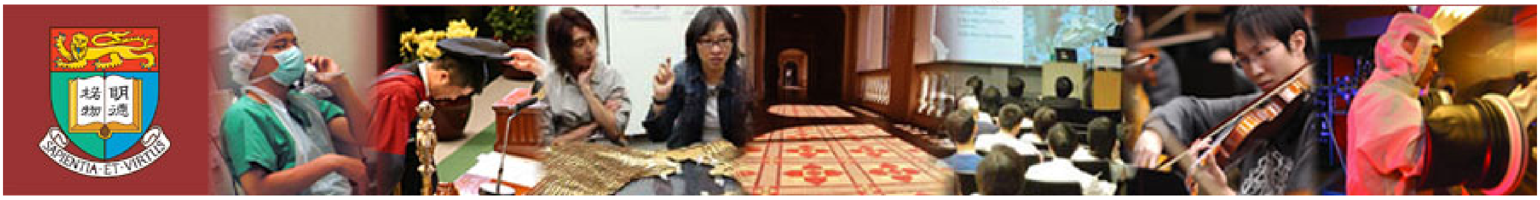

Title	Reproducibility of transmission line measurement of bipolar I-V characteristics of MOSFET's
Author(s)	Chen, TP; Chan, R; Fung, S; Lo, KF
Citation	Ieee Transactions On Instrumentation And Measurement, 1999, v. 48 n. 3, p. 721-723
Issued Date	1999
URL	http://hdl.handle.net/10722/43266
Rights	Creative Commons: Attribution 3.0 Hong Kong License

Reproducibility of Transmission Line Measurement of Bipolar *I–V* Characteristics of MOSFET's

T. P. Chen, R. Chan, S. Fung, and K. F. Lo

***Abstract*—Reproducibility of transmission line (TL) measurement of bipolar current–voltage (*I–V*) characteristics of grounded gate MOSFET's has been examined. It is observed that the reproducibility is related to the duration of the pulses generated by the transmission line, and a longer pulse duration gives a better reproducibility. For a short pulse duration, it is more difficult to reproduce the *I–V* characteristics in the triggering region than in other regions (i.e., the pretriggering and snapback regions).**

***Index Terms*— Bipolar actions, electrostatic discharge, high current pulses, MOSFET's, transmission line.**

ELECTROSTATIC discharge (ESD) is commonly known for its destructive effects on very large scale integrated (VLSI) chips. ESD is a short-time and high-current event. Currently, there are several types of ESD simulators such as human body model, machine model, and charged-device model available for characterizing various categories of ESD pulses [1]–[3]. However, these ESD simulators are of limited use because of the complexity of the waveforms they produce on the devices. The use of simple square pulses on the same time and current scale as ESD events can diagnose and solve ESD problems much more quickly and accurately. Transmission line (TL) pulse generators can provide such short-duration and high-current pulses [4]. The bipolar current–voltage (*I–V*) characteristics (i.e., the drain current versus the drain voltage) of a grounded gate MOSFET can be measured with a TL pulse generator [4]. The *I–V* characteristics are important because the grounded gate MOSFET's are the most commonly used structures in ESD protection circuits in advanced CMOS processes [5]. Note that, the *I–V* characteristics can also be determined by dc measurement, but if the dc current is larger than the second breakdown current, then the device under test (DUT) will be damaged permanently. For dc measurement, the measured *I–V* characteristics are reproducible if the current is smaller than the second breakdown current. However, for TL measurement, to the best of our knowledge no research on the reproducibility of the *I–V* characteristics has been reported. The examination on the reproducibility is particularly important because the bipolar actions (drain/substrate junction avalanche breakdown, negative resistance, etc.) are triggered by a very-short-duration, high-current pulse in TL measurement.

Manuscript received May 25, 1998; revised February 22, 1999.

T. P. Chen, R. Chan, and S. Fung are with the Department of Physics, The University of Hong Kong, Hong Kong.

K. F. Lo is with Chartered Semiconductor Manufacturing Ltd., Singapore 738406.

Publisher Item Identifier S 0018-9456(99)04991-8.

