REEDHOLM

APPLICATION NOTE

AN-112

High Resistivity (>5MΩ) Measurements

I) Overview

A customer driven requirement to make high resistivity measurements at high speed led to a battery of measurements on an RI-40 test system. Discrete resistors were used in order to illustrate test system hardware and software dependencies. When wafer based test structures are measured, characterization needs to extend to prober effects as well as parasitic conduction to other test structures. With typical prober noise, and reasonable isolation of test structures, test speeds should be comparable to that described in this note.

Graphs presented in this report were generated in EMAGE, software used for device and system characterization. The performance table was populated with data taken in EMPAC, software used for dc parametric measurements of devices and processes.

Before a definitive performance table could be generated, it was necessary to determine system capabilities as well as how the device under test interacted with the system. Results were generated for several bias conditions: 100V, 50V, and 7V.

II) System Characterization

As making high resistance measurements requires good low current measurements, systemic low current noise performance needs to be characterized with and without the probe card installed. While the probe card can be a source of error, it can be altered or changed to improve performance. However, the output analog cable is fairly immutable, so it was installed for all characterization.

A) Background Noise

A standard EMAGE tests permits digitization of current versus time with a variety of test conditions. Figure 1 shows the background current noise of the demo system with no voltage applied during the 100 milliseconds that current was measured.

Data was taken at approximately one-millisecond intervals, thereby permitting reconstruction of the line frequency (60Hz and harmonics) noise that was around 700pA peak-to-peak.

B) Response Time

Figure 2 shows the same test run with 50V applied simultaneously with starting to take data. Response time with 7V is the same but with a lower starting point. The system quickly returns to steady state, and open circuit noise is not a function of applied voltage.

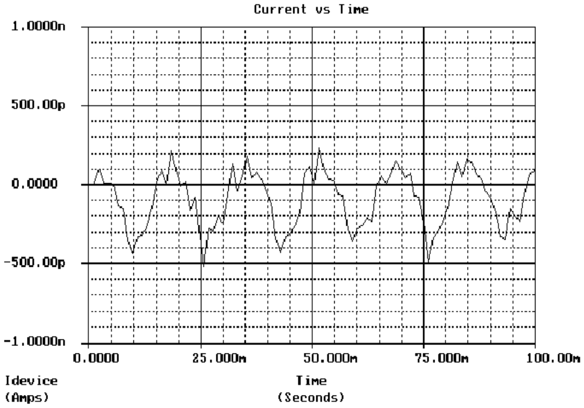

Figure 1 – Open Circuit a.c. Noise Current

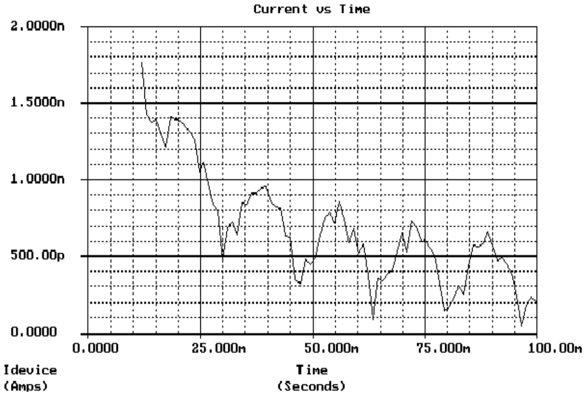

Figure 2 – Transient Response to 50V

III) Selecting a Testing Method

A) Response Time When Forcing Current

Figure 3 illustrates that forcing current and measuring voltage is an inherently slow test method. A current of 104nA was applied across a 480MΩ resistor to produce a final value of 50V. The roughly exponential response has a time constant of about 125 milliseconds and takes 350 milliseconds to get within 10% of the final voltage. As can be seen in figure 4, with 15nA being forced, response time is not proportional to the current. That is because an instrumentation guard amplifier drives much of the cable capacitance; however, around 300pF of unguarded capacitance needs to be driven by the test current. Vertical and horizontal scales are different for the plots to simplify reading the graphs. Note that figure 4 shows response to 7V.

