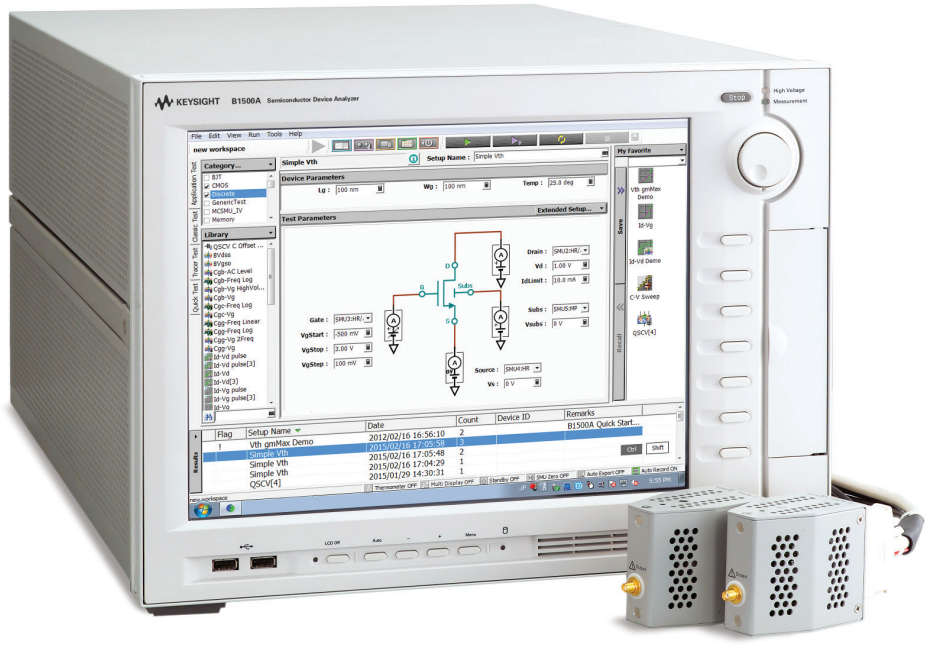
Keysight Technologies

Improve the Accuracy and Efficiency for Organic-Thin Film Transistor (Organic-TFT) Characterization

B1500A Semiconductor Device Analyzer

Application Note



KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights

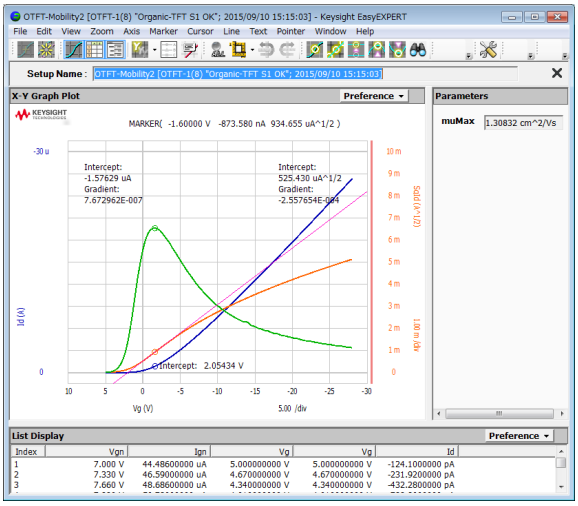
Introduction

Organic materials and devices have been extensively researched as part of the next generation of devices, due to the advantages they offer in terms of flexibility, thinness and low manufacturing costs, compared with the conventional inorganic materials and devices that are currently available.

Organic electroluminescence (organic-EL) applications for smartphones, wearable devices, digital signage etc. are already established but the choice of applications is expected to expand to take full advantage of the benefits of organic devices. The organic thin-film transistor (organic - TFT or OTFT) is therefore an important element in the development of a wide range of electrical devices and applications.

Although the current organic devices offer some attractive advantages, due to the unstable organic material characteristics and the immaturity of the fabrication process, the organic-TFT is needed to improve device performance and reliability. Accurate IV (current-voltage) characterization is important to improve the performance and reliability through an intrinsic understanding of the device characteristics.

