K-5-3

Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp1014-1015

Using Sub-microsecond Measurement to Monitor AC NBTI and Dividing Trap Types into N_{IT}, N_{HT} and N_{FT} through Adjustable Stress Frequency and Measure Frequency

C. H. Chiang, N. Ke, S. N. Kuo, A. Juan, and K. C. Su

United Microelectronics Corp., No. 3, Li-Hsin Rd. II, Hsinchu, Taiwan 30078
Phone: 886-3-5782258#33029; Fax: 886-3-5782965; E-mail: cheng_hao_chiang@umc.com

Abstract

This paper discusses a new measuring skill that helps us to realize characteristic of traps via measure frequency and stress frequency. After considering the activation energy (E_a), traps can be divided into three types. It includes simple concept of Reaction-Diffusion (RD) and two-stage models, and doesn't need complicated mathematics operations. Consequently, it's suitable for industrial process screening.

1. Introduction

The reliability of pMOSFETs is limited by NBTI. Recent NBTI studies for aggressive scaling CMOS technology found the recoverable component. According to the present observation, the recoverable component is contributed by hole trapping while the permanent component is explained by the creation of interface. It implies that NBTI results from two tightly coupled mechanisms [1]. The objective of this work is to propose a new measurement technique with simple concept of reliable trap analysis and realization of characteristic.

2. Experiments and Discussion

We characterized SiON pMOSFETs using instantaneous AC NBTI scheme as shown in Fig. 1 and observed variable ΔVth with different frequency range from 1KHz to 1MHz. The main reason to trigger variation of ΔVth is that *E'* center of hole trap has ability to trapping and de-trapping, and the higher frequency is, the less degradation is due to different capture and emission time (τ_c, τ_e) of trap. Moreover, the stress time is too short to increase permanent trap, so the pumping value of ΔVth is contributed by recoverable component. We can apply the feature of instantaneous AC NBTI to MSM measurement technique. At the same time, measuring points are shortened to two as shown by the dash line in Fig. 1. It has the advantage of reducing the recovery time and improving the convenience of data structure. Our proposed method is *Measure Stress Measure with adjustable Stress Frequency and Measure Frequency* (MSM-SFMF), see Fig. 2. The stress and measure are two separated systems, each frequency, voltage and duty can be modulated independently.

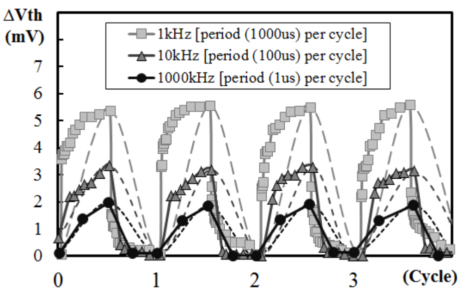

Fig. 1 Sub-microsecond Measurement for Multi-cycle transient ΔVth observed from instantaneous AC-NBTI.

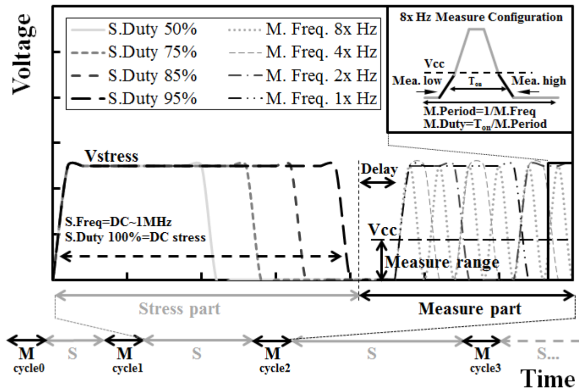

Fig. 2 Illustration of MSM-SFMF of the test Vg waveform. In measure part, observation points can be defined as measure low and measure high represented by dash line in Fig. 1.