For either, one would have to wait more than one second to assure measurement error <0.1%. Taking readings earlier might produce repeatable results, but only because the factors controlling time response would be stable short term. However, even if measurements were repeatable, they would be wrong.

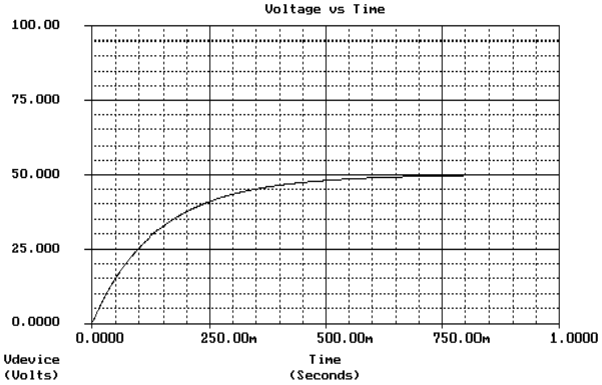

Figure 3 – Response Time, Forcing 104nA

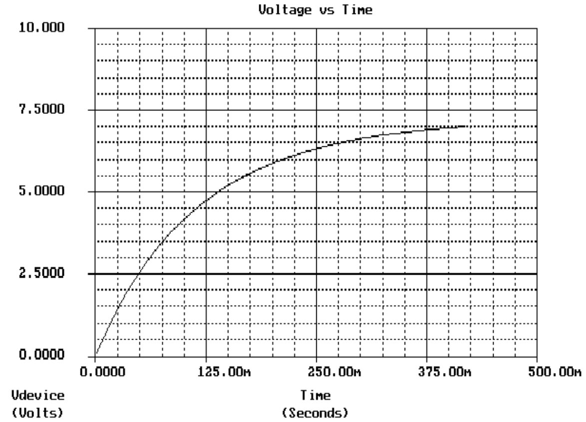

Figure 4 – Response Time, Forcing 15nA

B) Response Time When Forcing Voltage

Figures 5 and 6 show how much faster a force voltage, measure current technique is when measuring a high value resistor. For the 480MΩ test device, notice that the vertical scales have been expanded to cover only 10nA, or 10% of the final current when 50V is applied. Of course, when only 7V is applied, the same scale covers around 50% of the final current.

For both figures, the time scale has been expanded to show that even after 10 seconds, there is no change in the measured current. Also notice that current is indistinguishable from noise within 500 milliseconds.

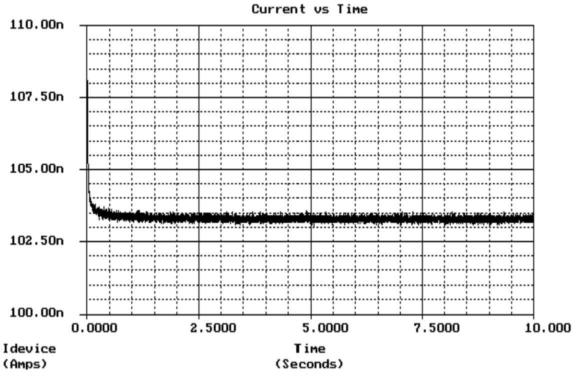

Figure 5 – Response Time, Forcing 50V

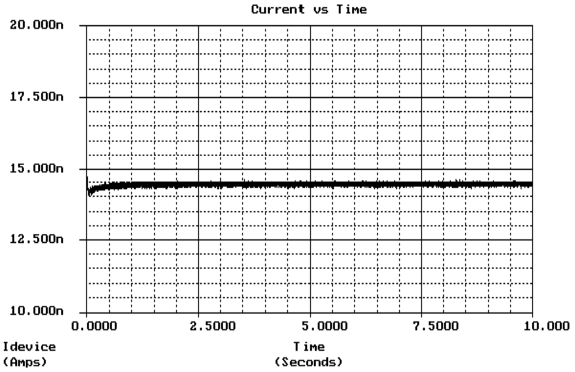

Figure 6 – Response Time, Forcing 7V

IV) Determining Test Conditions

A) Conversion to Resistance

EMAGE permits mathematical operations on data plots. That capability was utilized to create figure 7 by dividing the stimulus, 50V, by the measured current of figure 5. Since current is the denominator, calculated resistance was lower during the period immediately after voltage was applied. If one did not wait for final settling, measured resistance would be lower than its actual value.

