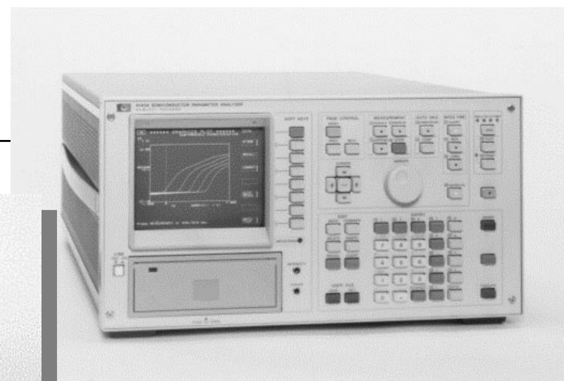
HEWLETT® PACKARD

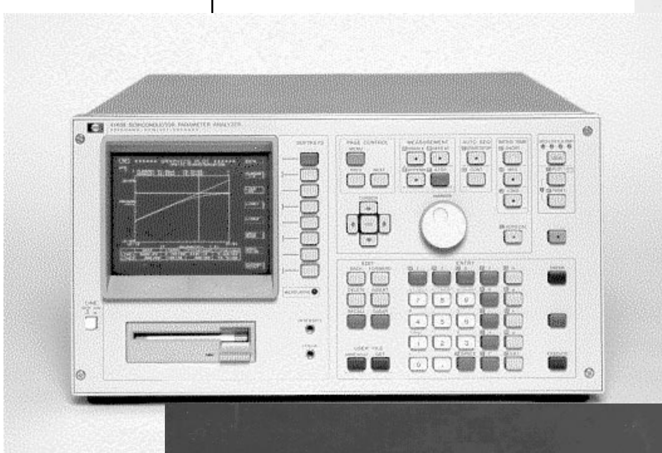
HP 4155B/4156B

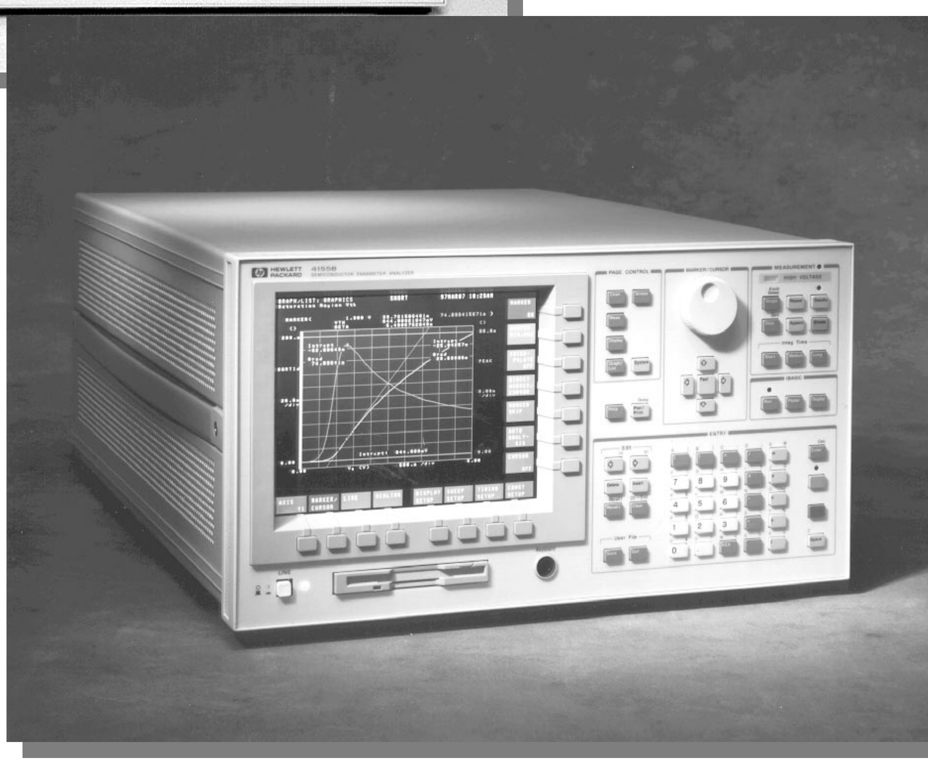
Semiconductor Parameter Analyzer

Product Note 4
Advantages over the HP 4145A/4145B

HP 4155B / 4156B
Semiconductor Parameter Analyzer







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1. Introduction

Recent decreases in device geometry require better performance and more capability in test equipment to evaluate the newest devices. The HP 4155B/4156B semiconductor parameter analyzer is our solution and has been developed incorporating customer input.