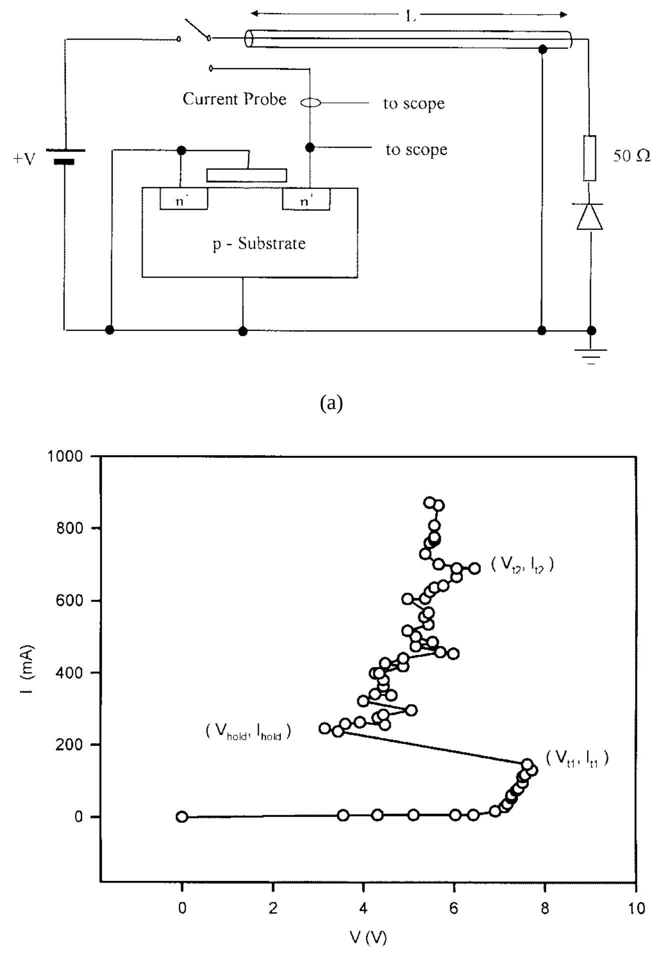

Fig. 1. (a) Experimental setup for transmission line measurements. The current injected into the drain of the device under test was measured with a current probe. (b) Typical bipolar *I–V* characteristics of a grounded gate nMOSFET obtained from transmission line measurement with a pulse duration of 160 ns.

To measure the bipolar *I–V* characteristics for a MOSFET with gate, source and substrate grounded, and with current injection at the drain without causing permanent damage to the device, a short-duration pulse should be used. A charged transmission line can provide such a pulse with the pulse duration $t = 2L/c$, where L is the length of the transmission line and c (≈20 cm/ns) is the propagation velocity. The setup of transmission line measurement for this study is shown in Fig. 1(a). A single square pulse supplied by the transmission line was applied to the drain of the DUT, and the current I passing through the drain and the voltage V dropped on the device were measured with a Tektronix TDS 540 four-channel digitizing oscilloscope (the current was measured by a Tektronix current probe). The devices used in this study were of polysilicon gate n-channel MOSFET's fabricated on p-substrate in a manufacturing environment with a 0.5 μm CMOS technology. A typical *I–V* curve of the grounded gate n-channel MOSFET's obtained from the TL measurement is shown in Fig. 1(b). The pulse duration for the measurement of Fig. 1(b) is 160 ns. The triggering voltage and current (V_{t1}, I_{t1}), holding voltage and current $(V_{\text{hold}}, I_{\text{hold}})$, and second breakdown voltage and current (V_{t2}, I_{t2}) of the DUT can be easily obtained in Fig. 1(b). These parameters are very important for the ESD protection with grounded gate MOSFET's.

In the present study, we observed that it is relatively more difficult to reproduce the *I–V* curves for the devices with some damages caused by high current pulses. If a device is damaged to some extent by high current pulses, the source-drain leakage current (i.e., the current before triggering) is larger, and the triggering voltage is usually smaller. As TL measurement is usually employed to study the effects of high current pulses, it is more important to examine the reproducibility of the measurement for those devices which have experienced some damages. Therefore, in the following discussions, we will focus on only the reproducibility for those devices which have been damaged to some extent. The damages can be generated by high-current (larger than I_{t2} which is about 700 mA for the devices used in the present experiments) pulses. In the reproducibility measurement, in order to avoid further damages caused by the measurement itself, the current used is much lower than I_{t2}.