Figure 8 shows resistance calculated from figure 6 when 7V was forced. Peak-to-peak variability is much higher than in figure 7 because a.c. pick-up noise is independent of forced voltage. Thus, the higher the voltage, the better—as long as the higher voltage does not cause the device characteristics to change.

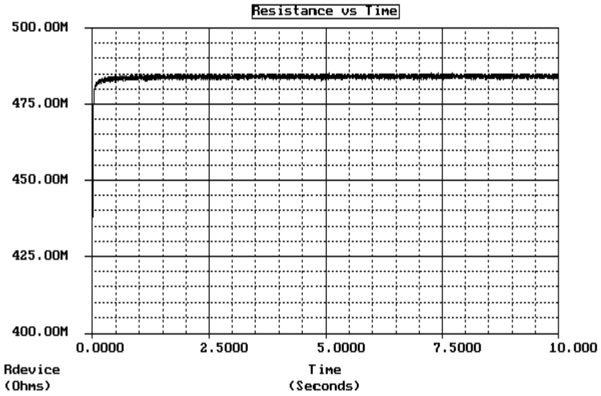

Figure 7 – Conversion to Resistance, Forcing 50V

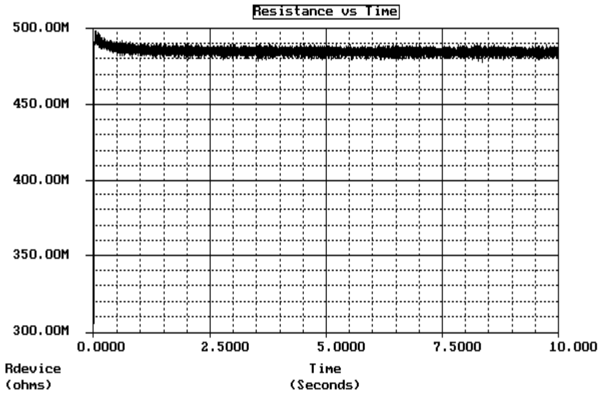

Figure 8 – Conversion to Resistance, Forcing 7V

B) Eliminating Effects of AC Line Noise

Because most of the noise was due to a.c. line pick-up, A/D readings averaged over a number of line cycles filter out much of the noise. Also, the sample and hold part of the A/D converter has a short aperture time which, coupled with rapid A/D conversion and accurate low-level timing code, permits extremely good a.c. noise rejection within one line cycle (16.67msec or 20msec, depending on power system). The number of A/D conversions per line cycle is computer speed dependent, and it is measured automatically during system initialization.

The synchronous measurement function was invoked in order to produce figure 9 when 50V was forced, and figure 10 when forcing 7V. Comparing figures 9 and 10 with figures 7 and 8 respectively, one can see that the a.c. line noise component is virtually eliminated.

