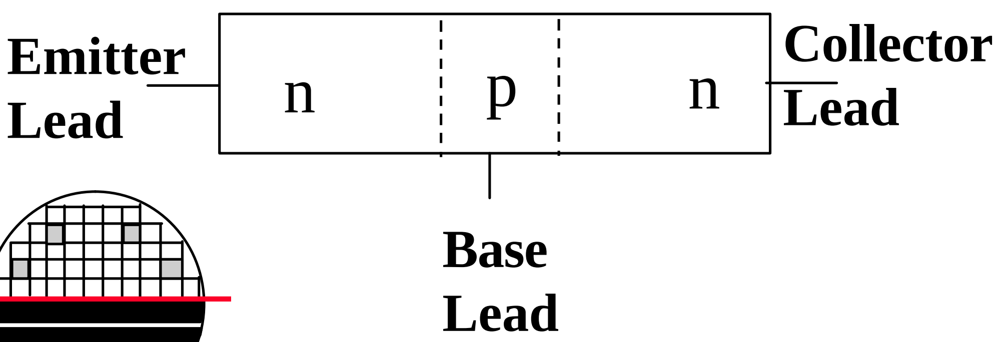
Theoretical BJT I-V Characteristics
Testing a BJT
Theoretical MOSFET I-V Characteristics
Testing a MOSFET

THEORETICAL BJT I-V CHARACTERISTICS

Schematic Symbol







Current Gain (Beta)

$B_{dc} = I_C / I_B = 5\text{ mA} / 20\ \mu\text{A} = 250$

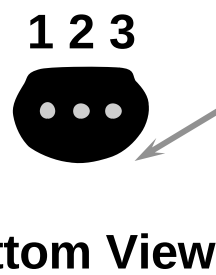
DEFINITIONS

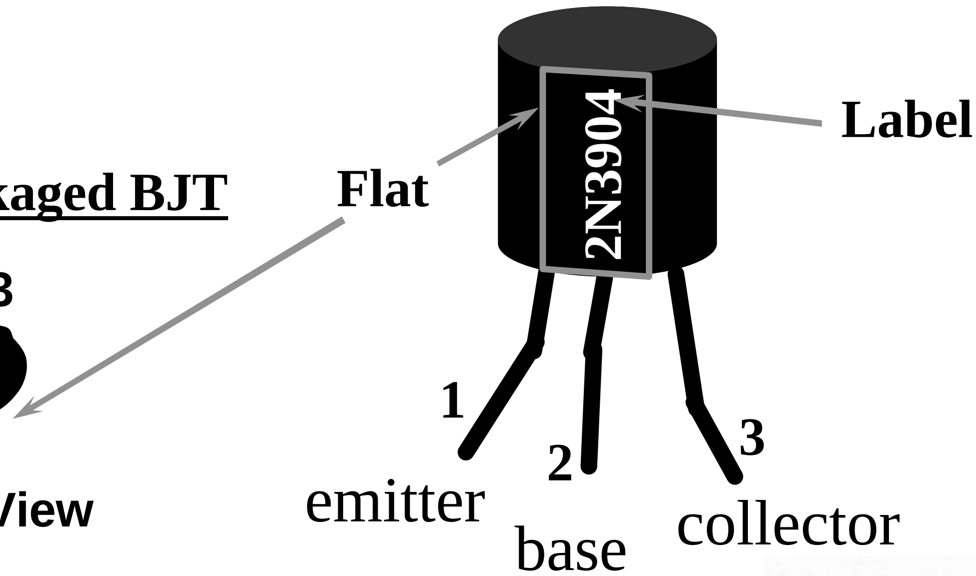
- **Bipolar Junction Transistor - (BJT) Both holes and electrons participate in the conduction of current, hence the name bipolar.**
- **Minority carrier - In a p-type semiconductor electrons are the minority carrier type, in an n-type semiconductor holes are the minority carrier type.**
- **Emitter - Emits minority carriers into the base region of a BJT. For example, in an NPN BJT the n-type emitter, emits electrons into the p-type base. The emitter usually has the highest doping levels of the three regions of a BJT.**
- **Base - Thin region (<1µm) which is used to control the flow of minority carriers from the emitter to the collector**
- **Collector - Collects the minority carriers that make it through the base from the emitter. The collector usually has the lightest doping concentrations of the three regions.**
- **DC Beta (b_{dc}) - The ratio of the steady-state collector current to the base current. (Current Gain)**

