Keysight Technologies

1 µs IV Characterization of Flash Memory Cells Using the Keysight B1530A

Application Note

KEYSIGHT TECHNOLOGIES

Introduction

The proliferation of memory-intensive electronic devices such as MP3 music players, digital cameras, third-generation (3G) mobile phones and the gradual replacement of hard disk drives with solid state memory continue to drive growth in the flash memory market. This growth demands improvements in memory density in order to reduce the cost per bit. To meet the demands of both high densities and faster programming speeds, memory manufacturers are increasingly using multiple bit or multilevel cell (MLC) memory technologies.

Why do flash memory cells require high speed IV characterization?

MLCs require that multiple programming states exist within a limited voltage range. Therefore, accurate control of the threshold voltage (Vth) is necessary to maintain sufficient margin between neighboring states so that the state of the memory cell can be read correctly (please see Figure 1).

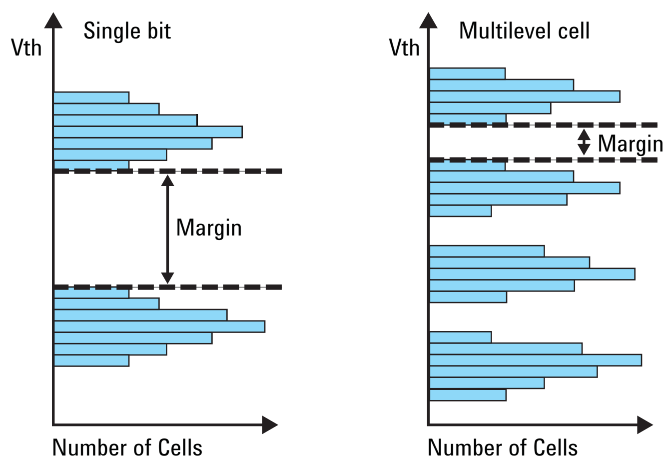


Figure 1. Vth distribution of multilevel cell

In general, program and verify (P&V) schemes are used to tighten the Vth distribution of the different states and maintain sufficient margin to read the state correctly (please see Figure 2). Since the verification operation is performed immediately after the programming operation, it is important to evaluate drain/source current characteristics right after the programming operation. If the Vth of the memory cell shifts after the P&V scheme has verified it to be within the target range, then the P&V scheme may not produce its expected results and the Vth distribution may exceed the desired limits. Consequently, it is important to verify that the drain/source current is stable after programming. In addition, since the P&V scheme iterates until the target Vth is achieved for each memory cell, it is also important to program the MLCs quickly.

Another way to increase the total programming speed is to program multiple memory cells in parallel, which requires careful control of and limits on the current going into the memory cells during programming.

The requirements of accurate Vth control and faster programming time present new parametric measurement challenges, such as the need for high speed current sampling measurement during and after the application of the programming pulses. Because the programming speed of flash memory cells is on the order of tens of micro seconds in the fastest case, high speed current measurement with a sampling rate of less than 1 µs is required to make this measurement.

In addition to the accurate control of Vth, random telegraph noise (RTN) or random telegraph signal (RTS) noise has become a serious concern in flash memories as devices have scaled down in size. RTS noise shows up as random fluctuations in the drain current, and it is believed to be caused by the charge trapping and de-trapping of a single electron (please see Figure 3). RTS noise also broadens the Vth distribution of a flash memory cell and it tends to increase after multiple program/erase (P/E) cycles. In a worse-case scenario it can induce a read failure (giving an incorrect status of the memory cell) and this failure mode is especially prominent in advanced process nodes such as 45-nm and beyond. Therefore, the evaluation of the RTS noise characteristics of flash memory cells is important to guarantee that MLCs manufactured in advanced process nodes have sufficient Vth margin