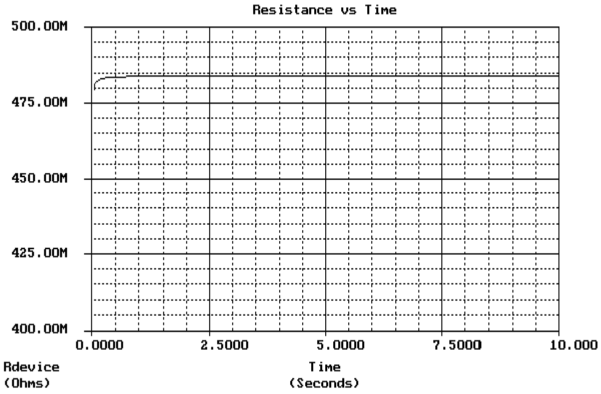

Figure 9 – Using Sync_Measure, Forcing 50V

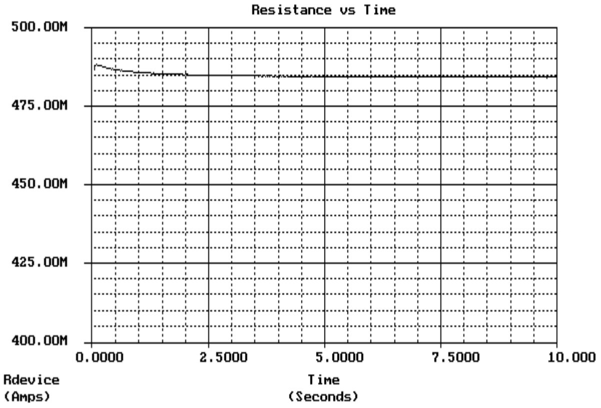

Figure 10 – Using Sync_Measure, Forcing 7V

C) Selecting Delay Times

With EMPAC, selection of delay time is very important. Otherwise, the very precise timing coupled with a constant environment can produce results that are wrong despite being extremely stable. For instance, the two preceding EMAGE plots show very repeatable current measurements immediately after a 7V or 50V step, but in both cases it takes a couple of seconds for the device current to stabilize within 0.1%. If test speed is important, the person setting up tests must understand interactions among accuracy, repeatability, and speed.

1) Times for 50V Bias

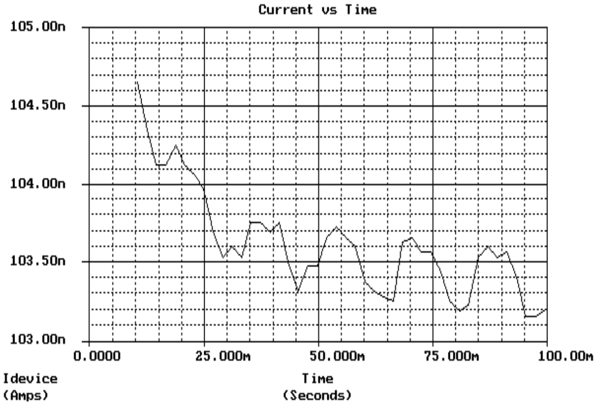

Figure 11 – Isolating Delay Time for 50V Bias

Figure 11 shows the first step in figuring delay requirements. After 30msec, current is ~103.7nA with 400pA peak-to-peak noise. Although not obvious in that graph, the current is still decreasing compared to its final value. The sync_measure function isn't used in this test because it delays the measurement by the integration time constant. If one needed to know the current or resistance within 1%, a delay of 25msec would be needed before a measurement was taken.

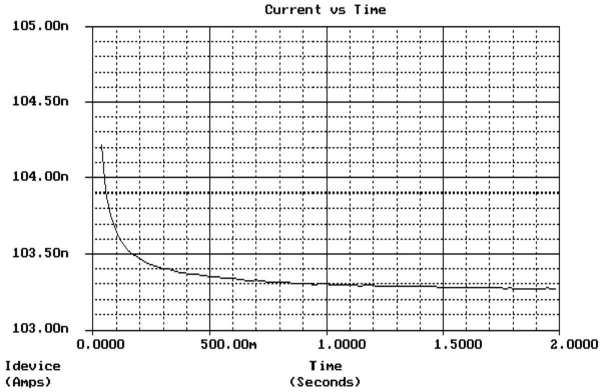

Figure 12 – Isolating 50V Delay with Sync_Measure

One line cycle using sync_measure was adequate for reducing uncertainty due to noise. In figure 12, current was 103.260nA after one second, with peak-to-peak noise of 16pA. Noise was thus <0.016%. However, current was still decreasing after two seconds, and declined another 0.1% before completely flattening after >10 seconds.

2) Times for 7V Bias

For comparison, figure 13 shows repeatable measurements averaging 14.2nA beginning ~8 milliseconds after application of 7V bias. That is somewhat misleading because peak-to-peak current at 400pA masks the continued decline in current evidenced in figures 6 and 10.

