Study on the negative bias temperature instability effect under dynamic stress*

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This paper studies negative bias temperature instability (NBTI) under alternant and alternating current (AC) stress. Under alternant stress, the degradation smaller than that of single negative stress is obtained. The smaller degradation is resulted from the recovery of positive stress. There are two reasons for the recovery. One is the passivation of H dangling bonds, and another is the detrapping of charges trapped in the oxide. Under different frequencies of AC stress, the parameters all show regular degradation, and also smaller than that of the direct current stress. The higher the frequency is, the smaller the degradation becomes. As the negative stress time is too small under higher frequency, the deeper defects are hard to be filled in. Therefore, the detrapping of oxide charges is easy to occur under positive bias and the degradation is smaller with higher frequency.

Keywords: negative bias temperature instability, dynamic stress, recovery
PACC: 7340Q, 7300, 7220J

1. Introduction

As the device dimensions continuously shrink with the rapid development of very large scale integration, negative bias temperature instability (NBTI) has been turned into the most dominant degradation mechanisms among the reliability problems of ultra-deep sub-micro devices. And people have paid more and more attention to NBTI and have done much work on it.[1−10]

The traditional interruption measurement of NBTI during direct current (DC) stress can reflect the degradation of devices, however, the gate bias of p-channel metal-oxide-semiconductor (PMOS) is switching between 'high' and 'low' voltages in the actual complementary metal oxide semiconductor (CMOS) circuits, and the DC stress overestimates the degradation and underestimates the lifetime of the device.[11] The stress with polarity switching is called dynamic stress. The NBTI under the dynamic stress can estimate the lifetime of PMOS field effect transistors (PMOSFETs) more accurately than that under DC stress. The recovery is involved in when 'high' voltage stress is applied to the device, and the passivation of interface states and the detrapping of oxide charges are generally thought to be the reasons of the recovery. However, there is no uniform recovery mechanism by now. In this paper, NBTI under alternate stress with long time period and then alternating current (AC) stress with higher frequencies is studied, and the possible mechanism is presented.

2. Devices and experiments

The PMOSFETs used here are of surface channel. They were manufactured using a 90 nm process technology with lightly doped drain structure and shallow trench isolation scheme. The gate oxides of all devices were annealed in N_2O atmosphere after thermal growth. The devices used here have an ultra-thin gate oxide thickness of 1.4 nm, gate width of 10 μm and gate length of 75 nm. CascadeS300 automatic probe station system, HPS300 pulse generator and HP 4156B, a high precision semiconductor parameter analyser, were used to complete the tests. Besides DC stress, there are another two kinds of stress as shown in Fig. 1: alternating stress, with long time period (in our paper, the time period is 1 thousand seconds); AC

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stress, with higher frequencies (to MHz). And when the gate bias is applied to the device, the source, drain and substrate are all grounded. The experiments are done at temperature 120 °C.

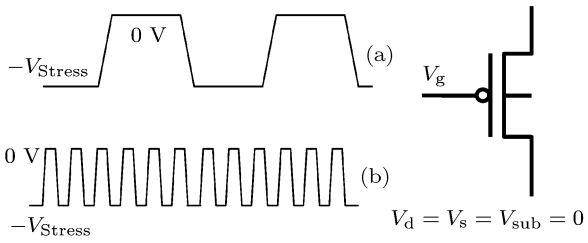


Fig. 1. Schematic diagram of alternating stress and AC stress.

3. Results and discussion

First, NBTI degradation under alternating stress is compared with that under DC stress. The comparison results are shown in Fig. 2. The DC stress is −1.8 V, and the stress time is 6000 s. The solid point lines are the NBTI degradation results of DC stress. The alternating stress includes two processes: the first 1000 s, the gate voltage is −1.8 V, and the second 1000 s, the gate voltage is +1.8 V. The two processes repeat three times, namely the alternating stress insists 6000 s. The hollow triangle and square lines are the NBTI degradation results of alternating stress.

