RESEARCH ON RELIABILITY OPTIMIZATION MECHANISM OF 28HKMG TECHNOLOGY

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ABSTRACT

With the aggressive scaling down of the gate dielectric, reliability issues especially NBTI (Negative Bias Temperature Instability) and HCI (Hot Carrier Injection) become serious challenges. In this study, the critical roles of both gate dielectric thickness and DPN process are investigated in 28 nm HKMG technology. It's found that under a commercial DPN process, a certain thickness of gate dielectric is required. When this requirement is fulfilled, qualitative changes of NBTI performance could be made through DPN power optimization. And thus, a nitrogen profile modulation model is proposed to explain this significant improvement of NBTI performance after choosing a proper gate dielectric thickness and DPN process power.

INTRODUCTION

With the continuously scaling down of transistors, high-k dielectrics and metal gates are introduced as new gate stacks for solving intolerable tunnel leakage problems [1-4]. Meanwhile, reliability problems such as NBTI and HCI have become major concerns when realizing highly reliable integrated CMOS devices [5-6]. Various NBTI models have been proposed, and Reaction–Diffusion (R–D) model is the most prevalent one, which is highly related to hydrogen terminated silicon dangling bonds [7]. However, the roles played by nitrogen in NBTI performance still have controversies.

In this study, the critical roles of both gate dielectric thickness and DPN process were investigated in 28 nm HKMG technology. And a nitrogen profile modulation model was proposed to explain the internal mechanism of the improvement of NBTI performance.

EXPERIMENT

Wafers of different gate dielectric thicknesses and various DPN powers were prepared. In this experiment DPN power was used to adjust N concentration. All wafers analyzed in this study were manufactured based on HLIC 28 nm HKMG technology. And the NBTI lifetimes of samples were tested by common practice in the industry.

RESULTS AND DISCUSSION

1. The Thickness of Gate Dielectric was Critical

As shown in table 1, only with a certain increase of gate dielectric thickness then a significant improvement of NBTI lifetime could be achieved. The benefit of adjusting the gate dielectric thickness or DPN power separately was low.

DPN Power	**Split**	**IL BSL**	**IL+x**	**IL+2x**	**IL+3x**
BSL	**HK BSL**	1X	6X	7X	70X
DPN-w	**HK BSL**	5X			
BSL	**HK+y**			10X	
DPN-w	**HK+2y**			200X	
DPN-3w	**HK+6y**		100X		

Table 1. The Extent of NBTI Lifetime Improvement under Different Conditions

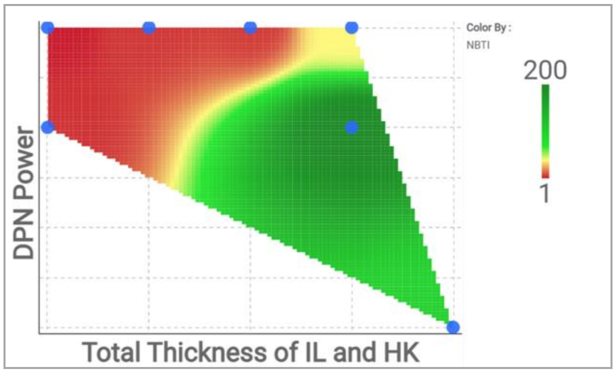

Figure 1. The Extent of NBTI Lifetime Improvement under Different Conditions

To make table 1 more easily be understood, figure 1 was made to illustrate the relationship between dielectric thickness, DPN power and NBTI lifetime. There were mainly three color regions, namely red, yellow and green, which stood for different NBTI lifetime performances. The dots in the red region meant under these combinations of gate dielectric thickness and DPN power the NBTI lifetime performance was not good enough. The results pass a certain criteria would distribute in the yellow or green region. To be noted that the darker the green region, the better the NBTI lifetime performance.

The top four dots in figure 1 illustrated that it's hard to improve NBTI lifetime performance by merely increasing the total thickness of gate dielectric and without lowering the DPN power. Similarly, DPN power alone could hardly make a difference to the reliability performance. However, combine these two factors together significant improvement was made, which was as high as 200 times. Moreover, it was found that to increase same thickness IL got better improvement than HK.

In a word, a certain thickness of gate dielectric was crucial to reliability of NBTI. And it should be related to both electric field intensity of gate dielectric and N distribution of commercial DPN process.

2. DPN Power Could Make a Difference

After the fundamental dielectric thickness was settled, further DPN power splits were carried out and the reliability results were impressive.

With a thicker interface layer (IL), IL+2x, DPN power could make a significant change of NBTI lifetime. Even 2 orders of improvements were demonstrated.

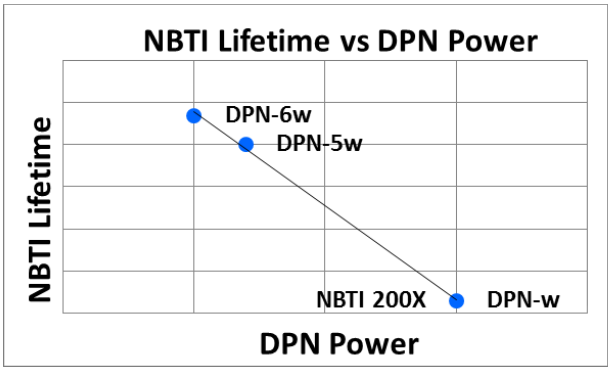

Figure 2. The Extent of NBTI Lifetime Improvement under Different DPN Power, The Interface Layer Thickness was IL+2x

N concentrations under two different DPN powers with same film stack were measured by SIMS as shown in figure 3. On one hand N concentration could be modulated by DPN power efficiently. On the other hand, there was still considerable N concentration in the region of IL even under lower DPN power. And this may be the reason why DPN power alone could not make a major difference to NBTI lifetime.