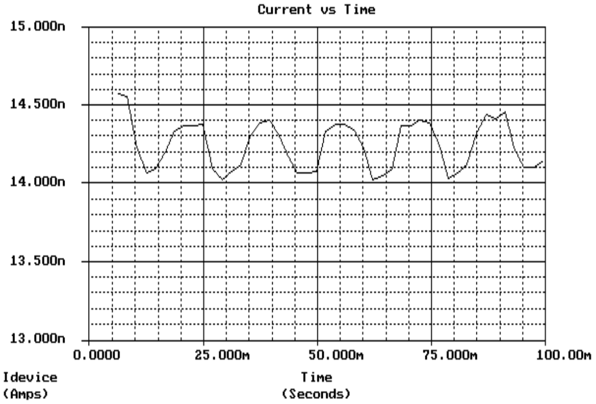

Figure 13 – Isolating Delay Time for 7V Bias

When sync_measure is used as shown in figure 14, it is obvious that the actual current is 14.41nA. Thus, it takes >100msec to be within 1% of the actual value, and the same 1 second delay as needed in figure 12 to be within 0.1%. Thus, bias voltage does not reduce delay time required to reach a given uncertainty.

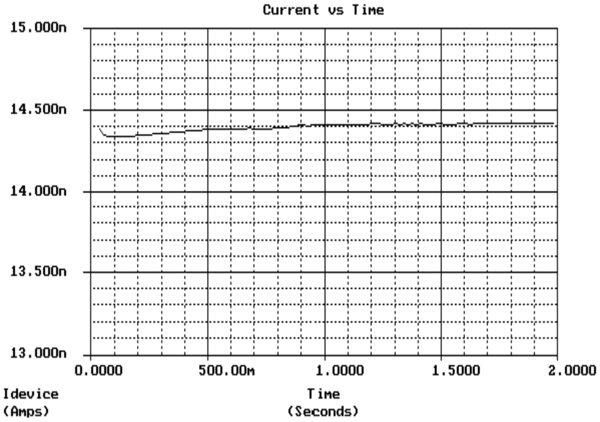

Figure 14 – Isolating 7V Delay with Sync_Measure

V) EMPAC Test Results with DMM

For optimum throughput-accuracy tradeoffs, the preceding type of characterization needs to be done before generating a test plan to gather parametric data.

With such characterization, guesswork that is otherwise used in determining test delays is eliminated. Furthermore, eliminating the guesswork eliminates surprises after a test plan has been approved for volume testing.

One of the nice features of EMPAC (and the Intranet version BUILD) is the ability to generate statistical characterization for tests along with precise test times.

Data in tables 1 and 2 were taken with that EMPAC feature. Notice that the target value of ~483MΩ took one second except for the first row in table 2. Without the timing characterization presented earlier, one would be mislead by the stability of the measurement, and average value, to conclude that the reading was accurate and set-up testing with a short 3 millisecond delay.

However, knowing that it was a coincidence that test results were so good would lead to picking conditions that do not take data on a steep portion of the time response curve. While results would look good during test plan development, it would take very little change in dielectric absorption or resistance to drop the current by almost 1% based on data in figure 14.

VI) Using the Picoammeter

Unlike the DMM, the picoammeter module (PAM) does not use digital averaging to eliminate line pick-up. Instead, an integrating A/D converter is used. A jumper is used to set the integration period for either 50 or 60Hz rejection. It takes the picoammeter ~75 milliseconds to perform an A/D conversion.

A) Noise

Figure 15 shows the open circuit noise using the picoammeter. Resolution is 50fA on the lowest range, so peak-to-peak noise is displayed as four least significant bits (0, -50fA, -100fA, and –150fA). Slanted lines are graphing artifacts connecting discrete data points.