To perform accurate IV characterization of organic materials and devices, Keysight Technologies, Inc. offers the B1500A Semiconductor Device Analyzer, a complete solution that provides a wide range of current-voltage measurement capability. The B1500A can configure multiple modular source/measure units (SMUs) that integrate the 4-quadrant precision voltage/current source, a precision voltage/current meter, and an electric load with DC and pulsing capabilities. This close integration of source and measurement capabilities provide the versatility for current-voltage measurement eliminating the cabling and timing complexities associated with discrete instruments. The B1500A can simultaneously control multiple SMUs so that various device characteristics can be measured much more quickly and easily than the conventional instrument. The EasyEXPERT characterization software enables the B1500A to perform the measurement intuitively on the GUI without any programming.



Example result of IV measurement

This application note explains the measurement challenges of organic materials and devices and the solutions available using the B1500A.

Challenges of Organic-TFT Characterization

The organic-TFT has notable characteristics that differ from Si based devices. Unlike a Si device, it is a high impedance device, so the drain current (Id) can be very small, typically in the range from a few nA to a few hundred µA. In addition, the following characteristics must be taken into account when evaluating organic devices.

Hysteresis characteristics

The diagram at Figure 1. shows an example of an organic-TFT device structure. In the fabrication process, traps, defects and impurities are placed in the organic layer as shown in the diagram. As a result, the organic device will likely show characteristics such as hysteresis.

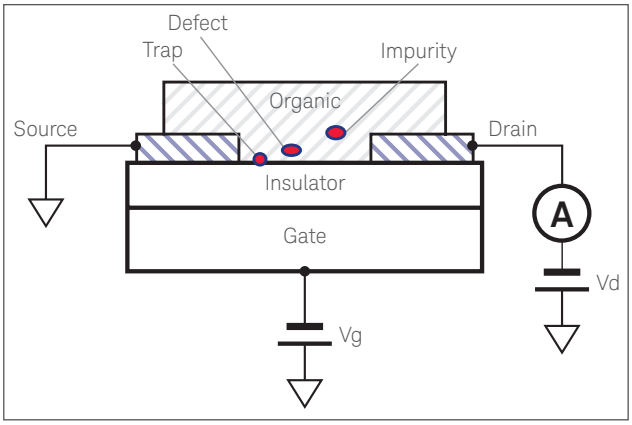


Figure 1. Basic device structure of Organic-TFT

Figure 2 is an example of a Id-Vg curve of p-type organic-TFT, which shows the hysteresis characteristics having different traces by the direction of voltage sweep. If the threshold voltage (Vth) is defined as the voltage at the specified Id (e.g. 1 µA), the switching voltage depends on the sweep direction and the voltages are different between turn-on and turn-off.

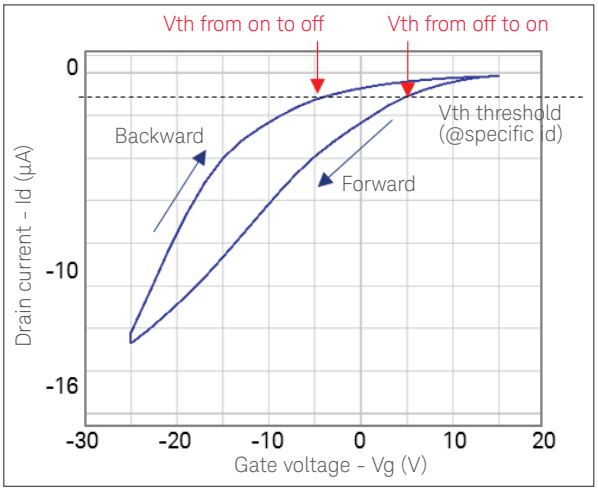


Figure 2. Example of Id-Vg hysteresis

The hysteresis characteristic provides the possibility for new function devices such as organic memory. However, the voltage difference when switching is an issue for a transistor used for circuit design, so it is important to understand the hysteresis characteristics and find a way to manage it. The magnitude of hysteresis usually depends on the voltage step level and the sweep speed, so it is necessary to evaluate it under various test conditions.

