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Electrically Detected Magnetic Resonance Study of Interfacial Traps in a Nitrided Submicron Metal-Oxide-Semiconductor Field Effect Transistor

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1. Introduction

As the semiconductor manufacturing technology proceeds, the size of a metal-oxide-semiconductor field effect transistor (MOSFET) has been shrunk more and more. With this trend, the effect of traps at the SiO_2/Si interface generated by the electrical stress becomes larger.

To overcome this problem, several processes have been developed. Among them, the nitridation with nitrous oxide (NO nitridation) has been widely applied. NO nitridation largely enhances the immunity against the Fowler-Nordheim (FN) stress, however, it is known that it can accelerate the negative bias temperature instability (NBTI). Kushida-Abdelghafar *et al*. investigated its mechanism [1]. According to their study, because Si-N bonds formed at the interface by NO nitridation is more stable than Si-H bonds, the amount of interfacial traps generated from the bond breaking by the FN stress can be reduced, while the presence of Si-N bonds enhances the breaking of Si-H bonds, leading to larger NBTI. More detailed study in an atomic scale by electron spin resonance (ESR) was performed by Fujieda *et al* [2]. Their studies are very meaningful, however, samples in their studies are not MOSFET but MOS capacitors because of the poor sensitivity of the conventional ESR.

Therefore, the high sensitive method that makes it possible to investigate interface traps in MOSFET in an atomic scale has been strongly required. More recently, spin dependent recombination (SDR) with high sensitivity was applied to MOSFET to observe the NBTI effect and successfully detected the incremental of P_b-, K-, and E'-centers [3,4]. However, their MOSFET is very large (gate length/gate width (L/W)=100/100 um) in comparison to a recent developed MOSFET and is not NO nitrided.

When SDR is applied to evaluate interfacial traps in a NO nitrided submicron MOSFET, several difficulties are expected. Firstly, its size should matter. SDR detects the subtle change of a surface recombination current under the condition that MOSFET is used as a gate controlled diode. One can easily expect that it is impossible to observe a recombination current in a submicron MOSFET because the number of interfacial traps is very little. This means that the SDR measurement is impossible. In addition, NO nitridation can largely reduce interfacial traps, making the detection more difficult. Therefore, the effect of FN and NBT stresses on interfacial traps in a NO nitrided submicron MOSFET has not been investigated so far.

In this paper, we reported the experimental result about behaviors of interfacial traps in a NO nitrided submicron MOSFET investigated by spin dependent transport (SDT) that is a series of electrically detected magnetic resonance [5]. We could successfully observe interfacial traps and clarified their dependence on FN and NBT stresses in an atomic scale.

2. Experiment

The sample is a five-arrayed submicron nMOSFET (L/W= 0.1/0.18 um). The gate insulator is SiO_2 with 3.5 nm thickness. The nitridation and the annealing under H_2 atmosphere were performed. For the FN stress, -3.5 V was imposed on the gate electrode for 1000 s at room temperature. The NBT stress condition was -1.2 V for 20000 s at 523 K. To suppress the recovery of interfacial traps after the NBT stress, the imposed voltage was maintained during the sample cooling to room temperature.

SDT experiments were carried out with the house-build SDT system based on Jeol FA-300 X-band ESR equipment combined with a high sensitive picoammeter. nMOSFET mounted on a sample holder specially designed for SDT was inserted into the microwave resonator. Gate, source, and drain voltages were fixed to be 0.3, 0, and 0.3 V, respectively. The change of the drain current was measured as a SDT signal ($\Delta I_d/I_d \sim 10^{-5}$) by a lock-in techniques. The alternative field frequency and amplitude were 80 Hz and 0.1 mT. The microwave power was set to be 200 mW. During measurements, the sample temperature was maintained to be 90±5 K using liquid nitrogen. The angle of magnetic field from the [100] direction was 0°. Data acquisition periods were about several weeks for each measurement.

3. Results and Discussions

Fig. 1 showed measured SDT spectra for unstressed, FN stressed, and NBT stressed nMOSFET. We note these as Unstressed, FN, and NBTI below. All spectra show the presence of two traps although a signal is very noisy in Unstressed due to very little amount of traps. We tried detect traps by SDR using MOSFET as agate controlled diode [3,4], however, it failed because we did not found any detectable recombination current. This indicates the significant high sensitivity of our SDT.

In Fig. 1, their zero-crossing g-values are equal to 2.0058±0.001 and 2.0031±0.001 that are agrees well these of P_{b0}- and P_{b1}-centers [6]. The ratio between P_{b0}- and P_{b1}-centers is shown in Fig. 2. Note that because it is difficult to estimate the absolute number of traps from SDT, only P_{b0}/P_{b1} ratio is depicted. In Fig. 2, the ratio is almost equal between Unstressed and FN. This indicates that both centers almost equally increase by the FN stress. On the other hand, after NBTI, its ratio largely decreases. This is because NBTI accelerates the generation of P_{b1}-center, especially as described above.