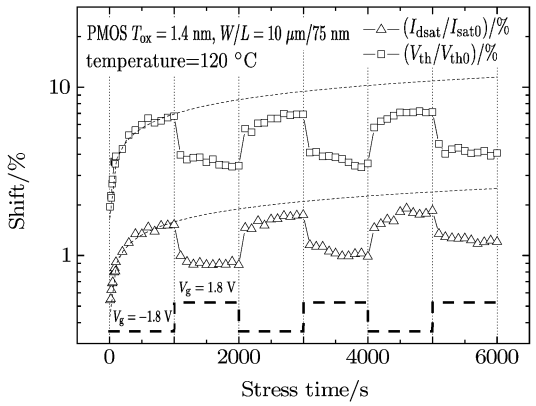


Fig. 2. The degradation shift of $V_{\rm th}$ and $I_{\rm dsat}$ under DC and alternating stresses.

From the results of Fig. 2, we can see clearly that during the first 1000 s, the degradations of threshold voltage $V_{\rm th}$ and the drain current $I_{\rm dsat}$ and DC under alternating stresses are almost the same to each other. During the second 1000 s, the phenomena are different. Under DC stress, the degradation keeps increasing, while there is recovery appearing in both $V_{\rm th}$ and $I_{\rm dsat}$ under alternating stress. As the gate voltage stress is switched from −1.8 V to +1.8 V during the second process, the degradations amount of $V_{\rm th}$ and $I_{\rm dsat}$ becomes smaller, namely, the recovery occurs. And then, when the negative gate voltage stress is applied to the devices for the second time, the degradation begins to increase again. Three time periods mean three cycles of degradation and recovery. The degradation under alternating stress is clearly smaller than that under DC stress after 6000 s. Therefore, the DC stress overestimates the degradation and underestimates the lifetime of the device. And with the time periods increasing, the difference between the degradations of DC and alternating stresses becomes larger.

Figure 3 shows the physical mechanism of degradation under NBTI stress. The NBTI degradation is generally thought to be related to the breaking of SiH bond.[12−14] When negative gate bias is applied, the holes (h^+) are accumulated at surface channel. With the interaction of holes, SiH bonds are broken at elevated temperature. Therefore, the Si dangling bonds are generated and the interface traps are formed. The product H related species moves into the oxide in the direction of PolySi under the effects of electric field and concentration gradient. The positively charged H^+ and holes (h^+) can be trapped in the oxide to produce oxide positive charges. The interface traps and oxide positive charges are the both reasons of generating the degradation during NBTI stress. When positive gate bias is applied, there will generate reverse reactions: the detrapping of H related species and the passivation of interface traps. Therefore, the degradation amount becomes smaller, namely, the recovery phenomenon appears.

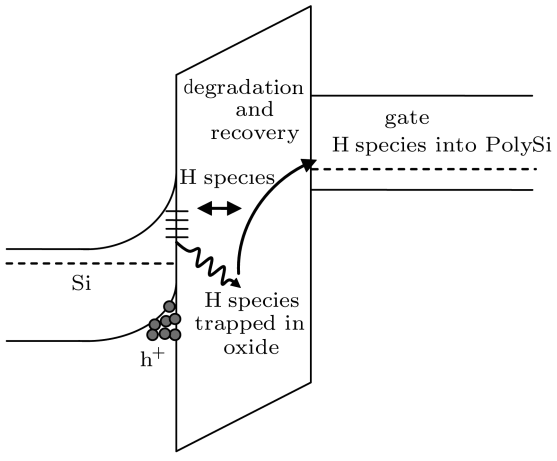


Fig. 3. The physical mechanism of NBTI degradation.

In order to study the mechanism of NBTI degradation clearly, the AC stress is adopted to supply to the device also. The AC stress schematic diagram is just shown as in Fig. 1(b). The AC frequency is from 0 Hz to 10^7 Hz. The negative polarity is −2.2 V, and the duty cycle is 50%. The temperature is 120 °C.

The degradation shifts of $V_{\rm th}$ and $I_{\rm dsat}$ under DC and AC stresses are shown in Fig. 4. From the results, we can see that the relationship of the degradation of both threshold voltage $V_{\rm th}$ and drain current $I_{\rm dsat}$ to the stress time shows a perfect linearity in the log–log scale.