The HP 4145A/4145B semiconductor parameter analyzer featured good low current measurement performance and an easy-to-use interface. It has been a very popular measurement instrument for both device development and process evaluation in the semiconductor industry.

This product note describes the advantages of the HP 4155B/4156B and also compares it with the HP 4145A/4145B..

Wide Application Capability

The HP 4155B/4156B has increased measurement performance and also includes powerful functions useful for testing the next generation of semiconductor devices. The functions are accessible via an easy-to-use operating interface similar to the HP 4145A/4145B. Table 1 shows examples of measurements that can be made using the HP 4155B/4156B.

Table 1. Wide Application Capability of the HP 4155B/4156B

Application	Function / Performance for Wide Applications	HP 4145A/4145B	HP 4155B	HP 4156B
Low Current Measurement MOSFET Bulk Current Diode Reverse Current Gummel Plot of Bipolar Transistor	Resolution of Current Measurement	50 fA	10 fA	1 fA
	Zero Offset Cancel	No	Yes	Yes
	Range Mode Setting	Auto	Auto/Fix/ Limited Auto	Auto/Fix/ Limited Auto
Low Resistance Measurement Contact Resistance Line Width	Kelvin Connection*1	No	No	Yes
	Resolution of Voltage Measurement	100 μV*2	1 μV*2	1 μV*2
High Current Measurement	Output / Measurement Rage	100 V/100 mA	200 V/1 A*3	200 V/1 A*3
	Pulsed Sweep	No	Yes	Yes
Evaluation of Oxide Reliability by TDDB	Minimum Sampling Interval	10 ms	60 μsec	60 μsec
	Number of Sampling Points	1024 points	10001 points*4	10001 points*4
Hot Carrier Injection	Stress Mode	No	Yes	Yes
Evaluation of Surface State Using Charge Pumping Methods	Pulse Generator	No	Yes	Yes
Evaluation of Oxide Reliability Using V-Ramp / J-Ramp Tests	Step Delay Time	No	Yes	Yes
Efficient Data Handling	FDD Format	4145A:5.25"unique 4145B:3.5" LIF	3.5", LIF/ MS-DOS	3.5", LIF/ MS-DOS
	Auto Analysis	No	Yes	Yes
	LAN interface	No	Yes	Yes

*1 : Connection to reduce the voltage drop by residual resistance. Refer to "3. Accurate Low Resistance Measurement" in detail.
*2 : By the VMU of the HP 4145A / 4145B. By the VMU differential mode of the HP 4155B / 4156B.
*3 : The HPSMU is installed in an expander box
*4 : Measurement can continue until satisfying stop condition with thinned-out sampling. Refer to "4. Oxide Reliability Test by TDDB method" for details.

Ultra low current measurements, low resistance measurements, oxide reliability testing using the TDDB method and high power measurements are described in this product note. Techniques for making these measurements using the HP 4155B/4156B are described and performance and functions are compared to the HP 4145A/ 4145B.

The HP 4155B/4156B can also be used in many other applications that were difficult to measure using the HP 4145A/4145B. This product note does not describe all of these applications. Refer to the application notes listed in Table 2 for more detailed descriptions of each application.

Efficient Data Handling

The HP 4155B/4156B includes functions that help make analyzing the data and creating test reports on your PC easier and more efficient, as shown in the last column of Table 1. The auto analysis function, one of the new features of the HP 4155B/4156B, can extract and automatically display the parameters after a measurement. Using this function, you can obtain accurate parameter data and eliminate missing operations and readings.

The HP 4155B/4156B includes an MS-DOS compatible disk drive to help you save and transfer the measurement data to your PC. You can then analyze the data and create test reports using your favorite software. In addition, the HP 4155B/4156B can access the setup and measurement files of the HP 4145B from a LIF formatted disk, so you can use previously saved measurement setups and data.

