KEITHLEY

Application Note Series

Number 2814

On-The-Fly V_{TH} Measurement for Bias Temperature Instability Characterization

Introduction

The need to monitor and control bias temperature instability—both negative (NBTI) and positive (PBTI)—in both scaled CMOS and precision analog CMOS technologies is growing. The current JEDEC standard for NBTI[1] identifies "NBTI recovery during interim measurements" as the concern that motivates reliability researchers to continue to refine test techniques. In simple terms, when the stress is removed from a device, the degradation begins to "heal." That means that slow interim measurements will produce an overly optimistic lifetime estimate. Therefore, the faster one can characterize the degradation, the less the recovery (of the degradation) affects the lifetime prediction. In addition, experimental data reveals that the time slope (*n*) of the measured degradation is strongly dependent on measurement delay and measurement speed.[2] Therefore, several measurement techniques have been developed in the effort to minimize measurement delay and increase measurement speed.

What is BTI?

Bias Temperature Instability (BTI) refers to instability in the threshold voltage (V_{TH}) when a MOS FET is subjected to temperature stress. Typically, a FET is tested at 125°C with an elevated gate voltage, and with the drain and source grounded. Over time, V_{TH} will increase. For applications such as logic and memory devices, a 10% shift in V_{TH} can cause the circuit to fail. With analog applications, such as matched transistor pairs, much smaller shifts can lead to circuit failure. Many of the process variations that affect matching of FETs can be mitigated by increasing the area of the transistor, which leaves BTI as the limiting factor.

On-The-Fly (OTF) Techniques

Denais et al[3] proposed one method to minimize recovery during interim measurements that uses an indirect measurement that could be correlated to V_{TH} shifts. The interim measurement sequence was designed to reduce the "off-stress" time by using only three measurements, as shown in ***Figure 1***. This technique can be implemented with almost any parametric measurement system with varying degrees of success. However, most GPIB-controlled instruments lack flexibility and are limited by GPIB communication time and the internal speed of the instrument; therefore, the device is likely to remain unstressed for roughly 100ms during the measurement. These limitations obscure visibility into degradation and recovery within that time limit (~100ms). The unique architecture of Keithley's Series 2600 System SourceMeter® instruments can typically complete the Denais OTF interim measurement and return the test structure to the stress condition in approximately 2ms.

Over time, variations of Denais' concept have been developed, proposed, and even put into routine use to monitor process-induced BTI shifts. Each of these techniques has benefits and drawbacks. This application note will discuss the instrument requirements as related to effective implementations of BTI application and will examine several techniques used to characterize both degradation and recovery.

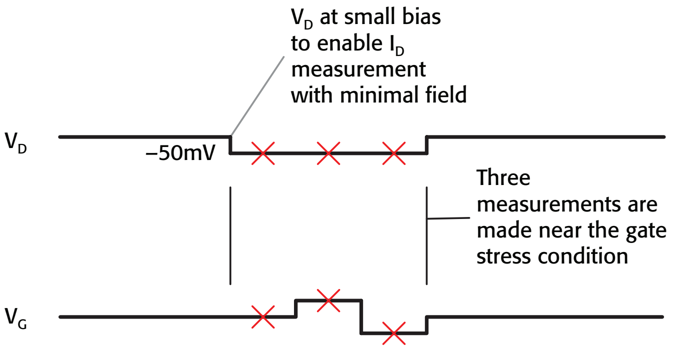

Figure 1. Off-stress time is greatly reduced using the on-the-fly (OTF) technique. Rather than performing exhaustive I_D-V_G sweeps (I_{Dlin} and I_{Dsat}) and extracting V_{TH}, the OTF technique keeps the gate stressed and the drain voltage near ground.

High Speed Source and Measure

The most critical element in implementation of the OTF techniques is the use of a high speed source-measure unit or SMU. The high speed SMU provides a number of crucial capabilities:

- Fast continuous measurement rates, less than 100µs between successive measurements.
- Microsecond resolution time stamp to ensure proper timing analysis.
- Precision voltage sourcing to address the need for low voltage bias of the drain.
- Fast source settling to maximize source-measure speed.
- Large data buffers to ensure continuous monitoring of device degradation and recovery

I_D Only OTF Technique

One popular OTF technique involves monitoring only the drain current. This is done by providing a small bias on the drain

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[1] "A Procedure for Measuring P-Channel MOSFET Negative Bias Temperature Instabilities," JEDEC Standard JESD90, 2004.

[2] M. A. Alam, "A simple view of a complex phenomena," tutorial presented at *IRPS*, 2005.

[3] M. Denais et al., "On-the-Fly Characterization of NBTI in Ultra-Thin Gate Oxide PMOSFETs," in *Technical Digest of IEDM*, 2004, p. 109.

(typically 25–100mV) and making continuous drain current measurements, as shown in ***Figure 2***. In this technique, the continuous sampling rate is critical. Using a Series 2600 System SourceMeter instrument, a continuous sampling interval of 90µs can be achieved, with up to 50,000 data points stored in the instrument's buffer.

An important advantage of this technique is that the recovery dynamics of the BTI mechanism can be captured very shortly after the stress is removed as shown on right side of ***Figure 2***. It has been found that the recovery dynamics show greater variability and sensitivity to process variation than the degradation dynamics.