$$b_{dc} = I_C / I_B$$

BIPOLAR JUNCTION TRANSISTORS

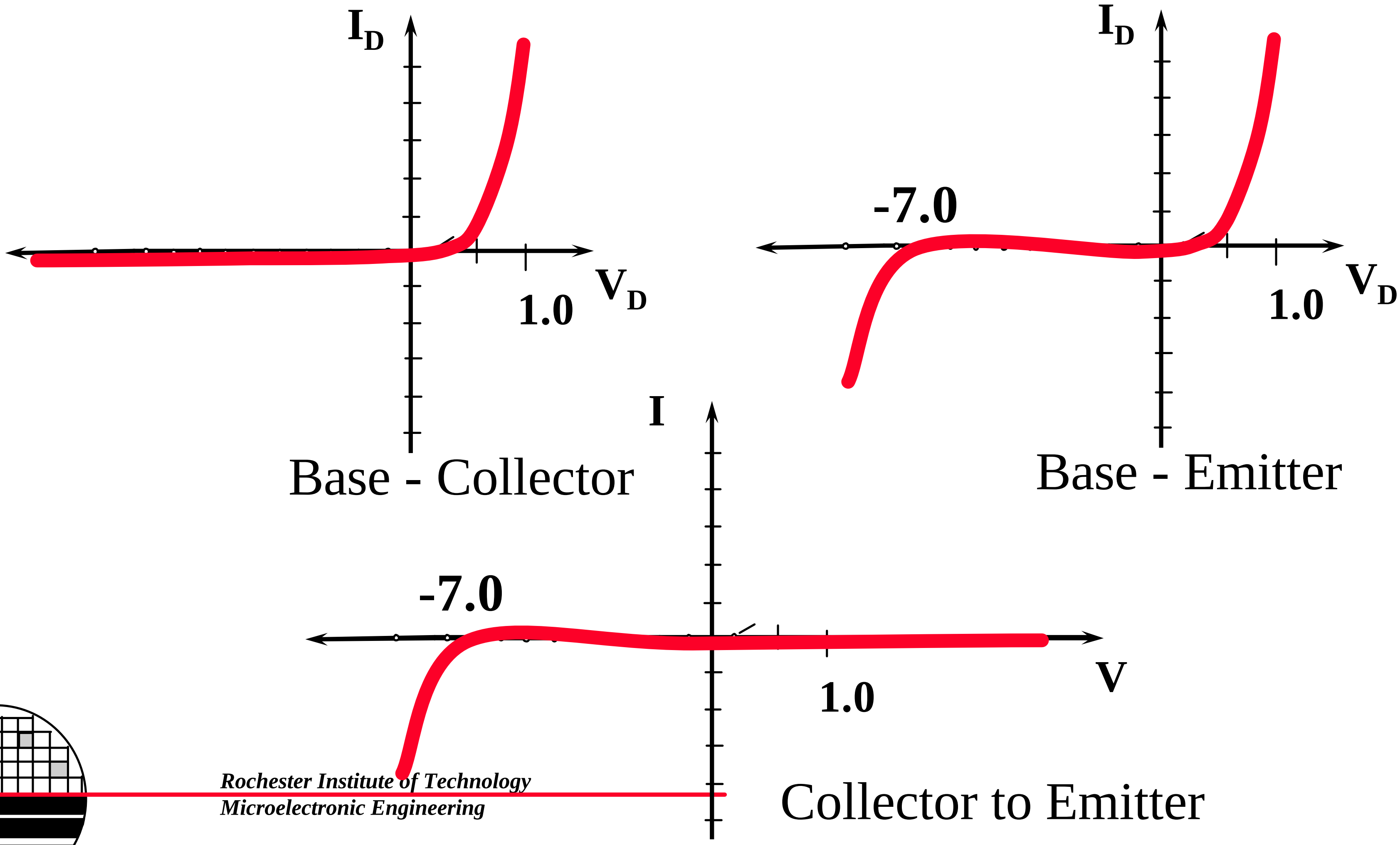
Discrete Packaged BJT