Response time coming from dielectric characteristics

The organic semiconductor material is closer to dielectric material than inorganic semiconductor material. The dielectric material has a response time to settle its polarization, and it requires an appropriate wait time for the current settling, when changing the voltage on the dielectric material.

This characteristic should be taken into account for the organic-TFT evaluation. As shown in Figure 3, the Id has a relatively slow response time to get the final value, after changing the Vg. Because the Id-Vg characteristics can be varied by the timing of the measurement, the appropriate wait time is important to perform an accurate Id-Vg measurement.

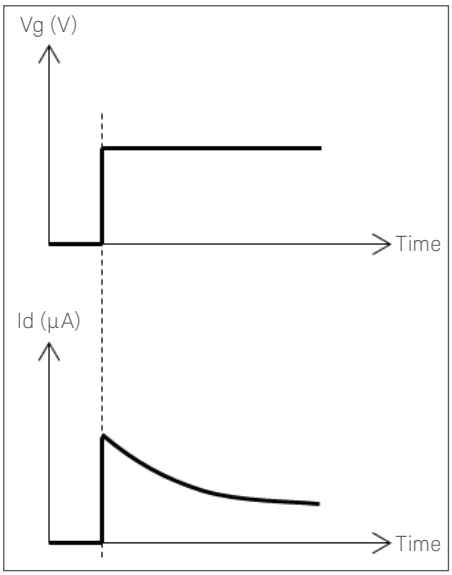


Figure 3. Id-Vg step response image of Organic-TFT

The settling time depends on the magnitude of the voltage step as well as the device and material. To study the detailed response time of the device, it is necessary to measure the Id with the range from µs to second order in time domain after changing the Vg.

Performance degradation by aging in the atmosphere

The stability of organic devices is also a challenge. As shown in Figure 4, the electrical characteristics (e.g. mobility) can degrade due to aging caused by chemical reactions to oxygen, moisture and light in the atmosphere.

Even though the fabrication process is matured, the electric characteristics of the organic device can vary unless it has been stabilized to the environmental factors (e.g. the room temperature, humidity, and exposure period, etc.). From a life time reliability viewpoint, it is important to seek stable materials and evaluate the device against the different environmental factors.

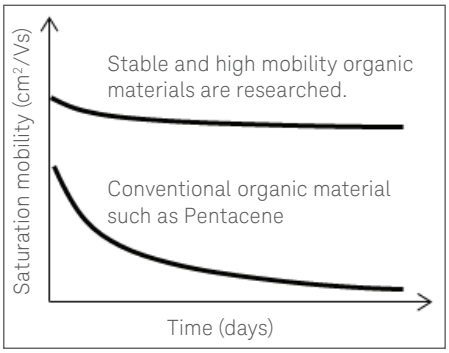


Figure 4. Degradation of the saturation mobility exposed in atmosphere

The B1500A Semiconductor Device Analyzer is the Complete IV Characterizing Solution for Organic-TFT Measurement Challenges

The advantage of using the B1500A Semiconductor Device Analyzer and its Source/Measure Units (SMUs)

Hysteresis and sub-threshold measurements can be measured accurately with the best resolution in the industry down to 0.1 fA resolution

The ΔId measurement needs to subtract one Id value from another Id with similar but small differences in value. Therefore, it requires enough high resolution for the measured Id value. For example, ΔId requires pA to fA resolution, when measuring Id around nA. In addition, the high impedance organic-TFT devices require a wide dynamic range from sub pA, for fully characterizing the leakage current and Id-Vg curve.