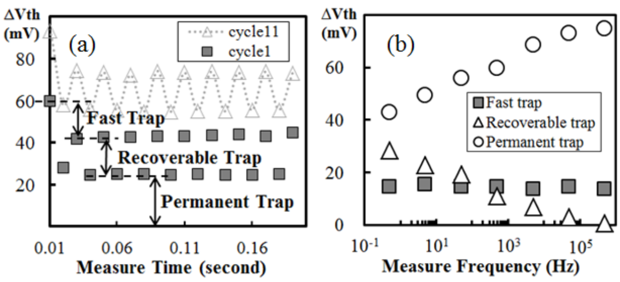

Fig. 3 ΔVth against measure time (a) separated of three trap types. (b) And quantity of different type traps versus measure frequency.

Definition of Trap Types and Measure Frequency Effect:

Fig. 3(a) shows actual monitored data which is adopted 50Hz as measure frequency. We can define three types of trap such as permanent trap, recoverable trap and fast trap. After realizing trap definition, we can modify measure frequency (MF) which is related to (τ_c, τ_e) to understand the behavior of traps. When measure frequency become larger, permanent trap will get more amplitude, on the contrary, recoverable trap will change into opposite result as shown in Fig. 3(b).

Activation Energy and Physical Explanation of Trap:

On the permanent trap view, characteristic of hole trap (N_{HT}) is repeated to make trapping and de-trapping, and it would be observed in high frequency ,and have low temperature sensitivity (E_a~0.02eV). On the other hand, interface trap (N_{IT}) depends on hydrogen diffusion. Hence, it is low frequency dominating, and diffusion coefficient is affected by temperature (E_a ~0.11eV). In addition, we should comprehend that recoverable trap is mostly contributed by hole trap, and permanent trap is contributed by interface trap. After Knowing

Table I E_a is traced by degradation versus temperature. Due to different trap type doesn't have similar behavior so that MF changing will affect E_a. As a result, experimental observation that CF~50Hz

Split	M.Frequency (Hz)	Trap Types	E_a (eV)
Permanent Trap	MF(5000)>>CF	$N_{IT}+\Delta N_{HT}$	0.103
	MF(500)>CF	$N_{IT}+\Delta N_{HT}$	0.106
	MF(50)=CF	N_{IT}	0.109
	MF(5)<CF	$N_{IT}-\Delta N_{IT}$	0.109
	MF(0.5)<<CF	$N_{IT}-\Delta N_{IT}$	0.109
Recoverable Trap	MF(5000)>>CF	$N_{HT}-\Delta N_{HT}$	0.021
	MF(500)>CF	$N_{HT}-\Delta N_{HT}$	0.021
	MF(50)=CF	N_{HT}	0.021
	MF(5)<CF	$N_{HT}+\Delta N_{IT}$	0.084
	MF(0.5)<<CF	$N_{HT}+\Delta N_{IT}$	0.091

about trap types are related to measure frequency and E_a. Critical frequency (CF) is equal to 50Hz which can be obtained from the relationship of E_a and MF referring to Table I. When MF is same as CF, the permanent traps are all N_{IT}, and recoverable traps are all N_{HT}. As for Fast trap (N_{FT}) is irrelevant to MF and not sensitive to temperature (E_a ~0.01eV). Moreover, fast trap will quickly de-trapping (<1μs) when the stress voltage removes, and it is hard to capture carrier again in measure level. According to previous description and concept of As grown Generation model [2], we can re-write new equation (1) as follow:

$$\Delta V_{th_{MSM-SFMF}} = -\frac{q(\Delta N_{FT}+\Delta N_{HT}+\Delta N_{IT})}{C_{OX}}$$

$$= \mathrm{F}\delta(t-T_1) + \mathrm{H}\sum_{N=1,3,5,\ldots}^{N}[S(t-T_N)-S(t-T_{N+1})] + \mathrm{I}t^n \quad (1)$$

F: Coefficient of fast trap. H: Coefficient of hole trap.
I: Coefficient of interface trap. T_N: Measurement points time.
$\delta(t-T_0)$: Dirac delta function. $S(t-T_0)$: Step function.