We will first examine the reproducibility of the *I–V* characteristics that were measured repeatedly for a given pulse duration. Then we will look at the influence of pulse duration on the *I–V* characteristics obtained. As examples, Fig. 2 shows the *I–V* curves which were measured repeatedly. Note that Fig. 2(a) and (b) were obtained with two different devices. The device of Fig. 2(a) showed a simple triggering behavior, while the device of Fig. 2(b) showed a complicated triggering behavior. It is relatively more difficult to reproduce the *I–V* characteristics if the complicated triggering behavior exists. As can be seen in Fig. 2(a), for the pulse duration of 90 ns, in the region before the triggering of the bipolar actions, the *I–V* characteristics can be essentially reproduced, and in the snapback region the reproducibility is also good. However, each measurement gave different triggering voltage and triggering current, i.e., the *I–V* curves were not reproducible in the triggering region. It was observed that for the devices which show a simple triggering behavior [similar to the device of Fig. 2(a)], a good reproducibility can usually be obtained when the pulse duration is larger than about 120 ns. For those devices which show a complicated triggering behavior [similar to the device of Fig. 2(b)], a pulse duration larger than 170 ns can normally give a good reproducibility. It is clear from the above discussions that the pulse duration has a strong influence on the reproducibility of the *I–V* characteristics, particularly in the triggering region.

(a)

(b)

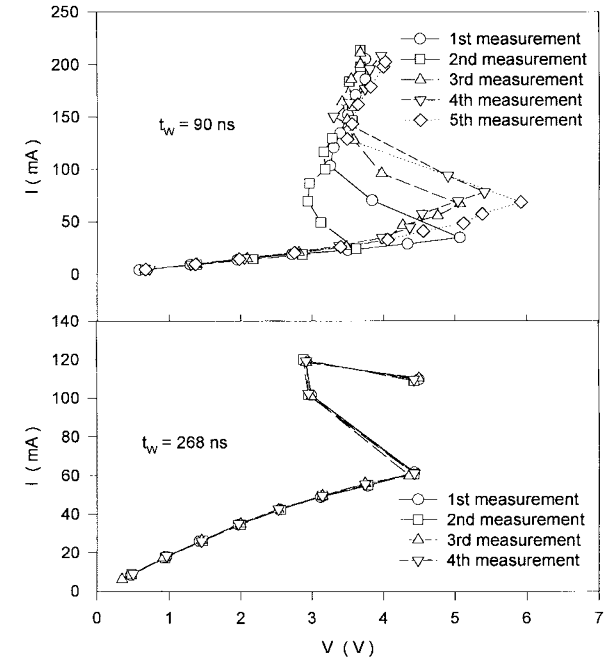

Fig. 2. The *I–V* characteristics which were measured repeatedly for several times with the following pulse duration: (a) 90 ns, and (b) 268 ns. Note that the *I–V* characteristics in (a) and (b) were obtained from two different devices (both had experienced some damage by high-current pulses before the measurements).

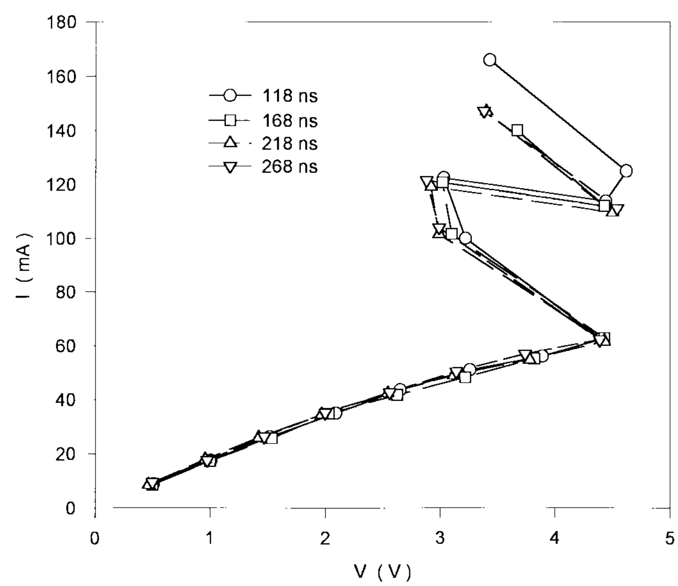

Fig. 3. Influence of pulse duration on the *I–V* characteristics obtained.