To perform such low current and high resolution measurements, the B1500A and its SMUs are the best solution. Its integrated source and measurement capabilities provide 6 digit high resolution and low current measurement down to 0.1 fA resolution, while sourcing and sweeping the voltage, either forward or backward. In addition, the auto-ranging feature provides the best accuracy across the ranges from fA to mA. These capabilities enable you to easily and accurately measure Id-Vg characteristics without the need to use extracting instruments, complex cabling and settings or change the resources.

Figure 5 shows an example of the Id-Vg hysteresis characteristics measurement using the B1500A. Using the GUI based EasyEXPERT software, the B1500A enables you to quickly setup the measurement condition, perform a measurement, and obtain the result graphically. As described later in this section, the B1500A has advanced data analysis functions, so it is possible to draw a Id-Vg curve and extract the ΔId automatically.

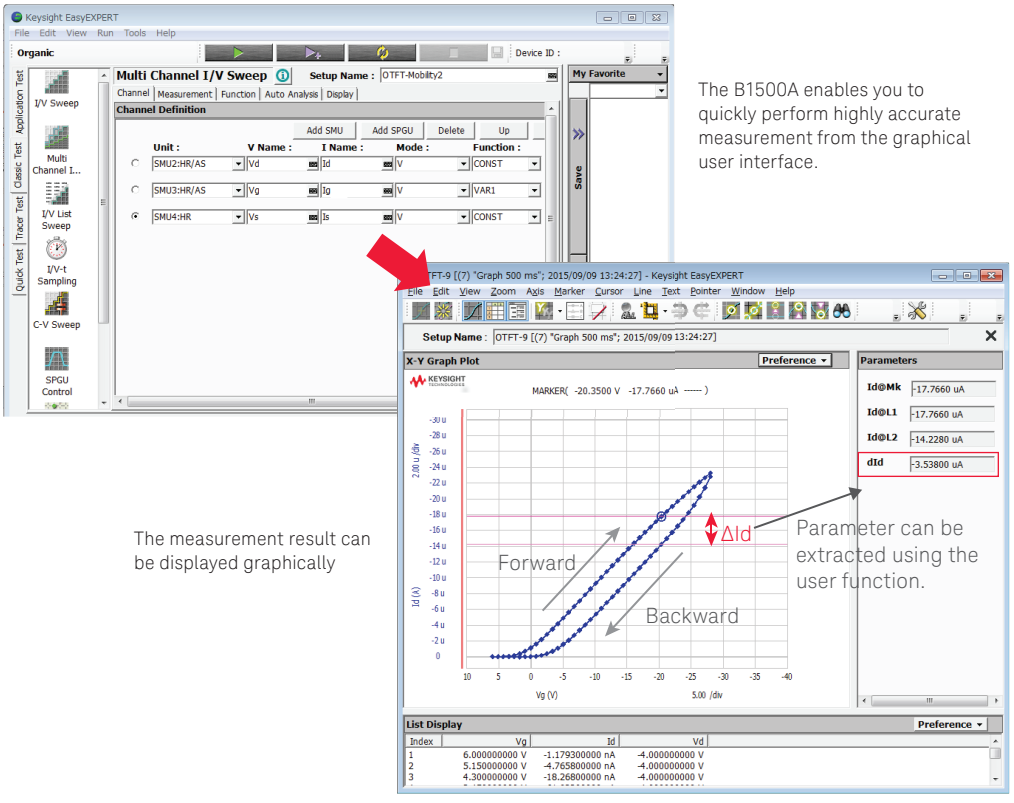


Figure 5. Example of hysteresis of Id-Vg curve

Adjustable delay time to appropriately wait a current settling time for dielectric characteristics

Due to the dielectric characteristics of organic-TFT, the Id depends on the time that passes after applying the voltage, and appropriate wait time is required for the accurate Id-Vg measurement.

The B1500A allows you to easily specify a delay time in the sweep measurement. It is a minimum wait time to start the measurement on each voltage sweep step, as shown in Figure 6. (Additional time can be inserted, when the range change occurs in the sweep.) The hold and delay time can be set as well as other sweep measurement parameters, as shown in Figure 7.