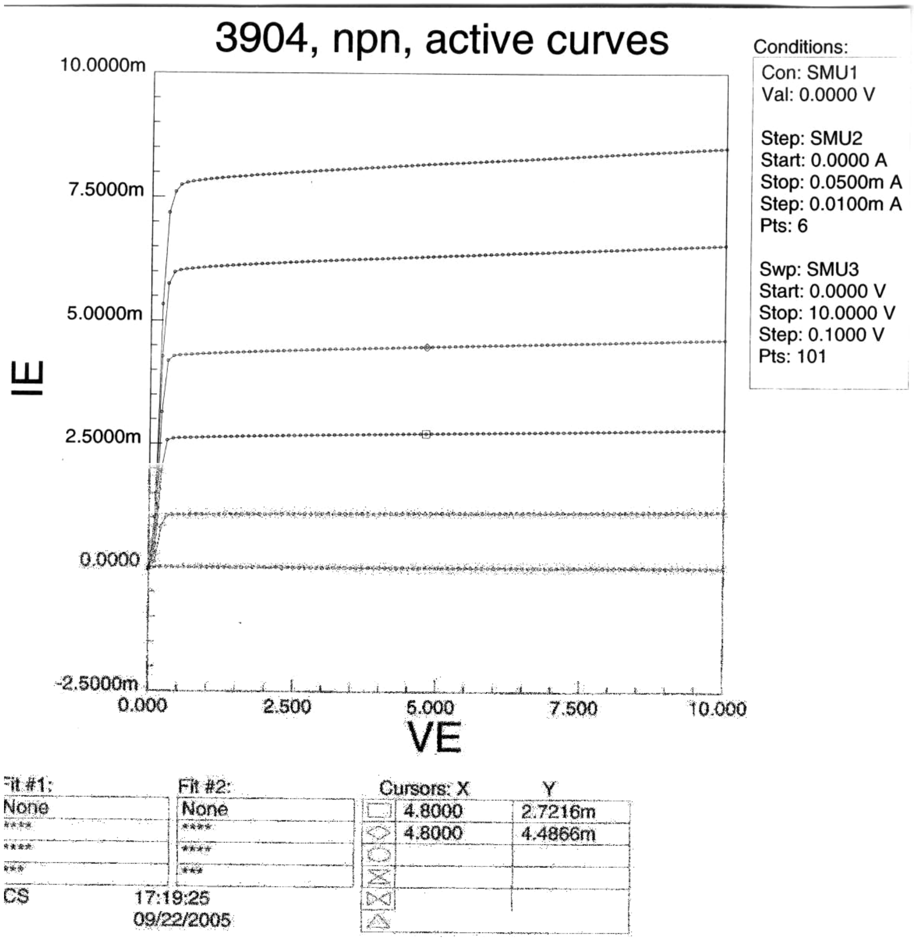
2N3904
NPN
Gain ~200
Maximum VCE = 30V
Maximum IC = 800mA
Maximum Power = 1.8watts

