Failure Analysis of Semiconductor Devices: A Systematic Approach

This study of failure modes correlates DC measurements at the device terminals with the nature of the internal damage

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This study employs a detailed current/voltage (I/V) measurements at the device terminals in order to characterize the nature of the failure of the device. It is intended to relate this I/V deviation to physical damage which may be observable using various analysis techniques. It is strongly recommended that this approach be used prior to physical analysis, so that we have a good idea of what, where and how we can achieve a conclusive and comprehensive understanding of the failure mode.

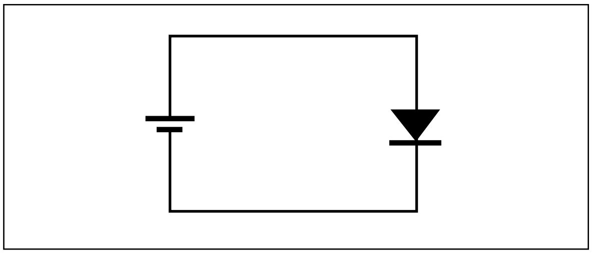
Due to the length of the complete report, this particular article is only intended to be the initial step of analysis, describing the detailed DC measurements.

When a semiconductor device fails electrical tests, a physical analysis is required to find out the reasons for this failure. Ordinarily the electrical tests are either with gain, or functional measurements which provide very little knowledge on the physical position of the failure on the chip. The prescribed approach employs a detailed DC current/voltage (I/V) analysis of the device terminals in order to pinpoint the failures on the circuit. It is intended to relate the deviation of the I/V plots to the damage of the elements on the chip. .

Failure analysis procedure

An outline of the general procedure for failure analysis is given here, with a brief description of the purpose of each procedure.

- *Package examination* — Physical examination is conducted for physical abuse or damage.
- *Functional tests*
- *X-Ray analysis* — When open or shorts are present on plastic parts, X-Ray analysis is used for checking broken wires.
- *DC tests* — Detailed I/V measurements are conducted to check the deviation from a normal unit.
- *Decapsulation* — Careful decapsulation is essential in order to preserve the nature of the damage. Decapsulation should not damage the package integrity.
- *Optical examination* — Good photography is essential for damage observation.
- *Electrical measurements after decapsulation* — Additional tests may be needed after device examination has been done.
- *Further analysis* — Using SEM, voltage contrast SEM, IR spectroscopy, etc.
- *Cross section* — Physical cross section, focused ion beam (FIB) cross section, etc



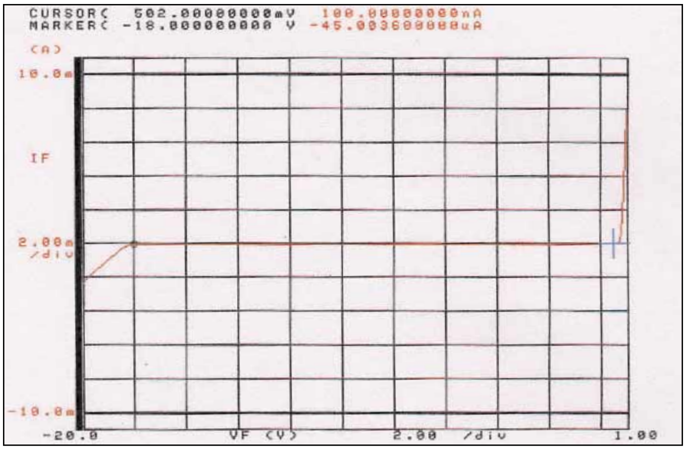
▲ **Figure 1. DC equivalent circuit for a diode.**

Detailed DC measurement at device terminals

A simple illustration of the device terminal with a p-n junction diode will be shown here. Various damages of this junction are simulated using simple resistor elements of known value.