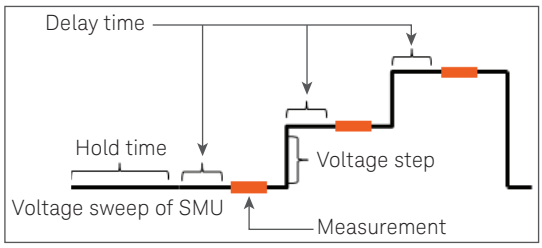


Figure 6. Delay time can wait the current settling after changing the voltage

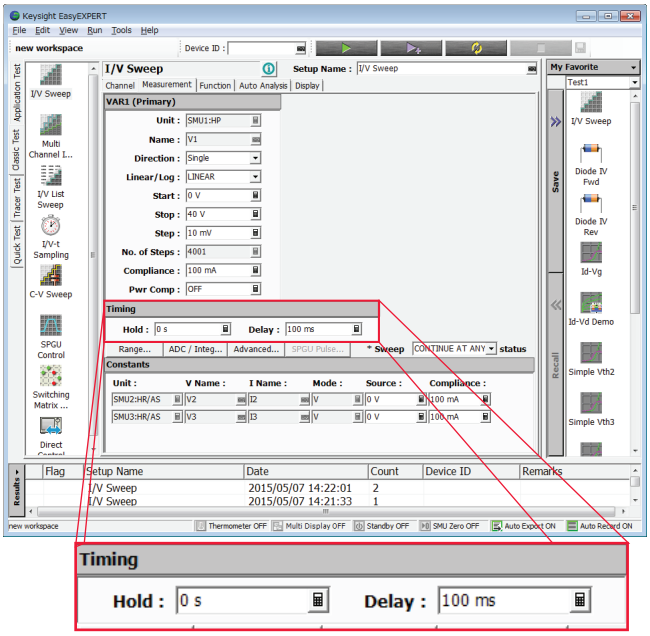


Figure 7. Wait time control in the sweep parameter

I-t (current vs time) measurement as fast as 100 µs sampling interval for finding appropriate wait time

In addition to the sweep measurement, the B1500A's SMU can also perform the I/V-t sampling measurement under the specified DC condition. It enables you to evaluate the I-t (current vs time) characteristics for the applied step voltage as fast as 100 µs sampling interval. Figure 8 shows the Id time response (orange trace on the right scale) when changing the Vg (blue scale on the left scale) from 0 V to -8 V. The measurement is performed from 100 ms to 10 sec, by setting the hold time.

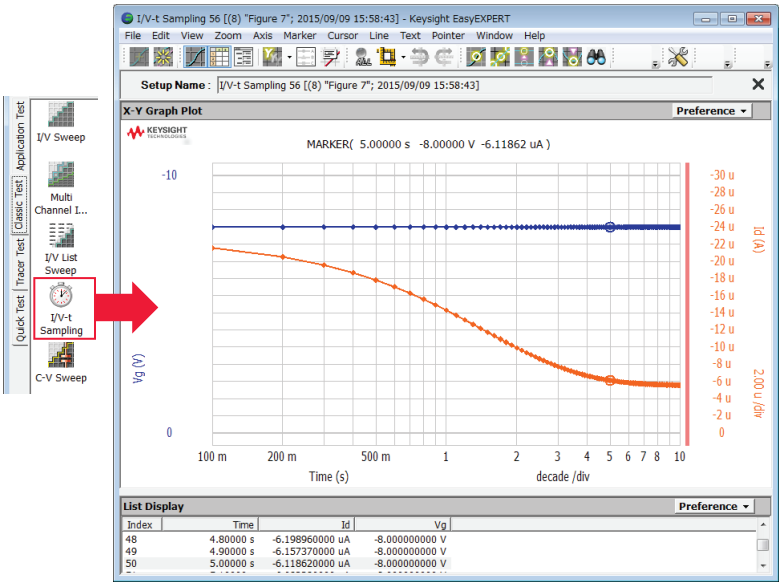


Figure 8. I/V-t sampling is useful to find out the settling characteristics.