To manage setup and measurement data more efficiently, LAN capability is a standard feature on the HP 4155B/4156B. This results in faster data transfer and having the files on an NFS server makes them much easier to manage. Now files can also be shared between multiple HP 4155B/4156Bs.

To configure the network environment, refer to Product Note 2 in Table 2 for more detail.

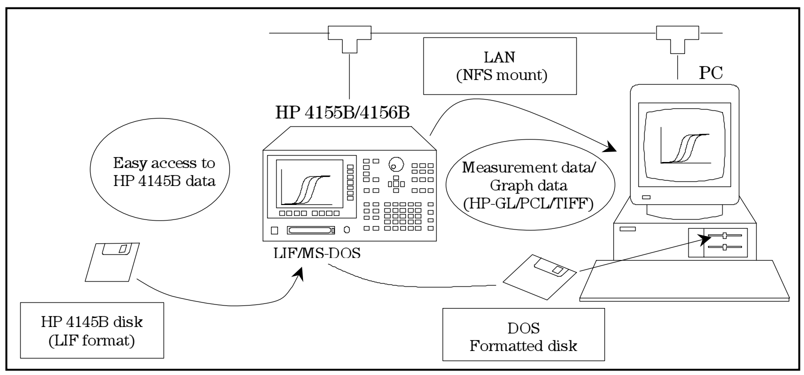

Fig 1. Efficient Data Handling

Table 2. Technical Application Literature

Application	Technical Literature		Pub. No.
Low Current	AN 4156-1	Ultra Low Current DC Characterization of MOSFETs at the Wafer Level	5963-2014E
	AN E5250A-1	Low Current Measurement with HP E5250A Switch Mainframe	5964-9112E
Low Resistance	Product Note 3	Prober Connection Guide	5966-4185E
Hot Carrier Injection	AN 4156-3	Evaluation of Hot Carrier Induced Degradation of MOSFET Devices	5963-1111E
	AN E5250A-2	Evaluation of Hot Carrier Induced Degradation of MOSFET Devices	5964-9113E
Evaluation of Surface State Using Charge Pumping Methods	AN 4156-9	Evaluation of Surface State Using Charge Pumping Methods	5964-2195E
Evaluation of Oxide Reliability Using V-Ramp/J-Ramp Tests	AN 4156-8	Evaluation of Oxide Reliability Using V-Ramp/J-Ramp Tests	5963-1248E
Electromigration Using the SWEAT	AN 4156-7	Evaluation of Electromigration Using the SWEAT Procedure	5963-1110E
Evaluation of Flash Memory Cell	AN 4156-4	Evaluation of Flash Memory Cells	5965-5657E
Incoming Inspection	AN 4156-6	Optimizing the Incoming Inspection of Semiconductor Devices	5963-2364E
Efficient Data Handling	AN 4156-2	Automated Extraction of Semiconductor Parameters Using the HP 4155B/4156B	5963-1249E
	Product Note 1	Differences from the HP 4155A / 4156A	5965-9846E
	Product Note 2	Configuring an NFS and Print Server For Network Capability	5966-4184E

2. Ultra Low Current Measurement for Next Generation Semiconductor Device

Lower power consumption devices are needed as device geometries get smaller. Accurate ultra low current measurement of transistor junction leakage and subthreshold characteristics are required to evaluate the process.

The increased accuracy and repeatability of the HP 4155B/4156B at ultra low current levels allows evaluation of next generation devices. As shown in the Table 3, the HP4155B/4156B has better performance when compared with the HP 4145A/4145B. Offset current is improved to 20fA on the HP 4156B and 3pA on the HP 4155B as compared to 6pA on the HP 4145A/4145B. Resolution is also improved to 1fA on the HP 4156B and 10fA of the HP 4155B as compared to 50fA on the HP 4145A/4145B.

Fig. 2 and Fig. 3 compare Id-Vg curves of a MOSFET device measured on the HP 4145B and the HP 4156B. The integration time is Medium (1 PLC : Power Line Cycle) in both cases. The measurement result is unstable and noisy in subthreshold under pA level when measured on the HP 4145B. Fig. 3 shows the HP 4156B can make a very stable measurement at the fA level.