Figures 4(a) and 4(b) show the results of the $V_{\rm th}$ degradation and $I_{\rm dsat}$ degradation. From the results, we can see that with the frequency increasing, the degradations of $V_{\rm th}$ and $I_{\rm dsat}$ get smaller. It is clear that the degradation of the device under DC stress is the most severe. The AC stress improves the lifetime of device compared with that under DC stress. The normalisations of the $V_{\rm th}$ and $I_{\rm dsat}$ degradations under different AC frequency stresses are shown in Fig. 4(c) and 4(d). After linear fitting, we obtain the exponents of degradation in the scale of 0.2–0.3.

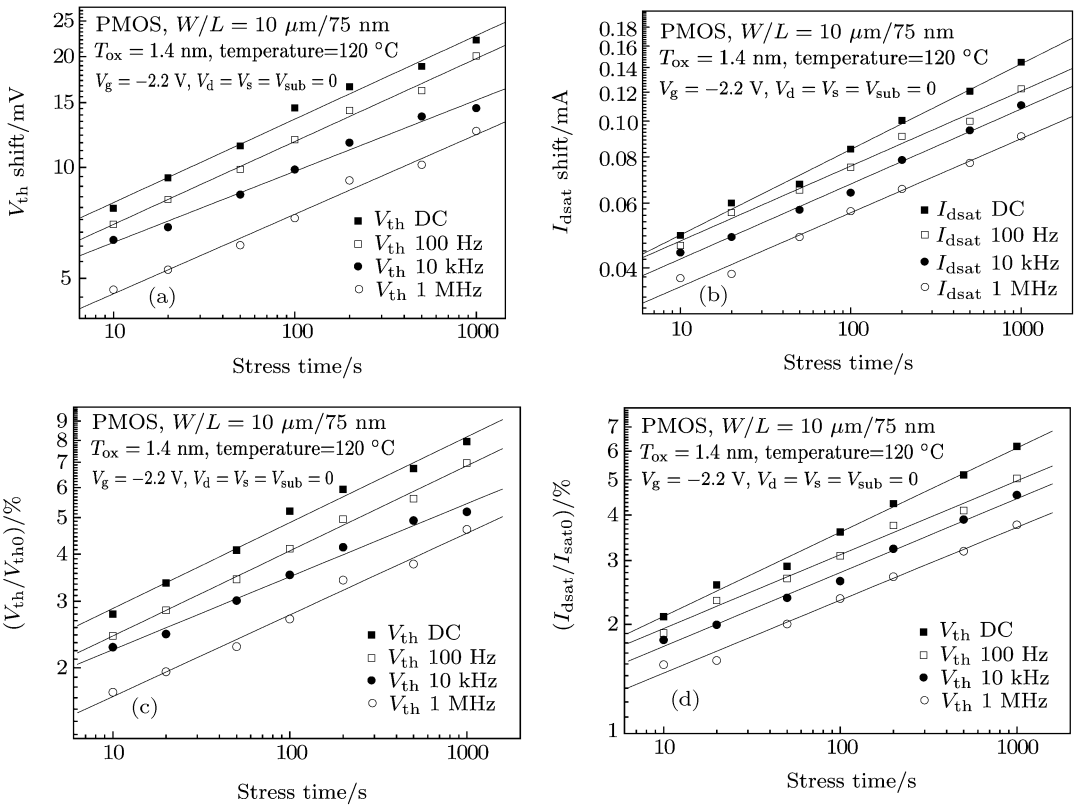


Fig. 4. The degradation shift of $V_{\rm th}$ and $I_{\rm d}$ under DC and AC stresses. (a) $V_{\rm th}$ degradation, (b) $I_{\rm dsat}$ degradation, (c) $V_{\rm th}$ degradation shift/%, (d) $I_{\rm dsat}$ degradation shift/%.

As discussed before, the degradation of device under NBTI stress results from the generation of interface traps and the trapping of positive charges including H^+ and h^+. Meanwhile, the recovery is produced by the reverse reaction: the passivation of interface traps and the detrapping of the positive charges. Therefore, the different degradation amounts should be resulted from the difference of the above reversible reactions.