The graphical data display enables you to quickly identify the settling time using the read out of the marker and the cursor. Once the response time to the step voltage is known, the accurate Id-Vg curve can be obtained by setting the appropriate delay time in the sweep measurement setup.

The Advantages of Using EasyEXPERT Software

Automatic data saving improves the file management and ensures the test data for long run measurements

When researching organic materials and devices, the measurements are performed intermittently over a specific time period, using a variety of materials, conditions and environmental factors, to evaluate the aging degradation. It is therefore important to be able to recode and manage the measurement results, along with any supplementary information (e.g. the device fabricated time, measurement conditions, date and time of measurement etc.) in order to track and trace any previous data. This typically requires cumbersome file management.

The EasyEXPERT software furnished within the B1500A provides the "workspace", the main operating area which provides easy to access measurement capabilities, parameter setup and execution panels and graphical analysis and data management tools. Its dedicated data storage allows you to save all of the measurement data (setup and result) manually or automatically after every measurement with a time stump, number of test (count), device identification and remark in the workspace. If needed, the image file and CSV files can also be exported in addition to saving the data into the workspace. This capability is very convenient when repeating the trial-and-error type of test. The data in the workspace can be quickly recalled for analysis or measurement reproduction at any time. You can create multiple workspaces, so you can manage them according to the user,

project, device type, and so on. These powerful capabilities dramatically simplify the data management process.

