A total dose radiation model for deep submicron PDSOI NMOS*

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Abstract: In most of the total dose radiation models, the drift of the threshold voltage and the degradation of the carrier mobility were only studied when the bulk potential is zero. However, the measured data indicate that the total dose effect is closely related to the bulk potential. In order to model the influence of the bulk potential on the total dose effect, we proposed a macro model. The change of the threshold voltage, carrier mobility and leakage current with different bulk potentials were all modeled in this model, and the model is well verified by the measured data based on the 0.35 μm PDSOI process developed by the Institute of Microelectronics of the Chinese Academy of Sciences, especially the part of the leakage current.

Key words: PDSOI; NMOS; total dose radiation model; bulk potential; leakage current

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1. Introduction

Silicon-on-insulator (SOI) technology is rapidly becoming a main stream commercial technology due to its lower power, higher speed and higher packing density. It has been developed for radiation-hardened military and space application for many years owing to its better radiation hardness[1].

Attributed to its full dielectric isolation between individual transistors and reduced sensitive volume, SOI technology offers performance advantages over bulk-silicon technology for single-event-upset (SEU) hardness and dose-rate hardness. However, the response of SOI devices during total-dose radiation is more complex and severe than for bulk-silicon devices[2]. Many papers have been published about the response of SOI devices during total-dose radiation, and they mainly focused on the drift of the threshold and degradation of the carrier mobility when the bulk potential is zero[3−6]. However, the measured data indicate that the total dose effect is closely related to the bulk potential, especially the leakage current changes a lot at different bulk potential.

In this paper, we present a total dose radiation model for deep submicron PDSOI NMOS; this model is a macro model which contains the influence of the bulk potential on threshold voltage, carrier mobility and leakage current. The model is well verified by the measured data based on the 0.35 μm PDSOI process developed by the Institute of Microelectronics of the Chinese Academy of Sciences (IMECAS), especially the change of the leakage current at different bulk potentials.

2. Experiment

The deep submicron PDSOI NMOS with H-gate were fabricated using the 0.35 μm SOI process developed by IMECAS. They were fabricated on UNIBOND SOI wafers. The thickness of the buried oxide, the top silicon film and the gate oxide is 400, 175 and 13 nm. Local oxidation of silicon (LOCOS) was performed to fully consume the active silicon layer in the isolation region. The arsenic was implanted at energy of 100 keV to form source/drain. $TiSi_2$ was formed in the source/drain region.

The channel length and width of the device used in this experiment are 0.35 μm and 10 μm. For the reason that the back channel of the device is radiation hardened, and the front channel is important for the NMOS, we pay attention to the character of the front channel. The bias configuration during radiation is ON, which means the potential of the gate is 3.3 V, and the others are all 0 V, since the worst case bias for the front channel is ON bias configuration[7]. The total dose radiation response of the PDSOI NMOS was characterized using the Co-60 gamma ray radiation facility at the Chemistry College of Beijing Normal University with a dose rate of 100 rad(Si)/s, and the total dose is 300 krad(Si), 500 krad(Si), 1 Mrad(Si) and 5 Mrad(Si). Immediately after radiation, DC characteristics were measured using a Keithley 4200 semiconductor characterization system by device characteristic program (DCP) in less than 1 h. The transfer curve was measured at different bulk potentials with the drain bias V_{ds} = 0.1 V and the back gate bias V_{es} = 0 V.

3. Model building and verification

The transfer curves of the NMOS pre-radiation and after 500 krad(Si) radiation were shown in Fig. 1. It can be seen that the carrier mobility nearly did not change, and the drift of the threshold voltage is related to the bulk potential. The lower the bulk potential, the larger the drift of the threshold voltage. In other words, the threshold voltage is easy to saturate with increasing the total dose. The drift of the threshold voltage and the degradation of the carrier mobility were focused in past studies, however, there is nearly no report about the influence of the bulk potential on the change of them. This will be considered in our model.