Figure 1 is an equivalent circuit schematic for a diode. The DC I/V plots in Figures 2 and 3 illustrate the characteristics of a good diode. The red color curve is the DC I/V plot and the

▲ **Figure 2. I/V curve (red) and resistance curve (blue) of a good diode.**



▲ **Figure 3. I/V plot scaled to show breakdown voltage and forward voltage drop.**

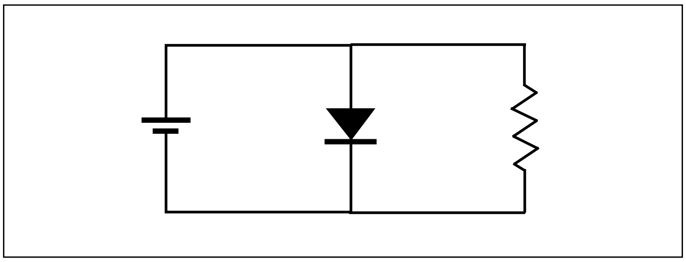
blue color curve is the resistance curve for the diode.

In Figure 1, the red curve and the blue curve above are both in log scale. In Figure 2, the red curve is in linear scale. From the graph, the break down voltage is about –18 V, and the forward bias voltage is ~700 mV.

Diode parallel with resistor (leaky diode)

The equivalent circuit with a resistor connected parallel with the diode as shown in Figure 4. This is to show how a diode behaves if there is a leakage of current or even a short circuit in a diode. A leakage diode is formed when there is physical and/or chemical change on the metal layer.

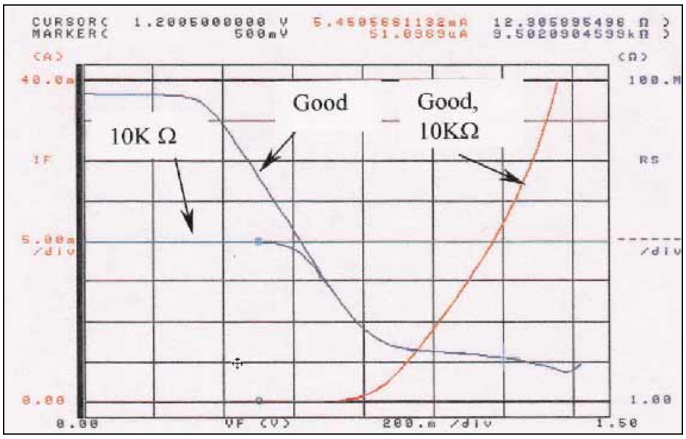
The DC I/V plots in Figures 5 through 12 illustrate the characteristics of a leakage diode with different resistor values. A good diode curve is plotted for comparison purposes. The red color curve is the DC I/V plot and the blue color curve is the resistance curve for the diode. The DC I/V plot in Figure 5 shows a good diode curve and a leaky diode curve. The red curve is in linear scale and the blue curve is in log scale. For the leaky diode with a 10 kohm parallel resistance, the DC I/V curve (red) falls on the same line as a good diode curve. For this case, a bad diode may not be determined. However, the resistance curve (blue) shows a very clear leakage of the diode as a 9.5 kohm resistance.



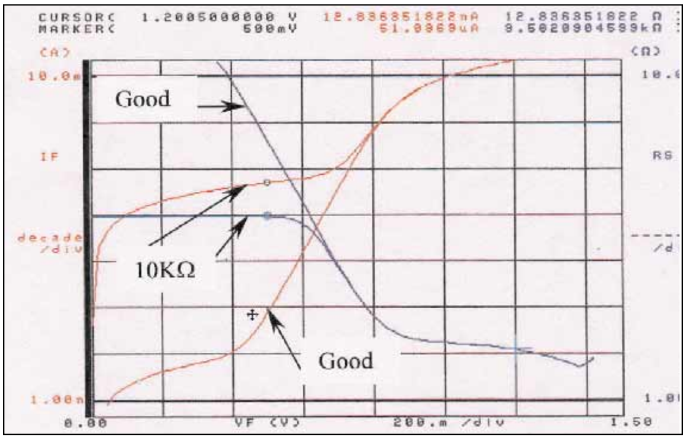
▲ **Figure 4. Equivalent circuit of a leaky diode with a parallel resistor.**

The red curve and the blue curve in Figure 6 are both in log scale. The log scale of the DC I/V curve (red) clearly shows the leakage for the diode with a resistance value of 9.5 kohm In this case, log scale is needed in order to distinguish the damaged diode from a good diode.