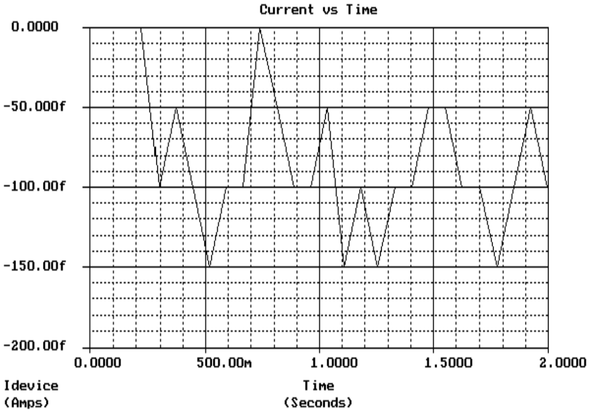

Figure 15 – Open Circuit AC Noise w/Picoammeter

Voltage Forced	Current Measured	Sync Measure	Test Delay	Test Time	Span of Current (1 σ)	Resistance Measured (MΩ)	Resistance Change (%)
7	14.50n	Y	1000ms	1031ms	9.3pA	482	0.06
7	14.72n	N	8ms	13.5ms	70.3pA	475	0.47
50	103.48n	Y	1000ms	1051ms	19.7pA	483	0.10
50	104.31n	N	29ms	34ms	215pA	480	0.45

Table 1 – Test Times and Variance for Resistor Measurement

Voltage Forced	Current Measured	Sync Measure	Test Delay	Test Time	Span of Current (1 σ)	Resistance Measured (MΩ)	Resistance Change (%)
7	14.5nA	Y	3ms	25.2ms	14.9pA	483	0.10
7	15.6nA	N	6ms	11.5ms	70.4pA	449	0.45
50	104nA	Y	15ms	37ms	232pA	479	0.22
50	104nA	N	15ms	20ms	343pA	471	0.32

Table 2 – Test Times and Variance for Resistor Measurement Using Shorter Delays

B) PAM Time Response

Figure 16 has EMAGE test results with the PAM. A 75-millisecond delay was used in addition to the conversion time. Notice that time response is the same for 7 or 45V bias. There are two sets of data, but they overlay so well that only one is visible at the plotted resolution.

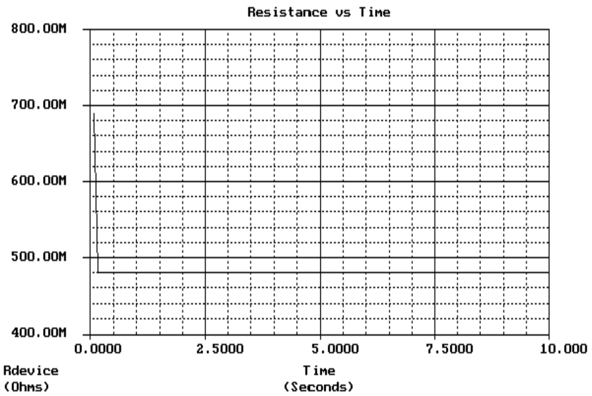

Figure 16 – 481.1MΩ (7V/14.55nA) and 480MΩ (45V/93.75nA)

C) EMPAC Test Results with PAM

Although 150 milliseconds is required for each test, the repeatability of the picoammeter shown in table 3 is quite good in 150 milliseconds, whereas the DMM-16 required 1000 milliseconds to achieve similar repeatability. Thus, the time it takes to get to 1% uncertainty is short, and if there were no device dependent dielectric absorption, the PAM would be faster than the DMM to 0.1% uncertainty. However stable they are, the results are low by ~0.75%, so a delay of around one second was needed even with the PAM to measure the correct value.

Voltage Forced	Current Measured		Resistance		Test Times	
					Delay	Total
(V)	Value	Variation (1σ)	Value (MΩ)	Variation (%)	(msec)	
45	93.85nA	12pA	480	0.03	75	157
7	14.55nA	5pA	480	0.01	75	157

Table 3 – Using the Picoammeter to Make Low Current Measurements

VII) Conclusions

The test results show that the Reedholm test systems can make high resistance measurements using several methods that can easily be set up by the user. Software tools permit investigation into the relations between accuracy, repeatability, and test throughput.

Information for this note was gathered using a Reedholm RI-40 D.C. Parametric Analyzer with 24 matrix pins, each of which can be tied to a picoammeter amplifier. The system was capable of sourcing ±200V and ±550mA. Modules such as the High Voltage SMU, High Current SMU, Capacitance Measurement Module, and Programmable Pulse Generators could have been installed without affecting the high resistance measurement performance. Information and specifications of Reedholm products are available at www.reedholmsystems.com.