Figure 2 shows that the leakage current significantly in-

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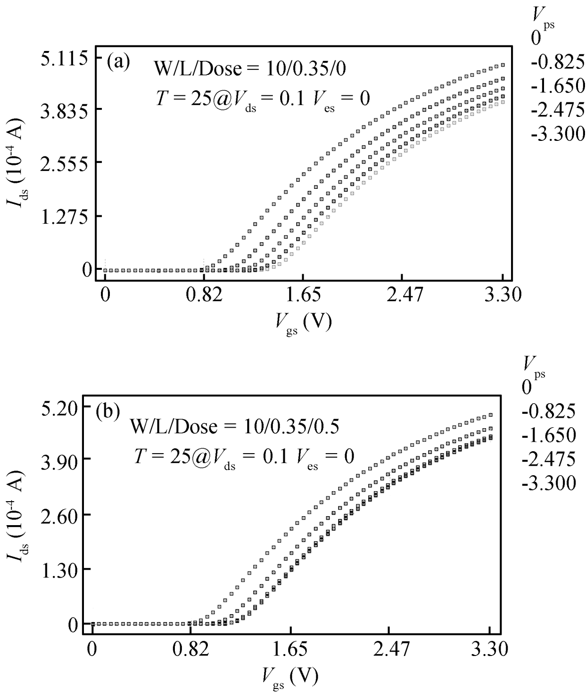

Fig. 1. Transfer curve with different V_{ps}. (a) Pre-radiation. (b) After 500 krad(Si) radiation.

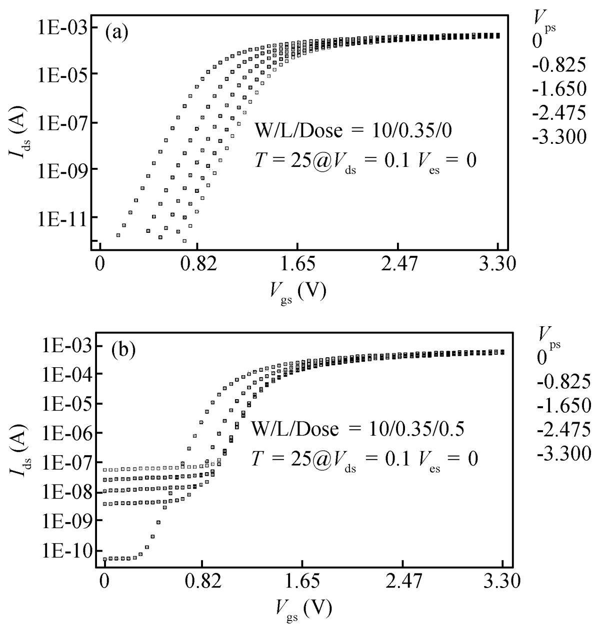

Fig. 2. Subthreshold characteristics with different V_{ps}. (a) Pre-radiation. (b) After 500 krad(Si) radiation.

creases after radiation, and the leakage current increases with decreasing the bulk potential after radiation. There have been many papers about the change of the threshold voltage and carrier mobility, but there is nearly no paper about the increase of the leakage current, let alone the model for this. To find the reason for this phenomenon, we tested the current of the body-drain diode at different bulk potentials after 12-day annealing at room temperature. From Fig. 3, we can get that the current of the diode is the main part of the leakage current. The reason for this is maybe that the interface charge on the depletion region of the PN junction enhances the recombination current of the body-drain diode.

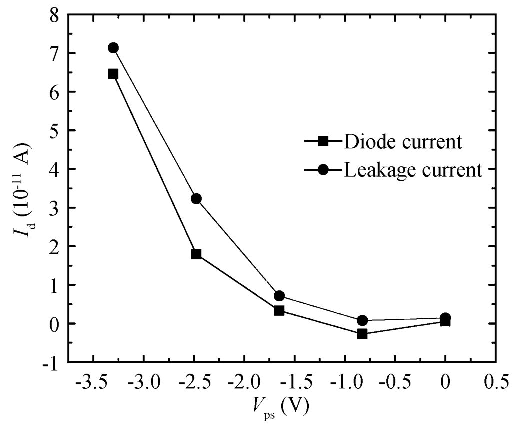

Fig. 3. Leakage current of the NMOS and the current of the drain-body diode at different V_{ps}.