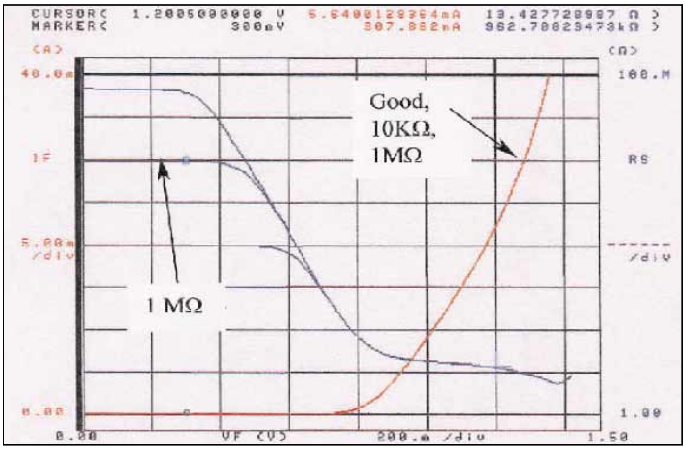
The red curve in Figure 7 is in linear scale and the



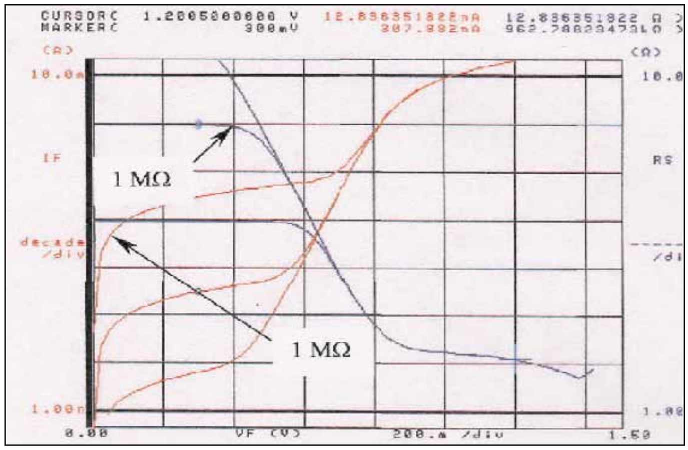
▲ **Figure 5. Leaky diode I/V curve with 10 kohm parallel resistance.**



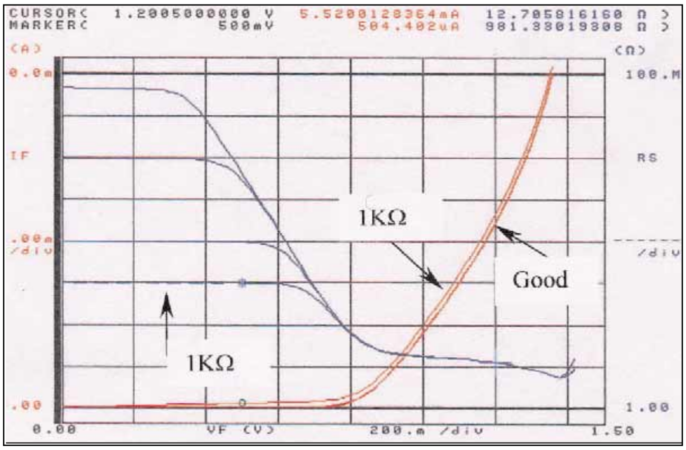
▲ **Figure 6. Resistance curve of a leaky diode with 10 kohm parallel resistance.**