Table 3. Comparison of function/performance for low current measurement

Function / Performance	HP 4145A/4145B	HP 4155B	HP 4156B
Resolution	50 fA	10 fA	1 fA
Offset current	6 pA	3 pA	20 fA
Zero Offset Cancel	No	Yes	Yes
Range Change Mode	Auto	Auto/Fix/ Limited Auto	Auto/Fix/ Limited Auto

Zero Offset Cancel

The HP 4155B/4156B provides a simple way to remove the dc offset error from low current measurements via the front panel. The zero offset cancel subtracts the offset current from the measurement data automatically. This function enables accurate measurements by minimizing the offset current caused by the instrument, cables, switching matrix and prober.

Measurement Range

The HP 4145A/4145B can set auto range only, and the lowest current measurement range is the 1nA range. The HP 4155B/4156B enables you to choose fixed, auto or, limited auto range*1. According to your request for a range or resolution, you can choose a suitable range mode. This makes it possible to reduce unnecessary range changes and reduces test time.

The lowest current range on the HP 4155B is the 1nA range. This is extended to a 10pA range on the HP 4156B. The lower range allows stable fA level measurements using short integration times. It also substantially increases measurement speed. When you make low current measurement on a wafer with a prober, it is necessary to pay attention to not only the instruments but also to the cables and the prober. For more details, refer to the application note AN 4156-1 listed in Table 2.

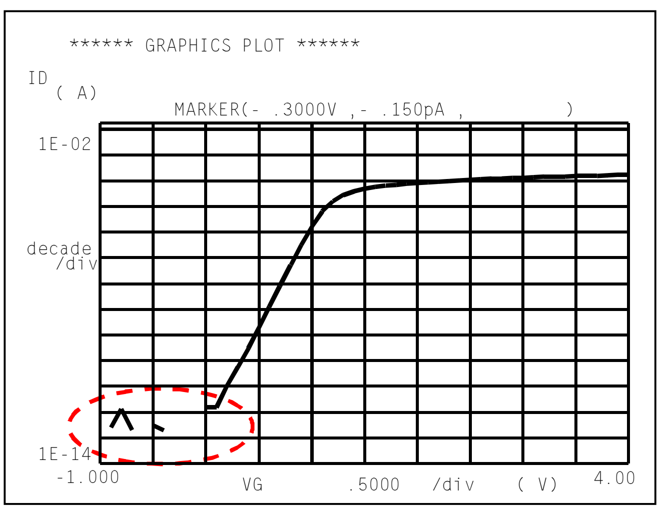

Fig. 2. Id-Vg curve by the HP 4145B

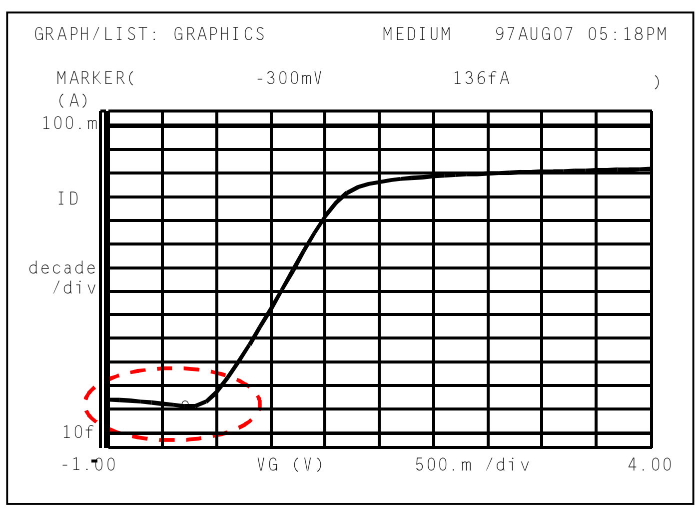

Fig. 3. Id-Vg curve by the HP 4156B

3. Accurate Low Resistance Measurement

Accurate low resistance measurements are needed to design and monitor the contact resistance and line width of today's scaled device geometries.