This paper proposed a macro model for the drift of the threshold voltage, degradation of the carrier mobility and the increase of the leakage current, and the macro model needn't the deep understanding of the physical mechanism. The model is implemented in BSIM3-SOI model, and the code of the model is as follows.

```
.param
+a1 = 0.606733   a2 = –0.259932   a3 = –0.219493
+ a4 = –2E-19   a5 = –2.845501E-24   a6 = 1.134E-10
b1 = 1.206E-8   + k10 = 0.53547   k20 = 2.99926E-2   vth00
= 0.714641   ub0 = 1.78982E-18
.subckt nmos d g s e p w = '10u'   l = '10u'   Dose = 0
.param
+k1 = 'k10+a1*Dose'   k2 = 'k20+a2*Dose'   vth0 =
'vth00+a3*Dose'   ub = 'ub0+a4*Dose'
+ a7 = 'a6*Dose'   a8 = 'a5*Dose'   b2 = 'b1*Dose'
M1 d g s e p nmos_pre w = w l = l
G1 d p poly (1) p s a7 a8 b2
.model nmos_pre nmos
***** Flag Parameter ***
+level = 57   version = 3.2   shmod = 1   binunit = 1 ...
vth0 = 'vth0'   k1 = 'k1'   k2 = 'k2'   ub = 'ub'
...
.ends nmos
```

A voltage controlled current source was added between the bulk (P) port and drain (D) port to model the leakage current, and of course, this current source is also related to the total dose. The drift of the threshold is modeled by the change of the parameters v_{th0}, k_1 and k_2, where v_{th0} is threshold voltage when $V_{ps} = 0$ V, and k_1 and k_2 are body effect coefficients. The degradation of the carrier mobility is modeled by the change of parameter ub, where ub is the mobility degradation coefficient.

From the measured data, the parameters are extracted by model builder program (MBP), and Figure 4 is the simulated transfer curve and measured data, where the point is the measured data, and the line is the simulated data. It shows that this model can fit the measured data well, especially the leakage current.

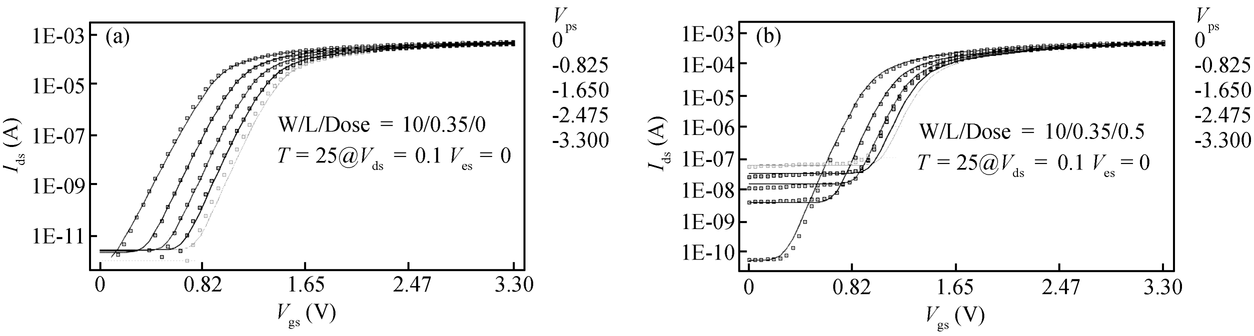

Fig. 4. Simulated and measured subthreshold characteristics. (a) Pre-radiation. (b) After 500 krad(Si) radiation.

4. Conclusion

Considering the influence of the bulk potential on the total dose effect of PDSOI NMOS, a macro model was proposed. The model is easy to build and does not require the deep understanding of the physical mechanism. Then the model is verified well by the measured data, especially the part of the leakage current.

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