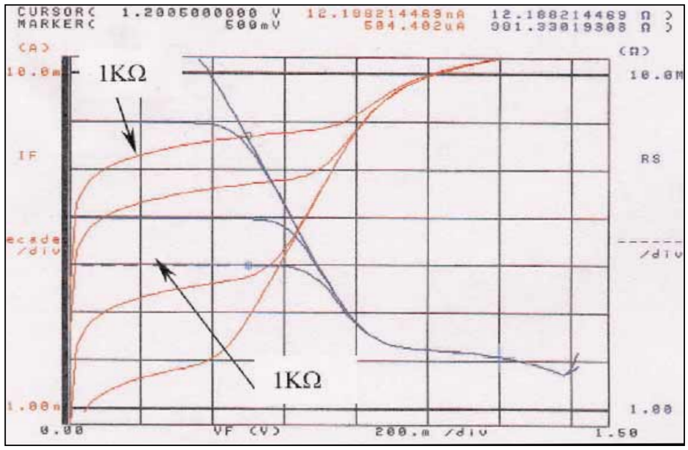
▲ **Figure 7. I/V curve with leakage represented by a 1 Mohm resistor.**



▲ **Figure 8. A log scale graph clearly shows the leakage due to 1 Mohm parallel resistance.**



▲ **Figure 9. I/V curves with leakage represented by a 1 kohm resistor.**



▲ **Figure 10. A log scale graph shows the greater leakage with the lower parallel resistance.**

blue curve is in log scale. For a leaky diode with a 10 Mohm parallel resistance, the DC I/V curve (red) falls on the same line as a good diode curve. However, the resistor curve (blue) shows a very clear leakage of the diode as a 962.78 kohm resistor.

The red curve and the blue curve in Figure 8 are both in log scale. The log scale of the DC I/V curve (red) clearly shows the leakage for the diode with a resistance value of 962.78 kohm.

The red curve in Figure 9 is in linear scale and the blue curve is in log scale. As the leakage increases with 1 kohm parallel resistance, it begins to show the difference on the DC I/V curve (red) when compared with the good diode curve. The resistor curve (blue) now shows the leakage diode with a resistance value of 981 ohms.

The red curve and the blue curve in Figure 10 are both in log scale. The log scale of the DC I/V curve (red) clearly shows the leakage for the diode with a resistance value of 981 ohms.

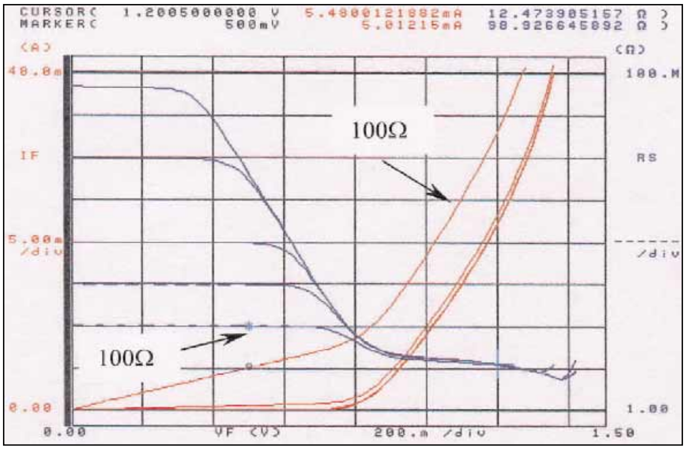
The red curve in Figure 11 is in linear scale and the blue curve is in log scale. As the parallel resistance decreases, the leakage increases. Clearer differences are shown on the DC I/V curve (red) when compared with the good diode curve (red). The resistor curve (blue) clearly shows the leakage of the diode with a resistance value of 98 ohms.

The red curve and the blue curve in Figure 12 are in log scale. The log scale of the DC I/V curve (red) clearly shows the leakage for the diode with a resistance value of 98 ohms.