To achieve an accurate low resistance measurement, the HP 4156B is equipped with Kelvin connections. With Kelvin connections, the sense lead accurately monitors the voltage as close as possible to your device. This method eliminates the voltage drop caused by cable and probe contact resistance. This connection is shown in Fig 4. Kelvin connections are recommended for accurate resistance measurements below 100 ohms.

Fig. 5 shows the results of measuring the emitter resistance *Re* of a bipolar transistor. With a non-Kelvin connection the measurement result included the error, *Rcable*, caused by the cable and probe contact. The HP 4156B Kelvin connection eliminates the *Rcable* error.

A cross section of special Kelvin triaxial cable is shown in the Fig. 6. Both Force and Sense are in the same cable. This reduces the guard capacitance and cable noise caused by cable motion. Wait time can be also reduced due to the low cable dielectric absorption.

Lower Resistance Measurement

The VMU of the HP 4155B/4156B can accurately achieve a much lower resistance measurement. The resolution and offset of VMU are much better compared with the HP 4145A/4145B as shown in the Table 4. In the differential mode, the resolution can be 1uV though the voltage drop is restricted to within 2V. In the differential mode, you can make accurate measurements reducing offset voltage by using the offset cancellation.

Device loading is minimized with the much higher input impedance of the HP 4155B/4156B VMU.

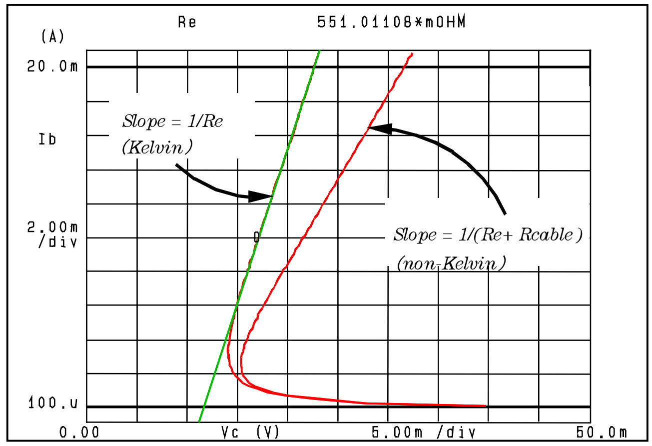

Fig. 5. Comparison of Kelvin and non-Kelvin Connection in Bipolar Transistor

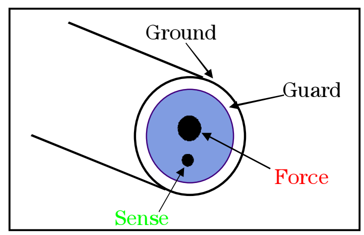

Fig. 6. A Cross Section of Kelvin Triaxial Cable

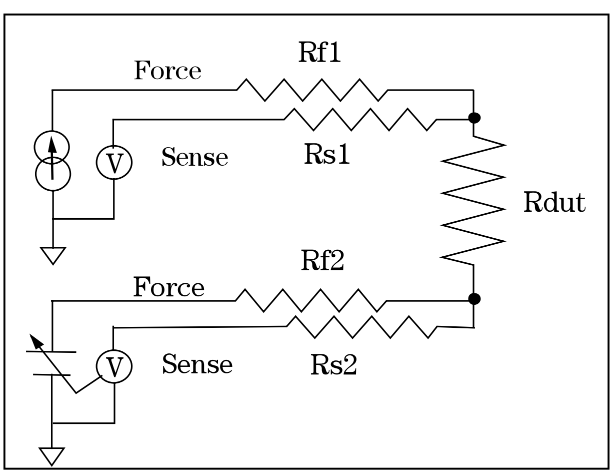

Fig. 4. Kelvin Connection

Table 4. Comparison of VMU Performance

Function/Performance	HP 4145A/ 4145B	HP 4155B/ 4156B
Resolution	100 μV	1 μV *1
Offset voltage *2	10 mV	100 μV
Input Impedance	10 Mohm	1 Gohm

*1 In the differential mode

*2 Offset voltage of the lowest range

4. Oxide Reliability Test using the TDDB Method

The thickness of the oxide becomes thinner as device geometries shrink. Precise evaluation of thin oxide integrity of sub micron MOS devices is crucial.