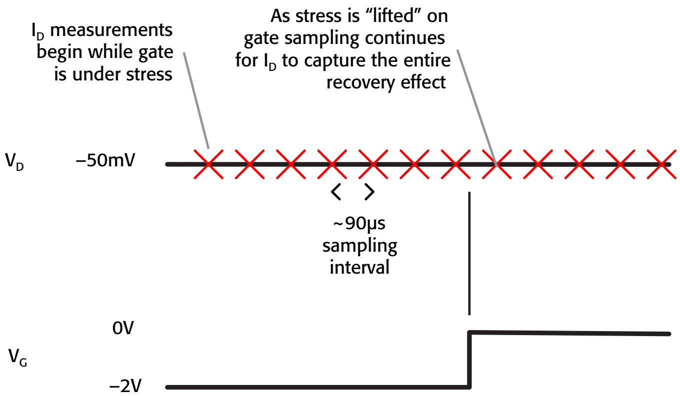

Figure 2. The I_D only OTF technique involves holding a small bias on the drain and sampling the drain current continuously. One advantage of this technique is that it allows capturing the recovery dynamics by removing the stress while the drain current is being sampled.

On-The-Fly Single Point Technique

This technique is much like the I_D only technique, except that I_D is measured in the linear region. The key point here is to minimize degradation recovery time by shortening the measurement time. Using the Keithley Series 2600 System SourceMeter instrument, a short gate voltage disruption of ~200µs can be achieved.

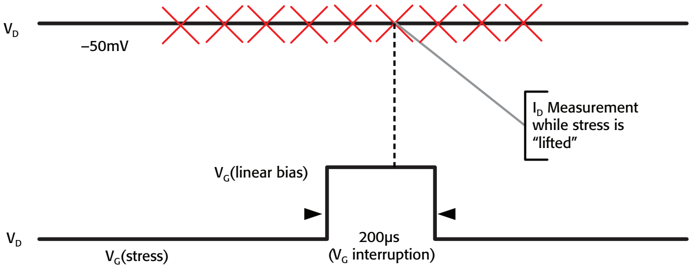

Figure 3. The single-point technique involves removing the gate stress and applying a gate voltage that's more consistent with normal use conditions before measuring the drain current.

On-The-Fly V_{TH} Technique

Some researchers may be concerned that many OTF techniques use indirect V_{TH} measurement techniques that are too distantly related to the parameter of interest. For instance, monitoring only I_D as the interim measurement may not provide enough visibility into actual V_{TH} shifts because other parametrics shifts, such as mobility degradation due to interface states degradation, might have an impact on I_D that's independent of that due to V_{TH}.

The OTF V_{TH} method simply replaces the three measurements of the Denais OTF technique shown in ***Figure 1*** with a sweep of a few points centered on the $g_{m\text{-}max}$, as shown in ***Figure 4***. The extracted V_{TH} is potentially more accurate than the V_{TH} extrapolated from just three measurements, depending on the noise floor of the test system, source settling speed, and measurement integration rate.

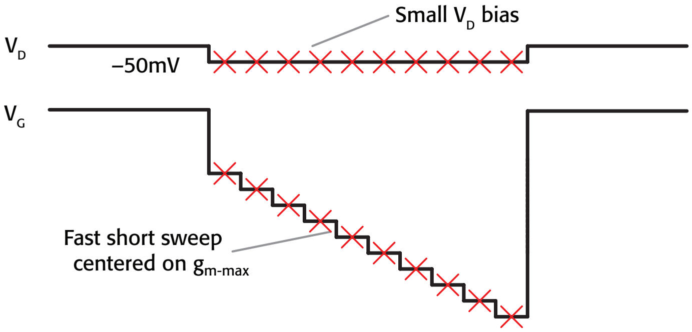

Figure 4. V_{TH} OTF uses a short fast V_g sweep centered on $g_{m\text{-}max}$. This technique allows a 10-point sweep to be completed and the stress conditions returned in less than 5.4ms. If only I_D is measured, the time is reduced to 3.8ms.

Implementation

The measurements described in this application note have been performed using the Series 2600 System SourceMeter instruments. A single Model 2612 incorporates dual four-quadrant source-measure units and an embedded script processor, which allows the instrument to perform a complete BTI characterization independently. In addition to the examples described here, this instrumentation allows performing more complicated tests, such as the "IV OTF Bias Patterns" suggested by Parthasarathy et al[4]. The Test Script language embedded in the Series 2600 instruments provides this flexibility. Keithley also makes example test scripts freely available to accelerate development of user-integrated solutions.

Channel Scaling

The architecture of the Series 2600 System SourceMeter instruments is optimized for scalability, which simplifies building a multi-channel parallel system for performing fast NBTI tests in lab or production environments. For guidance in system scaling, see the archived online tutorial titled "Meeting New Challenges in Wafer Level Reliability Testing using Source-Measure Units (SMUs)," available on Keithley's website at www.keithley.com/events/semconfs/webseminars, as well as other informative resources on www.keithley.com.

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[4] C. Parthasarathy, M. Denais, V. Huard, G. Ribes, E. Vincent and A. Bravaix, "New Insights Into Recovery Characteristics Post NBTI Stress," in *Proc. Reliability Physics Symposium*, 2006, pp. 471-477.

Custom Systems

Keithley can integrate multiple Series 2600 instruments into complete BTI test solutions. When integrated with 4200-SCS and Pulse I-V option (4200-PIV), these solutions offer unprecedented visibility into the Bias Temperature Instability mechanism. Fully automatic cassette-level wafer automation capabilities are available to allow gathering samples of statistically significant size.

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