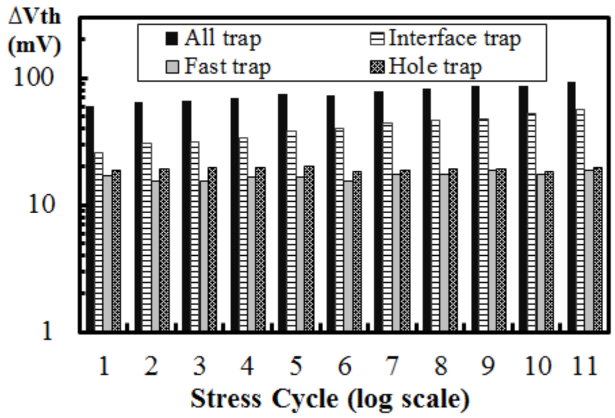

Fig. 4 Degradation of fast trap, hole trap and interface trap during cycle stress sequences.

Characteristic for Hole Trap, Fast Trap and Interface Trap:

All of the experiments below will adopt MF is the same as CF as index. The first experiment is cycle stress. Fig. 4 shows that hole traps and fast traps do not increase with stress time, on the contrary, interface traps increase with stress time showing a power law expected. In addition, we observed the time exponential 'n' for all traps containing a lot of hole traps are smaller

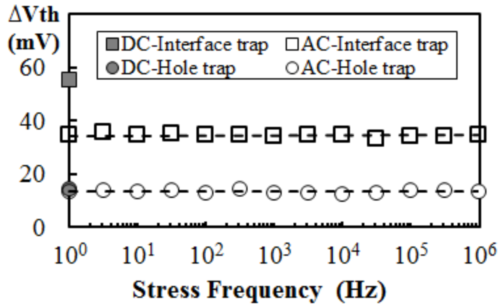

Fig. 5: ΔVth against the stress frequency.

than the RD model prediction that agree with our measured data of interface trap (n~1/6). The second experiment is ΔVth versus stress frequency (SF) as shown in Fig. 5. On AC stress, hole trap and interface trap do not increase with stress frequency. On DC stress, interface trap generates more than on AC stress. The last experiment is pulse duty cycle research (PDC). Our PDC studies can be separated into two parts. One is duty of stress frequency (SF.Duty) as shown in Fig. 6(a). Fast trap equals zero because of fast recovery at half of negative period, and hole trap is not changed with variable SF.Duty. However, interface trap consistent with RD model changes from variable SF.Duty. The other one is duty of measure frequency (MF.Duty) as shown in Fig. 6(b), Kirk effect can be observed [3] because permanent trap contains large quantity of hole traps when MF.Duty approaches to 100% on the DC stress.

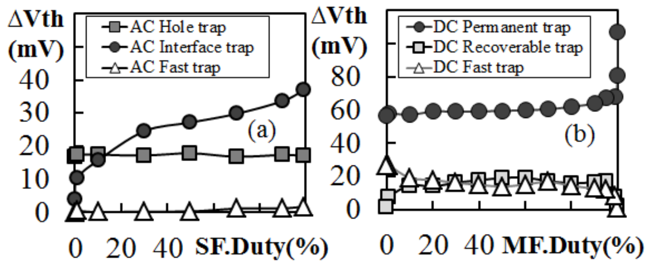

Fig. 6: AC duty cycle against ΔVth. (a) Duty of stress frequency (b) Duty of measure frequency.

3. Conclusions

MSM-SFMF can be used to split into three kinds of trap that are permanent trap, recoverable trap and fast trap. Utilizing measure frequency and activation energy can get critical frequency which is equal to 50Hz. Then interface trap, hole trap, and fast trap will be extracted if measure frequency is the same as critical frequency. The characteristics of the interface trap are increasing with rising stress time, enlarging SF.Duty or converting AC stress to DC stress. On the other hand, The hole trap doesn't change with stress time, SF or DC/AC conversion. Moreover, the fast trap doesn't change from MF, SF.Duty or stress time. In summary, MSM-SFMF owns intuitive concept with high feasibility, and it is very suitable for industrial process screening.

References

[1] T. Grasser, et al., IRPS, p.33, 2009.
[2] Z. Ji, et al., IEDM, p.413, 2013.
[3] S. Desai, et al., IRPS, pp. XT.2.1-9., 2013.