The Time Dependent Dielectric Breakdown (TDDB) method is commonly used for evaluating oxide defects. The TDDB method forces a constant voltage while continuously monitoring oxide leakage current.

Often it can take anywhere from a few days up to a week until oxide breakdown occurs. Conventional equipment is not well suited for this measurement due to limitations of data buffer size. The data buffer can fill before the breakdown occurs. If the data interval is widened to continue the measurement with the limited data buffer, then resolution at breakdown is lost. The HP 4155B/4156B resolves these problems using a new sampling method.

Sampling Interval

The time measurement functionality of the HP 4155B/4156B is more powerful than that of the HP 4145A/4145B. The minimum sampling interval has been reduced from 10ms to 60µs as shown in Table 5. This means the time resolution at breakdown is precise with a very short interval.

Table 5. Comparison of Sampling Function

Function / Performance	HP 4145A / 4145B	HP 4155B / 4156B
Min. Sampling Interval	10 ms	60 μs
Number of Points	1024	10001

Number of Data Points, and Thinned-out Sampling

The number of points is expanded to 10001 from 1024 as shown in Table 5. The expanded data buffer now allows 10001 measurement points for increased accuracy. However, even though the number of points is 10001, it might not be enough in TDDB, if it continues for a few days. In this case, the thinned-out sampling function is useful. This new feature allows the measurement to continue automatically until a stop condition is reached.

When the maximum specified number of samples is reached, the thinned-out sampling function will discard data as shown in Fig. 7. Sampling continues until the stop condition is satisfied. You can continue testing with no time limitation. In thinned-out sampling, the data at the early stage is caught roughly, and the data at the stage close to the breakdown is obtained with the same detail as it was in the initial interval.

Stop Condition

This function can automatically stop the measurement based on a predetermined stop condition. In TDDB, the current flows rapidly when the breakdown occurs. The sampling measurement is terminated as soon as the current threshold (stop condition) is exceeded.

An example of setup for TDDB is shown in Fig. 8. The thinned-out sampling mode is used, and the stop condition is set to 15mA. Fig.9 is an example of measurement result of TDDB using the setup shown in Fig. 8. Accurate time measurement for TDDB is achieved using the thinned-out sampling mode without limiting the number of points.