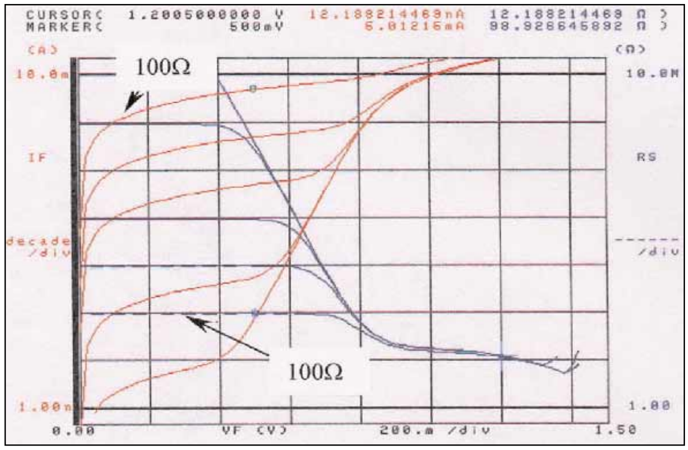
Diode in series with resistor (high series resistance)

A resistor is connected in series with the diode as shown in Figure 13. This is to show how a diode behaves if there exists a high series resistance on a diode. A high series resistance diode formed when there is physical and/or chemical change on the metal layer. Physical change includes displacement of the contact metal. When metal contact is displaced, a short or open circuit will result. Chemical effects include the change of metal properties such as melting.

The DC I/V plots in Figures 14 through 19 illustrate



▲ **Figure 11. 100 ohm parallel resistance show clear variation on the I/V curve.**



▲ **Figure 12. On a log scale, the leakage due to 100 ohm parallel resistance is clearly shown.**

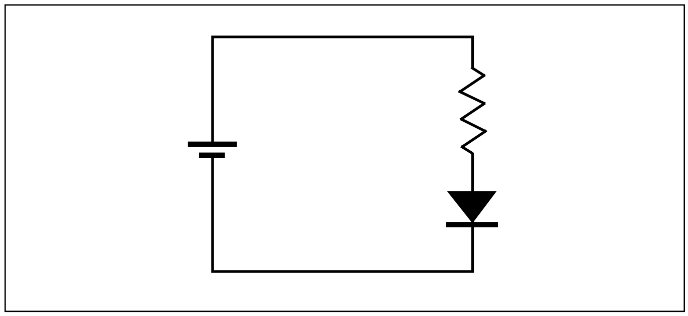
the characteristics of a high series resistance diode with different resistor values. A good diode curve is plotted on the same graph for comparison purposes.

The red curve is the DC I/V plot and the blue curve is the resistance curve for the diode. There are two scales of format for the plots. This is to avoid hidden information from the curve.

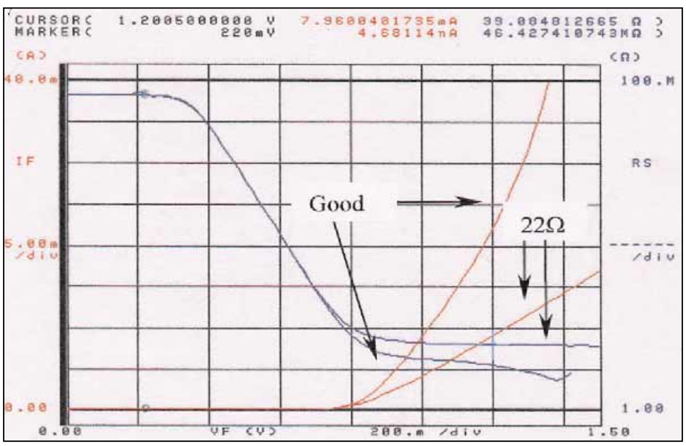
The examples in Figures 14 through 19 illustrate several degrees of high series resistance. The smaller value the series resistance, the smaller the damage of the diode. However, a small damage on a diode may be causing serious damage on the overall circuitry. This is because each of them is dependent on one another. For example, if this damaged diode occurs on the first level of the overall circuitry, the final electrical characteristic will be multiplied to a factor accordingly. The electrical characteristics will then be related to the visual examination results. With detailed and clear electrical test results along with the visual examination results, the failure mode will then be determined.