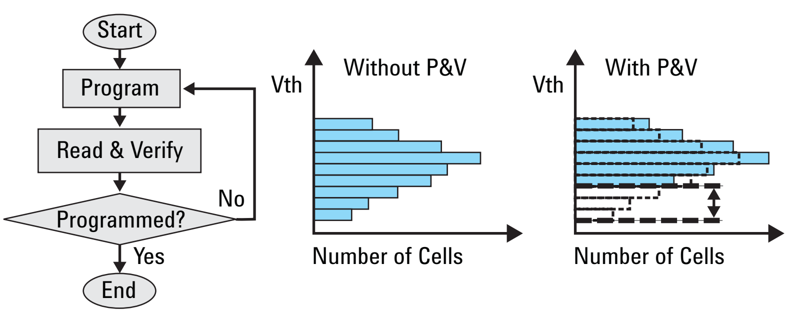
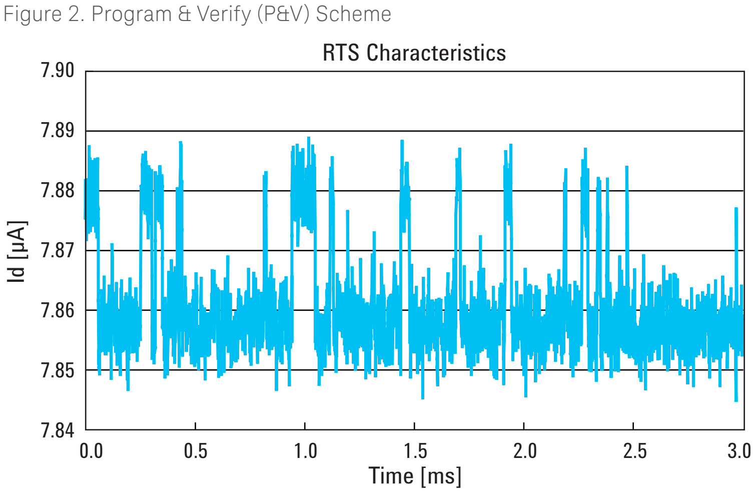


Figure 2. Program & Verify (P&V) Scheme



B1530A features

The Keysight Technologies, Inc. B1500A Semiconductor Device Analyzer's new Keysight B1530A waveform generator/fast measurement unit (WGFMU) module provides an arbitrary linear waveform generation (ALWG) function that is synchronized with a fast current or voltage (IV) measurement capability. These features meet the needs of MLC flash memory cell evaluation (please see Figure 4).

The WGFMU has 2 channels per module, and up to five WGFMU modules can be installed in a B1500A mainframe. Each channel of the WGFMU has four voltage force ranges; -3 V to 3 V, -5 V to 5 V, -10 V to 0 V and 0 V to 10 V. The available current measurement ranges are 1 µA, 10 µA, 100 µA, 1 mA and 10 mA for high speed current measurements made at a sampling rate of 5 ns.

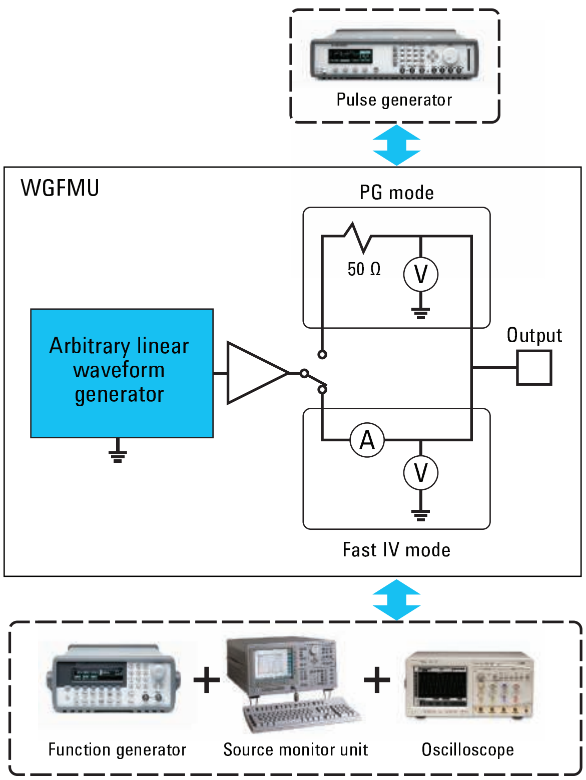


Figure 4. Equivalent circuit schematic of one WGFMU channel — various instruments in a unit

Why is the WGFMU module an ideal solution for MLC evaluation?