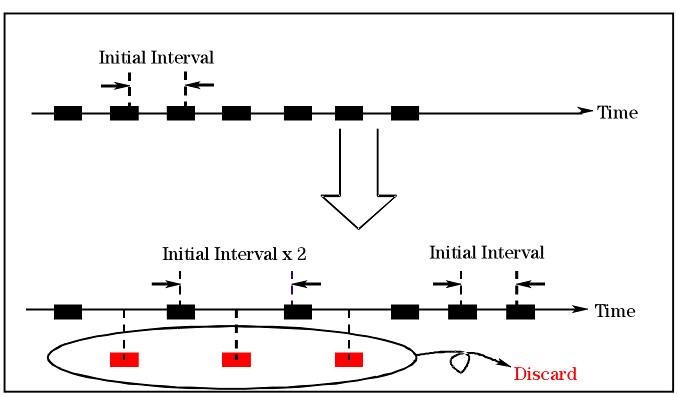

Fig. 7. Thinned-out Sampling

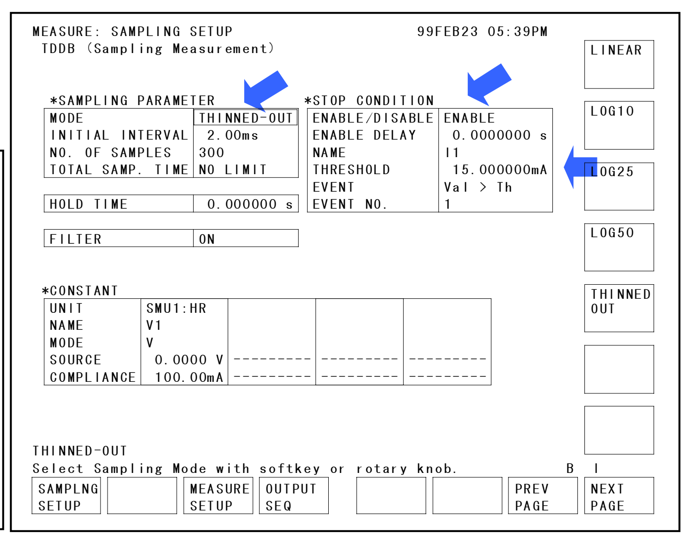

Fig. 8. Example of Setup for TDDB method

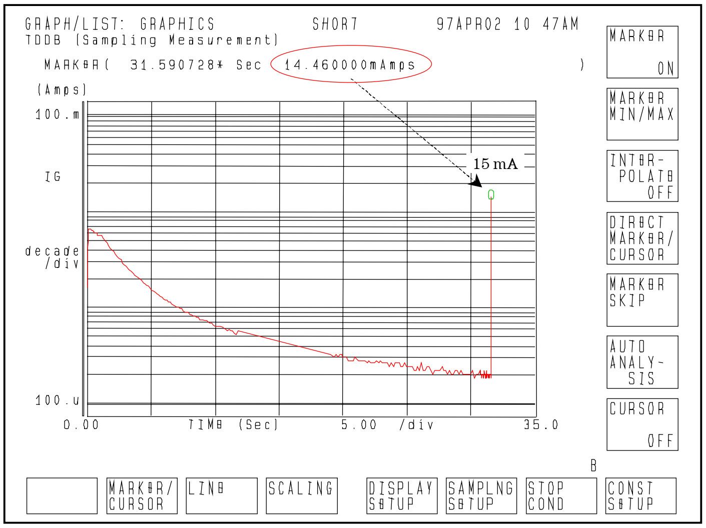

Fig. 9. Example of Oxide Reliability Test by Sampling Measurement

Fig. 12 shows an example of Id-Vg curve using a normal staircase sweep of the HPSMU. The MOSFET drain current increases due to thermal heating. On the other hand, Fig. 13 shows an example using pulsed sweep. Thermal drift is suppressed by the pulsed sweep and stable and repeatable results can be obtained.

The HPSMU can output up to 1A, however, other SMUs can sink the current up to 100mA. If you use the HPSMU over 100mA, use the GNDU to sink the current. The GNDU is a standard unit of the HP 41501B expander box and can sink up to 1.6A.

5. Measurement with High Power (200 V / 1 A)

The HP 4145A/4145B operating range is limited to 100V/100mA for each channel. This can be increased to 100V/ 200mA by connecting channels in parallel.

This range can be further extended to 200V/1A using the HP 4155B/4156B with an optional High Power SMU (HPSMU) channel. See Fig. 10.

The HPSMU is controlled from the front panel in the same way as the standard SMUs. You can also use any of the SMUs in pulsed mode to reduce heating during high power measurements. This heating, called thermal drift, changes the device characteristics.

To prevent thermal drift, the HP 4155B/4156B can perform pulsed sweeps. The output is reset to the start value after each step as shown in Fig. 11. A duty cycle of 1% or less is recommended to prevent device heating and to increase measurement accuracy.