From the results before, the longer the negative bias stress time is, the larger the degradation is. The reason is the fact that besides the more interface states generated, there are more positive charges produced in the oxide. When we apply the positive bias to the device, there are detrapping effect of the oxide charges besides the passivation of the interface states, this results in the recovery of NBTI.

Under the AC stress, the degradation is related to the frequency. The higher the frequency is, the smaller the degradation is. As shown in Fig. 5, the positive

charges formed in the oxide spread from the lower energy level and shallower location to the higher energy level and deeper location with degradation stress time increasing. It is harder for the oxide charges with higher energy level and deeper location to detrap from the oxide, namely the recovery effect is smaller. During each cycle of the AC stress, the negative bias stress time is shorter with the higher frequency. Therefore, the positive charges with higher energy level and deeper location are fewer in the oxide. And it is easier for the charges with lower energy level and shallower location to detrap from the oxide and can result in the recovery more easily than that with higher energy level and deeper location. Therefore, under the different frequency of AC stresses with the same duty cycle 50%, though the degradation or recovery times are the same, the positive charges are formed with lower energy level and shallower location in the oxide, and can result in the recovery more easily and get lower degradation at last.

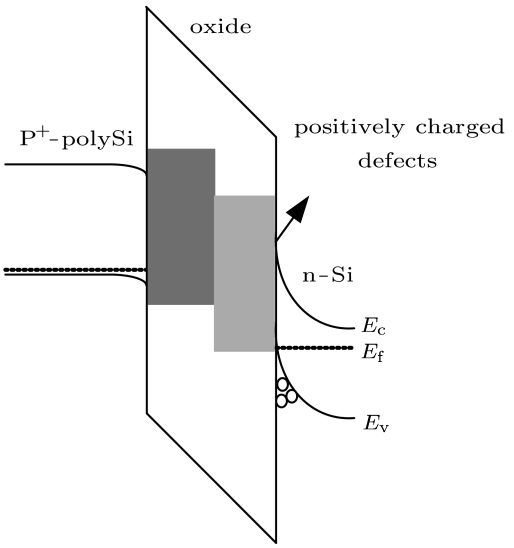


Fig. 5. The positive charges formed in the oxide with different energy levels and locations.

The degradations of $V_{\rm th}$, $I_{\rm dsat}$, and $G_{\rm mmax}$ under different frequency of AC stress are obtained just as shown in Fig. 6. The relationship of the degradations to the frequency shows a perfect linearity in the log–log scale. With the frequency increasing, the degradations all get smaller and testify the validity of the theory.

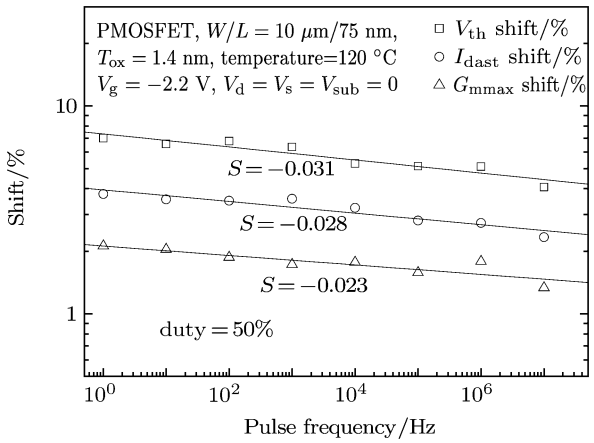


Fig. 6. The NBTI degradations under different frequency of AC stress.

4. Conclusions

In this paper, the NBTI under dynamic stress is studied. From the experimental results, we can obtain that the degradation gets smaller with higher frequency of AC stress. This is because with degradation stress time increasing, the positive charges formed in the oxide spread from the lower energy level and shallower location to the higher energy level and deeper location. In each cycle of the AC stress, the higher the frequency is, the shorter the negative bias stress time is and the fewer the positive charges with higher energy level and deeper location in the oxide. Then the recovery occurs more easily and lower degradation is obtained.

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