The ALWG function of the WGFMU module can generate not just DC voltages but also various types of AC voltage waveforms, such as rectangular waveforms, ramped waveforms, trapezoidal wave-forms and staircase sweeps with 10 ns programmable resolution. This permits the WGFMU channels to apply multiple arbitrary waveforms synchronized with each other to the terminals of the multi-level flash memory cell. Please note that the exact shape of the applied waveforms for a given evaluation depends on the device type (please see Figure 5 and Figure 6).

In addition to its impressive ALWG capabilities, the WGFMU can also synchronize high speed IV measurement with these waveforms at a sampling rate of less than 1 µs. The other mea-surement settings, such as the measurement range, averaging time, etc., can be specified with the 10 ns programmable resolution that is required by advanced MLCs.

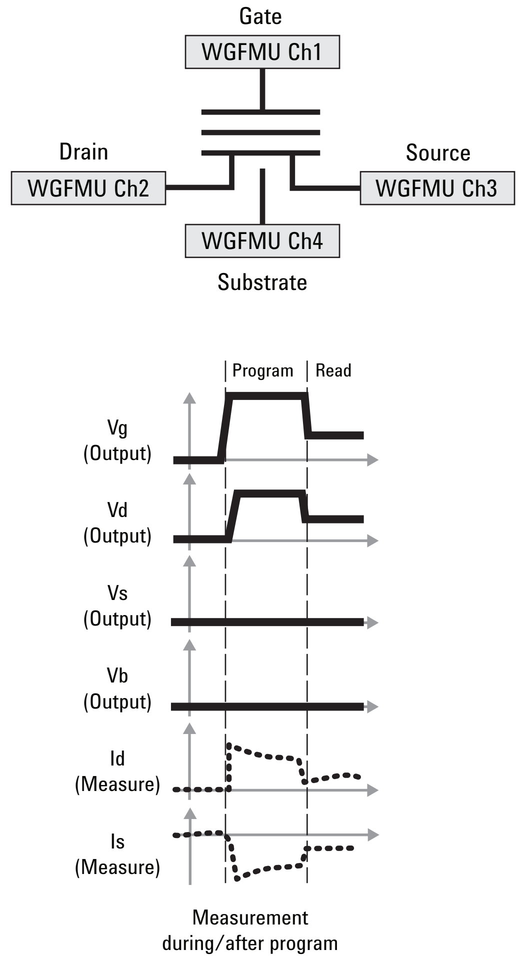


Figure 5. Evaluation of flash memory cell

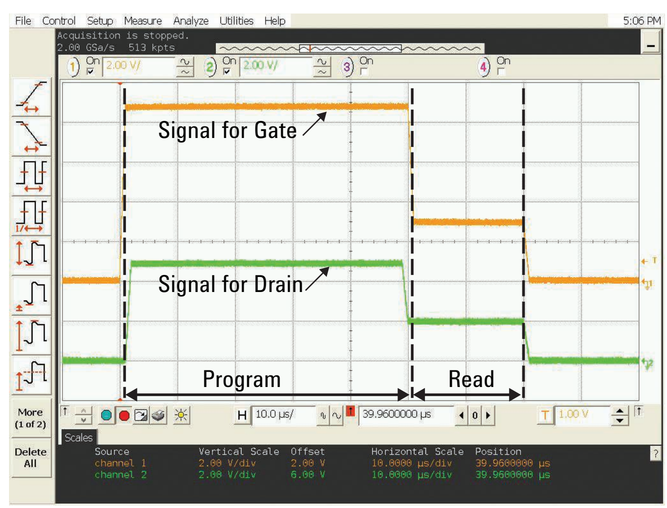


Figure 6. Example of waveform from WGFMU

The combination of these B1530A's functions enables the characterization of the drain/source current of flash memory cells during and after forcing the programming pulse signals at a high speed sampling rate. The WGFMU enables you to evaluate microamp current levels at a sampling rate of less than 1 µs (please see Figure 7).

The WGFMU is also capable of evaluating the RTS characteristics of flash memory cells using the fast IV measurement function, in conjunction with an RTS Data Analysis Tool (please see Figure 8).