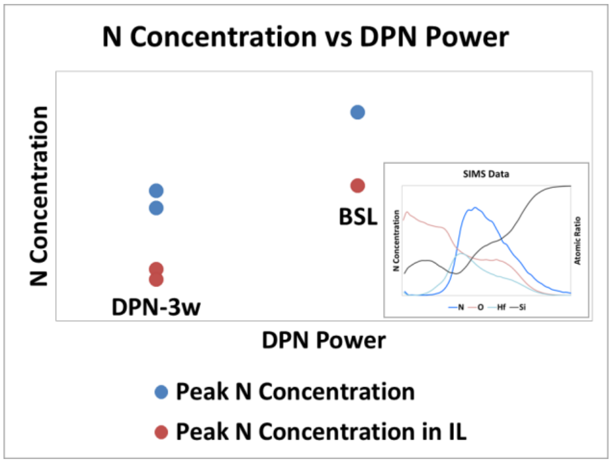

Figure 3. Nitrogen Concentration and Distribution

3. Proposed Model

Based on these results, we proposed a nitrogen profile modulation model to explain the internal mechanism of NBTI improvement, as illustrated in figure 4 and figure 5.

The main idea of this model was that limited by the minimum penetration depth of nitrogen of commercial DPN process, the gate dielectric required a minimum thickness in order to push nitrogen profile away from the interface of IL and silicon(channel). Because nitrogen terminated silicon dangling bonds trend to attract positive hydrogen ions and become stable positive charge centers, which were detrimental to NBTI. Only with enough thickness of gate dielectric, DPN power modulation could be efficient of improving NBTI lifetime.

$$V_T = \phi_{MS} - \frac{Q_{ox}}{C_{ox}} - \frac{Q_{it}}{C_{ox}} + 2\phi_F + \frac{Q_S}{C_{ox}} \tag{1}$$

$$\Delta V_T = -\frac{q(\Delta N_{ox} + \Delta N_{it})}{K_{ox}\varepsilon_0} t_{ox} \tag{2}$$

$$\Delta N_{it}(t) \approx k_F N_0 t \tag{3}$$

$$\Delta N_{it}(t) \approx \sqrt{\frac{k_F N_0}{2k_R}} (D_H t)^{1/4} \tag{4}$$

Formula (1) and (2) were about threshold voltage (Vt) and its shift. In order to minimize the shift of Vt during NBTI test initial interfacial trap density was important according to formula (3) and (4), representing the reaction and diffusion dominated regions respectively according to R-D theory. Further, gate dielectric thickness was also important. Not only because it would affect the electric field intensity directly, but also the N distribution that discuss in this paper.

N in the interface of IL and silicon channel would form Si-N bonds, which had strong attraction to H+ that released from hydrogen terminated silicon dangling bonds. And thus seriously affect NBTI lifetime.

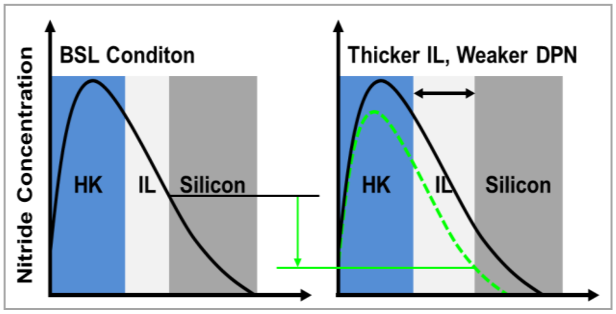

Figure 4. Nitrogen Profile Modulation Model of NBTI Improvement

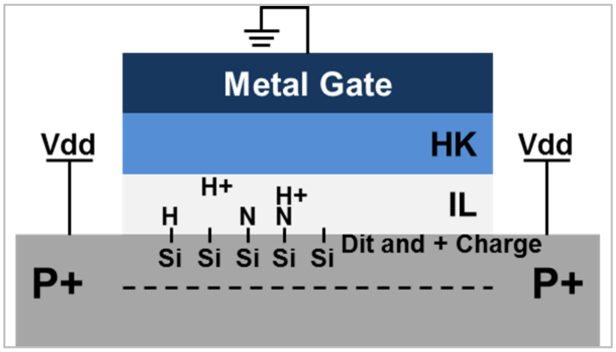

Figure 5. Nitrogen and Dangling Bonds in the Interface

CONCLUSION

We proposed a nitrogen profile modulation model to explain the internal mechanism of NBTI improvement in 28 nm HKMG technology. Limited by the minimum penetration depth of nitrogen of commercial DPN process, the gate dielectric required a minimum thickness in order to push nitrogen profile away from the interface of IL and silicon. With enough thickness of gate dielectric, DPN power modulation could be efficient of improving NBTI lifetime.

ACKNOWLEDGEMENTS

I would like to appreciate senior engineer Ran Huang, Yamin Cao, Wei Zhou for their support and advice on this experiment. At the same time, I am grateful to the reliability team of HLIC for their testing and discussion.

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