These phenomena can be explained referring to previous studies [1,2,6]. NO nitridation incorporates nitrogen atoms into the interface and can passivate Si dangling bonds. Nitrogen atoms prefer to terminate P_{b0}-center dominantly. Subsequent H_2 annealing can terminate both P_{b1}-center and resultant P_{b0}-center by hydrogen atoms. This stage corresponds to Fresh. Because during FN stressing, electrons with high energy can break both Si-H and Si-N bonds, both P_{b0}- and P_{b1}-centers increase almost equally. On the other hand, holes with low energy flowing during NBT stressing can dissert Si-H bonds predominantly since the bonding energy is higher for a Si-N bond than for a Si-H bond. Also, it is possible that the presence of Si-N bonds accelerates the breaking of Si-H bonds as pointed out by Kushida-Abdelghafar *et al.* [1]. This means that the generation of P_{b1}-center rather than P_{b0}-center can be largely enhanced. These are reflected in spectral shapes in Fig. 1 and 2.

Noted that unlike a previous study [3,4], no other traps could be detected. We think that it is due to the difference of the measurement technique. Lenahan *et al.* observed *K*- and *E*'-centers inside SiO_2 near the interface with P_b-centers in a NBT stressed large MOSFET by SDR [3,4]. However, we could not detect them by SDT. This fact may imply that although they can play a role as a recombination site, they are irrelevant to the charge transport inside a channel of our nMOSFET. In other words, electrons can flow without being captured by *K*- and *E*'-centers. From this consideration, we think that SDT, unlike SDR, can detect only traps closely correlating with the charge transport in MOSFET.

We believe that high sensitive SDT technique can provide very useful information for manufacturing a submicron device. However, in order to understand the mechanism of the degradation induced by FN and NBT stressing in more detail, it is required to investigate behaviors of traps not only at the interface but also inside SiO_2 in an atomic scale. We have no information about them so far, unfortunately. Other techniques that overcome this problem are strongly desired.

4. Conclusions

Our results can be summarized as follows.

(1) By SDT, interfacial traps even in a submicron MOSFET with very high quality can be detected and its behaviors also can be investigated in an atomic scale.

(2) Because our experimental condition is not special and same with the usual condition for measuring MOSFET transfer characteristics, SDT spectra directly reflect behaviors of only traps that affect on MOSFET transfer characteristics.

(3) We clarified the electrical stress dependence of behavior of interfacial traps in a NO nitrided submicron MOSFET.

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References

[1] K. Kushida-Abdelghafar, K. Watanabe, J. Ushio, and E. Murakami, Appl. Phys. Lett. **81** (2002) 4362.

[2] S. Fujieda, Y. Miura, M. Saitoh, E. Hasegawa, S. Koyama, and K. Ando, Appl. Phys. Lett. **82** (2003) 3677.

[3] J. P. Campbell, P. M. Lenahan, A. T. Krishnan, and S. Krishnan, Appl. Phys. Lett. **87** (2005) 204106.

[4] J. P. Campbell, P. M. Lenahan, A. T. Krishnan, and S. Krishnan, J. Appl. Phys. **103** (2008) 044505.

[5] M. Stutzmans, M. S. Brandt, and M. W. Bayerl, J. Non-Crystalline Solids **266-269** (2000) 1.

[6] Y. Miura and S. Fujieda, J. Appl. Phys. **95** (2004) 4096.

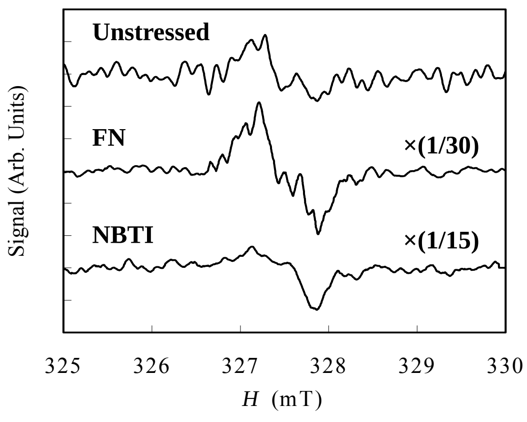

Fig. 1. Measured spectra of all samples.

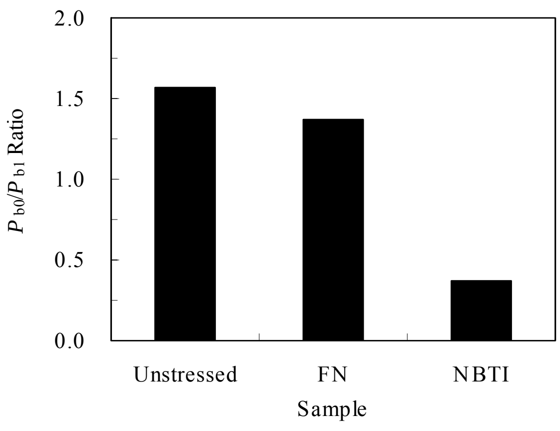

Fig. 2. P_{b0}/P_{b1} ratio of all samples.