The above discussions imply that different pulse duration may lead to different *I–V* characteristics. As an example, Fig. 3 shows the *I–V* characteristics which were obtained with pulse duration of 118 ns, 168 ns, 218 ns, and 268 ns, respectively. The device for Fig. 3 is identical to that for Fig. 2(b). As can be seen in this figure, the measurements for the pulse duration of 168 ns, 218 ns, and 268 ns essentially agree with each other, but there is a significant departure for the pulse duration of 118 ns, particularly in the triggering region. It was generally observed that different pulse duration may give different *I–V* characteristics (the largest difference appears in the triggering region), but as the pulse duration increases, the measured *I–V* characteristics become less dependent on pulse duration. As the *I–V* characteristics are related to the bipolar behaviors of a MOSFET, carrier diffusion/drift and capacitance of the p-n junctions involved may be responsible for the influence of pulse duration on the reproducibility.

In conclusion, the reproducibility of the bipolar *I–V* characteristics of grounded gate MOSFET's determined from TL measurement has been examined. It was observed that the reproducibility is related to the pulse duration, and a longer pulse duration gives a better reproducibility. For a short pulse duration, it is more difficult to reproduce the *I–V* characteristics in the triggering region than in other regions (i.e., the pretriggering and snapback regions). To obtain reliable *I–V* characteristics, the pulse duration must be long enough.

References

[1] MIL-STD-883C, "Electrostatic discharge sensitivity classification," Tech. Rep. Note 8, DOD, Mar. 1989.

[2] R. Renninger, M. Jon, D. Ling, T. Diep, and T. Welsher, "A field-induced charged-device model simulator," in *Proc. EOS/ESD Symp.*, 1989, pp. 59–71.

[3] L. Roozendaal, A. Amerasekera, P. Bos, W. Baelde, F. Bontekoe, P. Kersten, E. Korma, P. Roomers, P. Krys, U. Weber, and P. Ashby, "Standard ESD testing of integrated circuits," in *Proc. EOS/ESD Symp.*, 1990, pp. 119–130.

[4] T. J. Malony and N. Khurana, "Transmission line pulsing techniques for circuit modeling of ESD phenomena," in *Proc. EOS/ESD Symp.*, 1985, pp. 49–54.

[5] C. H. Diaz, S. M. Kang, and C. Duvvury, *Modeling of Electrical Overstress in Integrated Circuits*. Norwell, MA: Kluwer, 1994.

T. P. Chen was born in 1964 in Guangdong, China. He received the B.Sc. and M.Sc. degrees in physics (semiconductors and devices) from Zhongshan (Sun Yat-Sen) University, China, in 1983 and 1987, respectively, and the Ph.D. degree in semiconductor physics from The University of Hong Kong in 1994.

From 1989 to 1991, he was a Visiting Scientist at Fritz–Haber Institute, Max Planck Society, Germany. From 1994 to 1997, he was a Postdoctoral Fellow/Researcher at the National University of Singapore and The University of Hong Kong. He is currently a Senior Scientist with the National Measurement Centre, Productivity and Standards Board, Singapore, working on precision electrical measurements and QHR standard. His research interests are novel semiconductor materials and devices, microelectronic devices and reliability, precision electrical measurements, and quantum standards. He is the author or co-author of more than 50 publications.

R. Chan, photograph and biography not available at the time of publication.

S. Fung was born in Hong Kong in 1950. He received the B.A. degree (first class honors) in physics in 1977, the Dr.Phil. degree in semiconductor physics in 1980, and the D.Sc. degree in 1996, all from Oxford University, Oxford, U.K.

He is currently an Associate Professor, Department of Physics, University of Hong Kong, where he has been since 1983. His major research interests are in semiconductor defect and device characterization using optical, electrical, and positron annihilation techniques.

Dr. Fung is a Fellow of he Institute of Physics (U.K.).

K. F. Lo, photograph and biography not available at the time of publication.