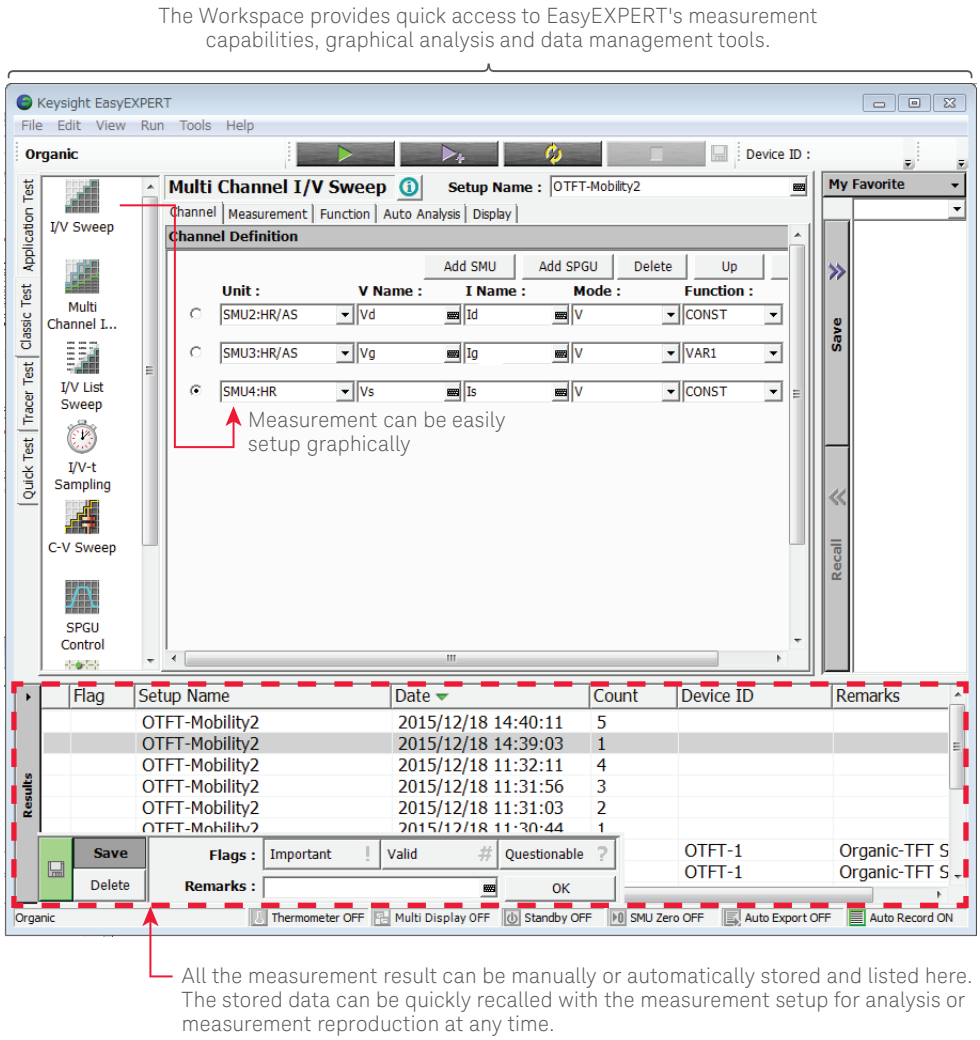


Figure 9. Main screen provides easy access to the data in the workspace and measurement capabilities

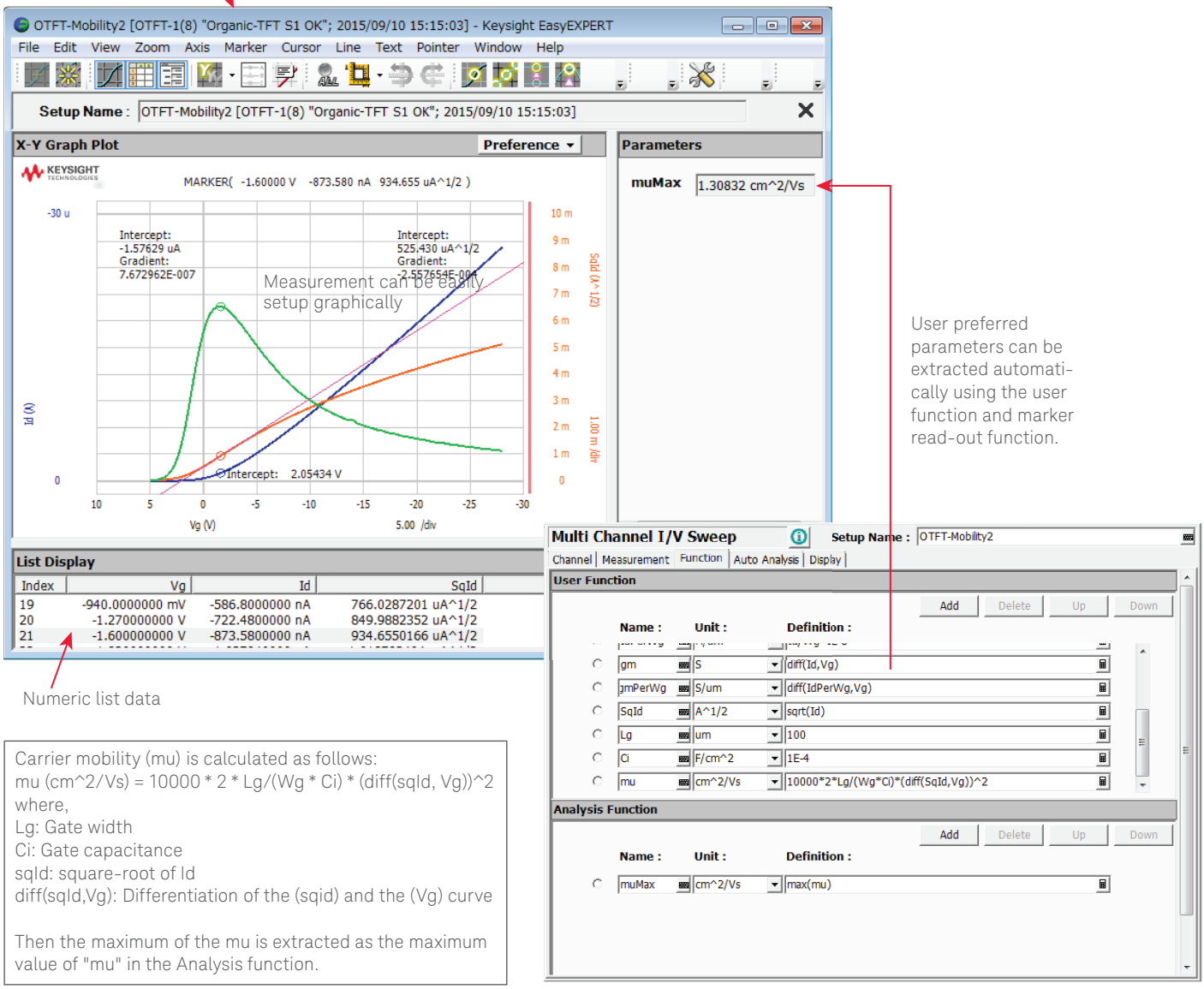
Quick debugging and analysis are supported by graphical data display and data extraction