The DC I/V plot in Figure 14 shows a good diode curve and a series resistance diode curve. The red curve is in linear scale and the blue curve is in log scale. A diode with a 22 Ohm series resistance DC I/V curve (red) is obviously offset from a good diode curve. The resistor curve (blue) shows an offset with a 39 ohm resistor. The 39 ohm resistance value includes the internal resistance of the diode itself plus the series resistance. In this case, the diode internal resistance value is 39 – 22 = 17 Ohms.

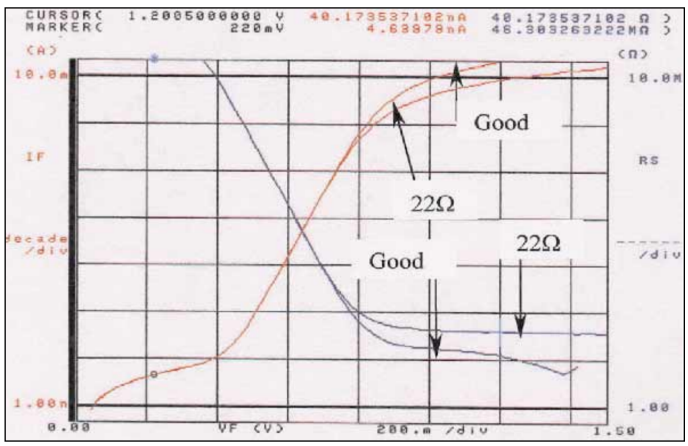
The red curve and the blue curve in Figure 15 are both in log scale. The log scale of the DC I/V curve (red)



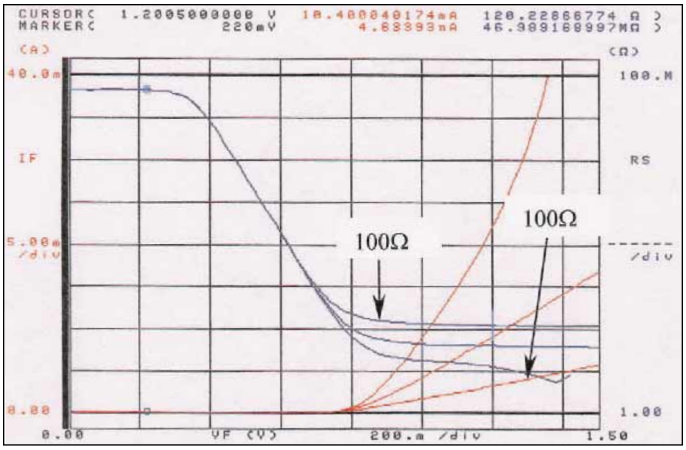
▲ **Figure 13. High series resistance equivalent circuit.**



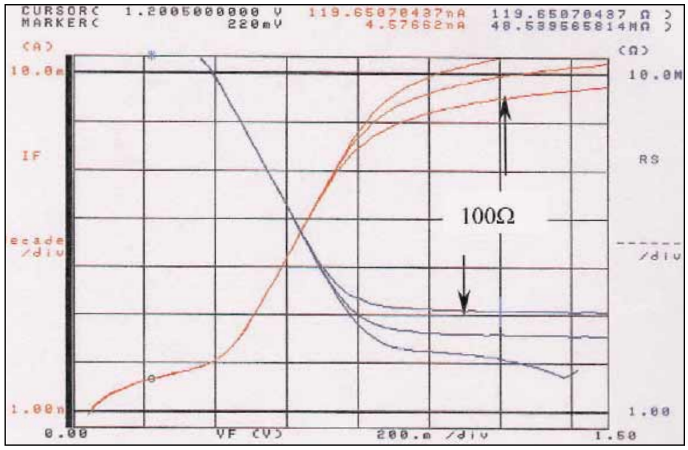
▲ **Figure 14. I/V curves with a good diode and one with an additional 22 ohms series resistance.**