All-in-one solution

Until now, solutions to evaluate the characteristics of flash memory cell drain/source current during and after programming had to be created using off-the-shelf instruments and user-developed software as shown in Figure 9. As can be imagined, these sorts of solutions can be both complex and unreliable, making it difficult to obtain accurate and stable measurements.

On the other hand, since the WGFMU module is an all-in-one solution, accurate high speed IV measurement can easily be performed without any complex integration or calibration. In addition, the WGFMU can simultaneously measure current on both the drain and source, whereas the instrument-based solution can measure current only on the drain.

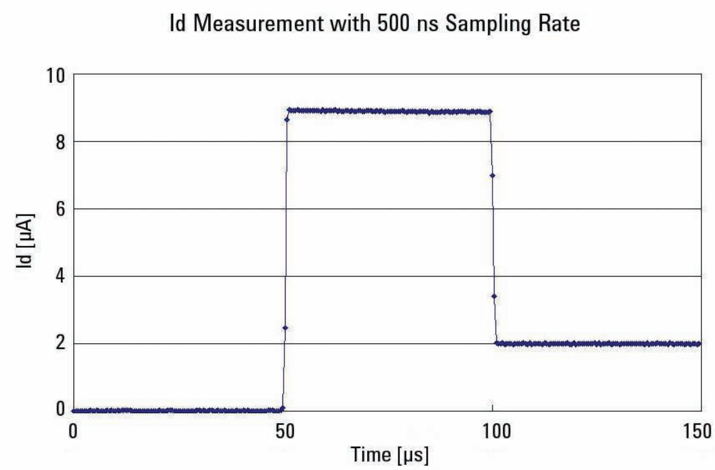


Figure 7. Id measurement with 500 ns sampling rate

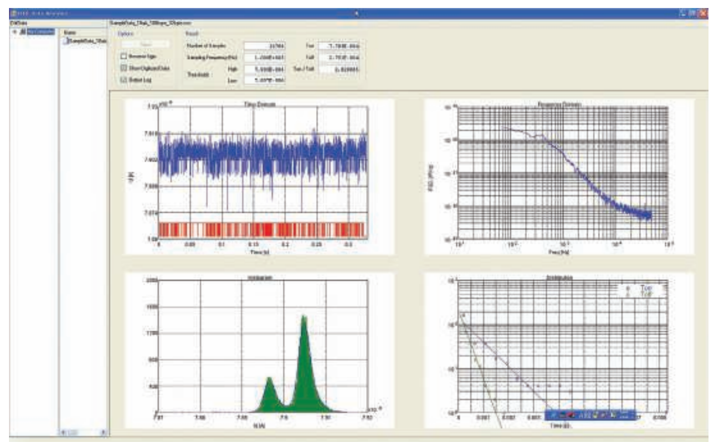


Figure 8. Random telegraph signal (RTS) noise with RTS data analysis tool

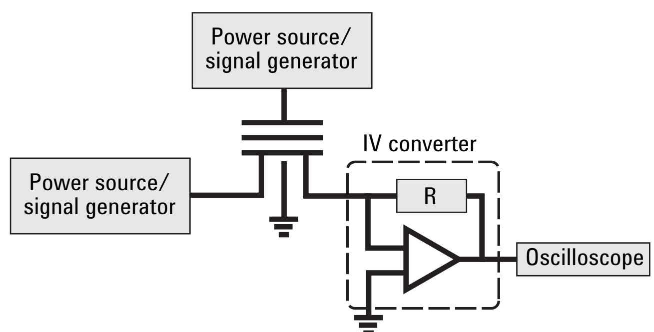


Figure 9. Conventional integrated system

Conclusion

This application note has shown how the B1500A's new WGFMU module can be used to solve the measurement challenges faced when performing high speed IV characterization of flash memory cells. This includes difficult measurements such as measuring the drain/source current during and after P/E operation and performing RTS noise characterization.

The WGFMU has an accurate high speed IV measurement capability that is synchronized with the waveforms outputted by its ALWG function. The WGFMU is an all-in-one solution that supports the evaluation of drain/source current characteristics, and it can replace cumbersome instrument solutions (such as a pulse generator, oscilloscope and external IV converter). In addition, the high speed IV measurement capabilities of the WGFMU also enable it to perform accurate RTS noise measurement characterization on flash memory cells.

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