Since the organic device tends to degrade for long running measurements, it is important approximately check the device characteristics before the detailed measurement takes place. EasyEXPERT has the built-in graphical analysis capabilities that enable you to quickly and accurately check the device characteristics on the graph and produce numerical list data in real-time during and after the measurement, without the need for extra analysis tools.

It also provides the powerful graphical analysis features such as marker, cursor, user function and so on, which enable you to perform the analysis, in addition to displaying the data. The auto-analysis and user functions enable you to move the marker position, recall the data at each marker position and automatically calculate the user preferred parameters after each measurement. Figure 10 shows an example of Id-Vg curve and extraction of maximum carrier mobility. It dramatically reduces the time and effort needed in order to obtain the data that the user requires.

The data display provides more powerful capabilities such as the comparison of multiple data stored in the workspace, exporting the data in various file formats (Excel, images, and CSV) and so on for accelerating the post measurement analysis.

The Data display window enables quick recalling of results and detailed graphical data analysis.



Numeric list data

Carrier mobility (mu) is calculated as follows:
mu (cm^2/Vs) = 10000 * 2 * Lg/(Wg * Ci) * (diff(sqId, Vg))^2
where,
Lg: Gate width
Ci: Gate capacitance
sqId: square-root of Id
diff(sqId,Vg): Differentiation of the (sqid) and the (Vg) curve

Then the maximum of the mu is extracted as the maximum value of "mu" in the Analysis function.

Figure 10. Powerful graphical data analysis and data extraction accelerates the device characterization of organic-TFT.

Summary

This application note explained the major measurement challenges of organic - TFTs and how to solve these measurement issues using the B1500A. The B1500A's SMU versatility, accurate low current measurement performance and timing control capabilities enable accurate IV characterization of organic - TFTs.

In addition to the superior hardware measurement performance, the EasyEXPERT software improves the entire characterization process with a powerful range of capabilities such as automated data saving and graphical analysis display. This combination ensures that the B1500A is the best solution for accurate IV characterization of organic - TFT.

The B1500A can also equip advanced measurement modules such as CMU for CV (Capacitance-Voltage) measurements and WGFMU for ultra-fast pulsed IV measurements. Further details on the B1500A can be found at **www.keysight.com/find/b1500a**.

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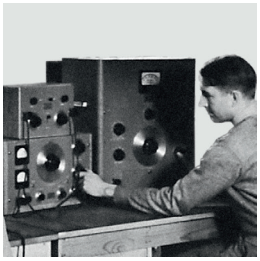

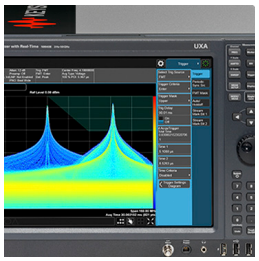

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