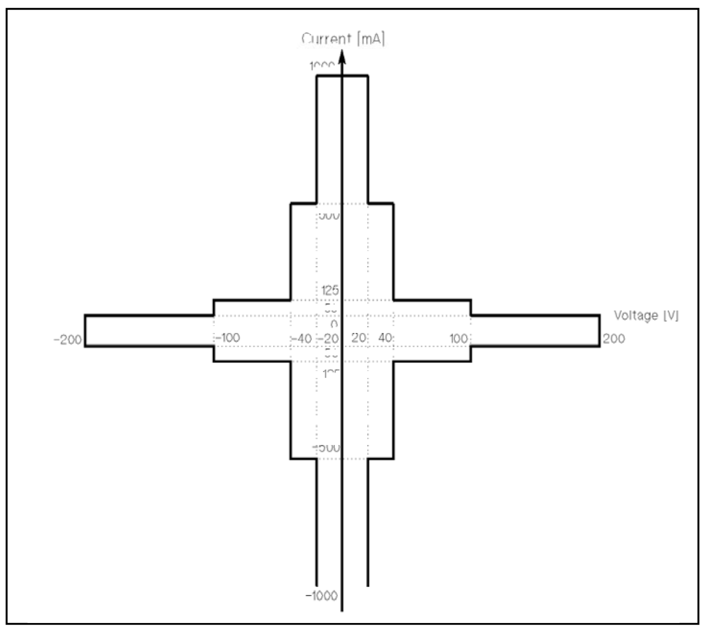

Fig. 10. Coverage of High Power SMU

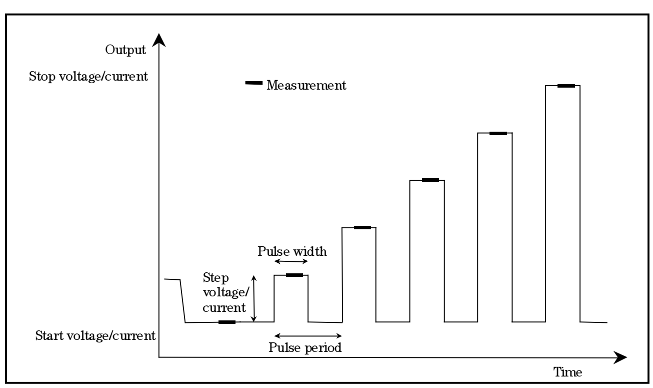

Fig. 11. Pulsed Sweep Measurement

6. Conclusion

Ultra low current in sub pA and low resistance measurements can now be performed very accurately. The HP 4155B/4156B has built-in capability to perform the wafer level reliability measurements critical for monitoring small geometry devices. Compatibility with the industry standard setup files of the HP 4145B has been preserved. MS-DOS disk drive and LAN compatibility is now standard for efficient data handling.

The HP 4155B/4156B has been designed as the semiconductor parameter analyzer for the next generation devices.

*1:Limited auto range specifies the lowest possible range. Measurement time for limited auto ranging is less than for auto ranging because the unit does not search below the specified range, thus reducing the number of range changes.

Note : Support period of the HP 4145A ended in November, 1993. Support for the HP 4145B will end in November, 1999 (As of June, 1999)

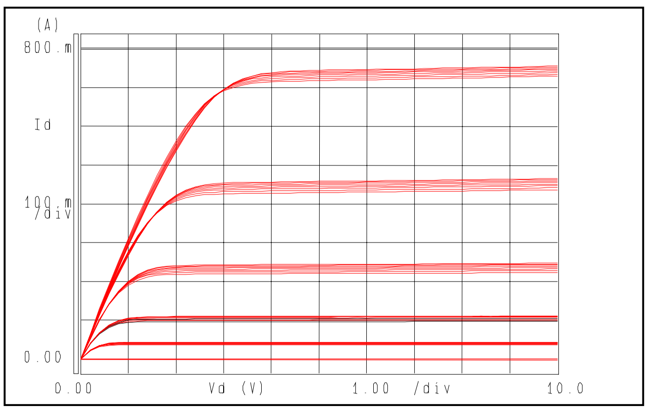

Fig. 12. Example of Id-Vg curve in normal sweep affected by thermal drift

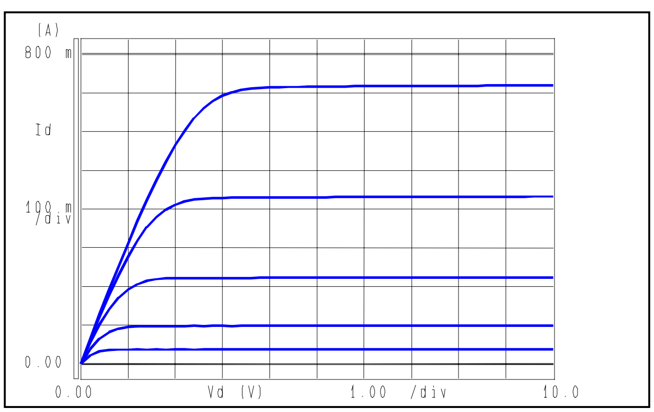

Fig. 13. Example of Id-Vg curve in pulsed sweep preventing thermal drift

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Technical data is subject to change

Printed in Japan 07/99
5968-6681E