TESTING A BJT



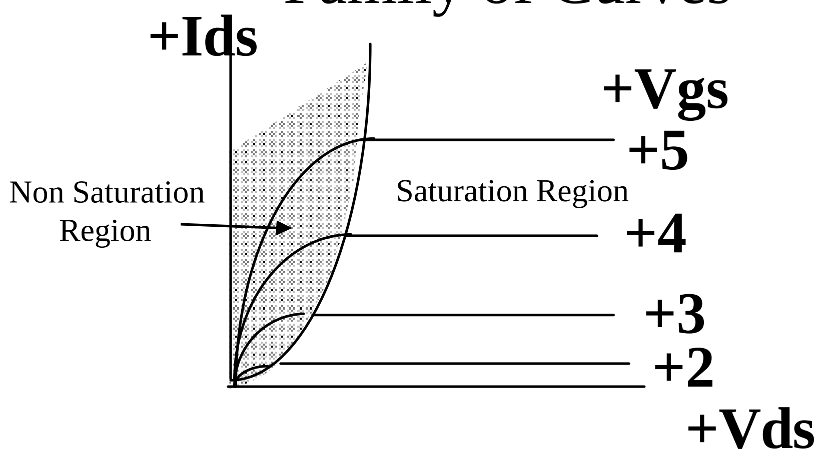
TESTING A BJT

General purpose npn 2N3904

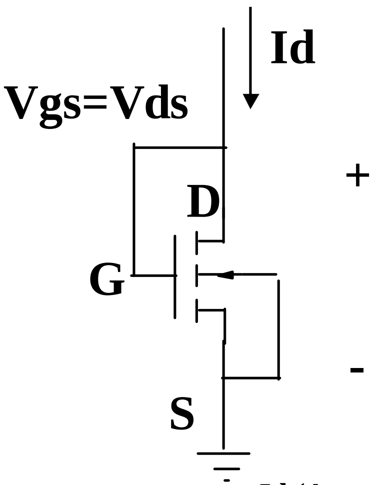


THEORETICAL MOSFET I-V CHARACTERISTICS

Family of Curves

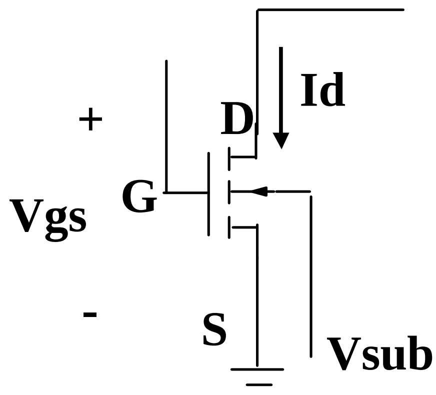


Saturation Region

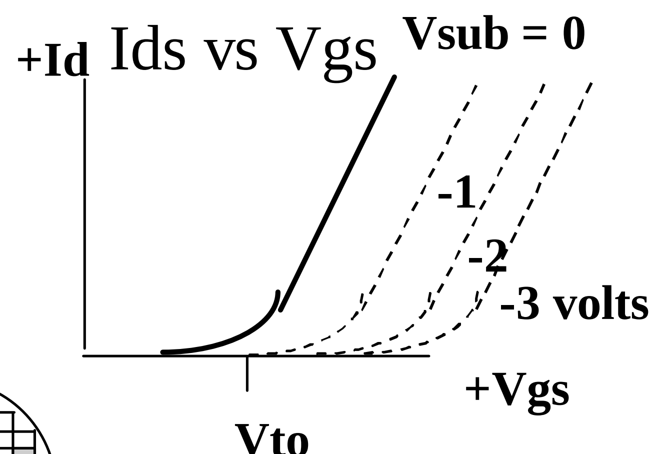


Non Saturation Region

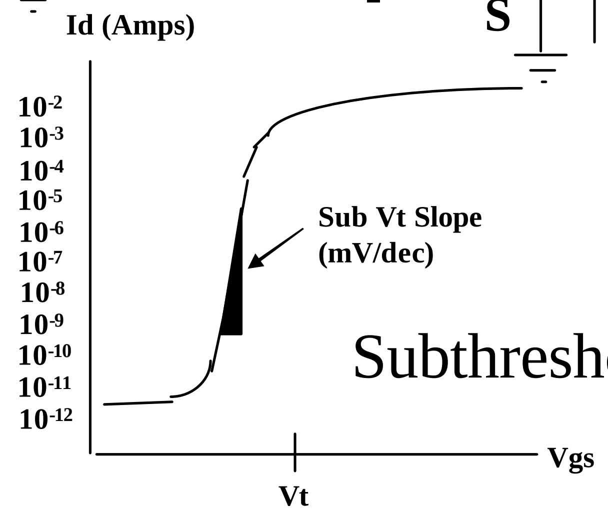
Vd = 0.1 Volt



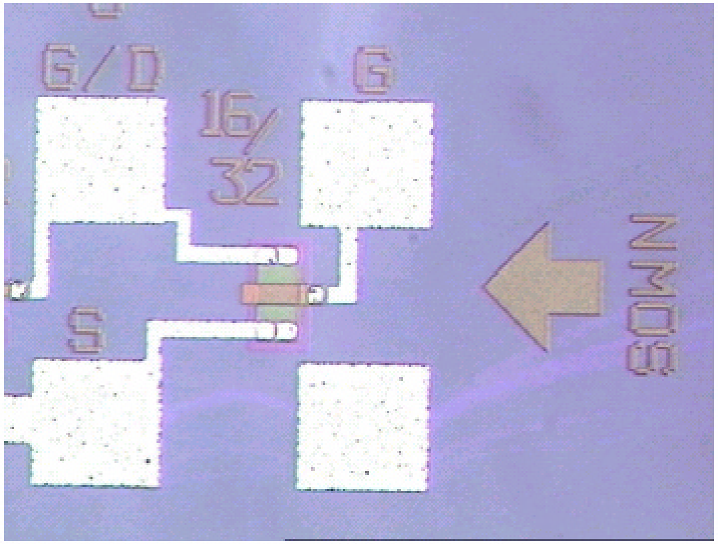
Ids vs Vgs

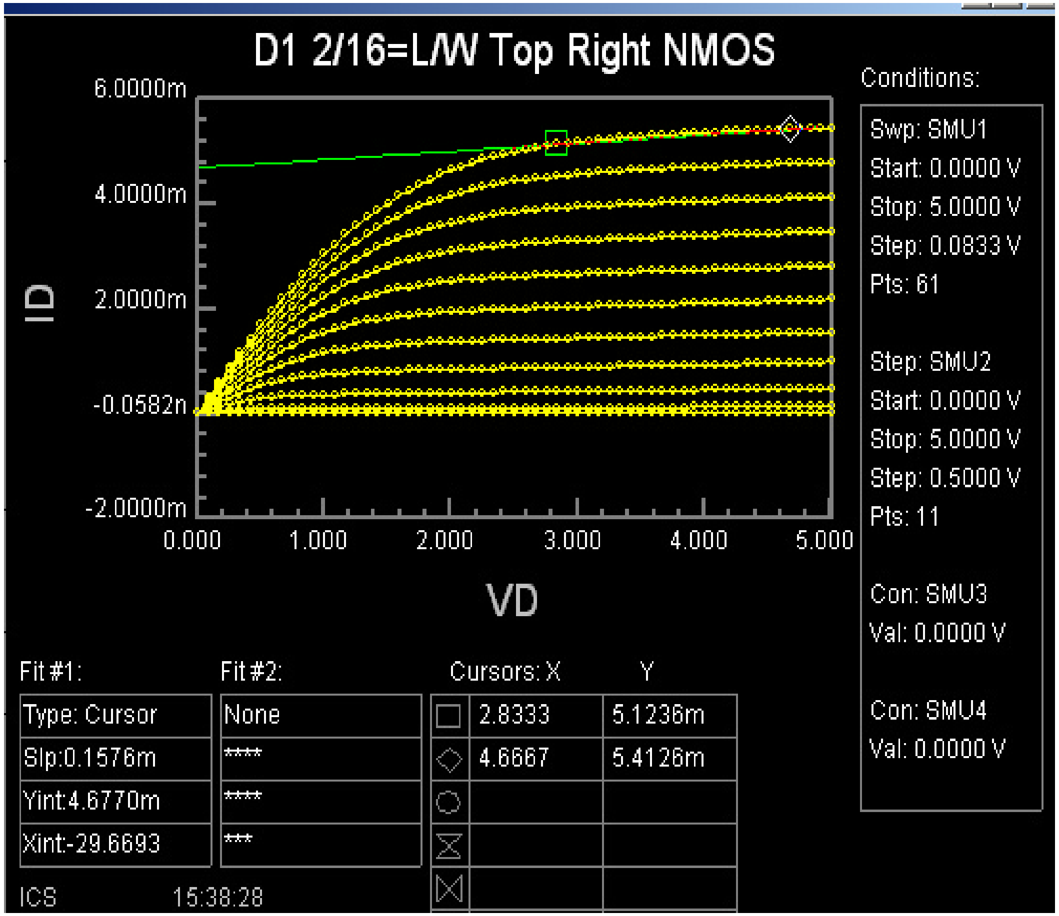


Subthreshold



TESTING A MOSFET

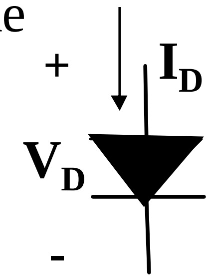




REFERENCES

1. Dr. Fuller's webpage http://www.rit.edu/~lffeee
2. more

REVIEW QUESTIONS



1. A 220 ohm resistor has 1.5 volts across it. The current through the resistor is a)1.5A b) 0.0068A c) 68mA d) 0.147A
2. A diode has voltage of -1.5 volts applied to it. The current is a) zero b) infinite c) 1A d) 68 mA
3. An npn BJT biased in the forward active mode has base current of 20 µA and current gain of 150. What is the collector current? a) zero b) infinite c)300 µA d)3 mA
4. A nMOSFET has 5 volts on the gate. The transistor is: a) On b) Off c) saturated d) subthreshold
5. A diode can be used to sense temperature. If the temperature increases the voltage VD: a) increases b) decreases c) stays the same d) none of above
6. A resistor can be used to sense temperature. If the temperature increases the resistance value will: a) increases b) decreases c) stay the same d) none of above