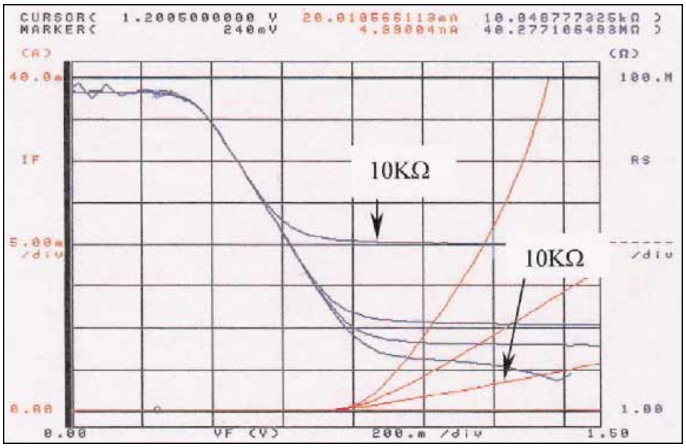
▲ **Figure 15. The resistance plot shows an offset equivalent to 39 ohms (diode internal resistance plus 22 ohms loss.)**



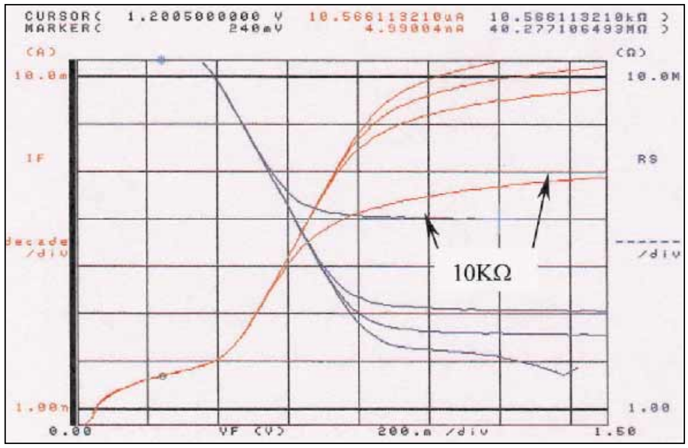
▲ **Figure 16. I/V plots comparing a good diode with an additional loss due to 100 ohms series resistance.**



▲ **Figure 17. Resistance plot shows the additional 100 ohm series resistance**



▲ **Figure 18. I/V curves with the bad diode having 10 kohm series resistance.**



▲ **Figure 19. Resistance plot shows a large deviation from behavior of a good diode.**

clearly shows a series resistance diode (40 ohms).

The red curve in Figure 16 is in linear scale and the blue curve is in log scale. A diode with a 100 ohms series resistance DC I/V curve (red) is offset from a good diode curve to the right hand side. The resistor curve (blue) shows an offset with a 120 ohm resistor.

The red curve and the blue curve in Figure 17 are in log scale. The log scale of the DC I/V curve (red) clearly shows a series resistance diode (119 ohms).

The red curve in Figure 18 is in linear scale and the blue curve is in log scale. A diode with 10 kohm series resistance DC I/V curve (red) is offset from a good diode curve to the right hand side. The resistor curve (blue) shows an offset with a 10 kohm resistor.

The red curve and the blue curve in Figure 19 are in log scale. The log scale of the DC I/V curve (red) clearly shows a series resistance diode (10 kohm).

The curves in Figures 14 through 19 illustrate the difference of the electrical characteristics of a diode due to various failure modes. A resistance (blue curve) is needed in order to show the degree of leakage of a diode. Although a log scale of the DC I/V curve is needed in order to show a small leakage of a diode, a small leakage will also result in the device's failure.

Summary

The detailed electrical measurements outlined in this article are needed for verification of damage observed by physical inspection of the failed device. By comparing the electrical characteristics with the visual examination results, a better confirmation of the failure mode will be obtained.

When the correlation between electrical measurements and physical damage is known, fewer failed parts require inspection to determine what portions of the device fabrication and assembly process require improvement. ■

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