Channel Lateral Pocket or Halo Region of NMOSFET Characterized by Interface State R-G Current of the Forward Gated-Diode[*]

HE Jin, HUANG Ai-hua, ZHANG Xing and HUANG Ru

(*Institute of Microelectronics, Peking University, Beijing* 100871, *China*)

Abstract: The channel lateral pocket or halo region of NMOSFET characterized by interface state R-G current of a forward gated-diode has been investigated numerically for the first time. The result of numerical analysis demonstrates that the effective surface doping concentration and the interface state density of the pocket or halo region are interface states R-G current peak position dependent and amplitude dependent, respectively. It can be expressed quantitatively according to the device physics knowledge, thus, the direct characterization of the interface state density and the effective surface doping concentration of the pocket or halo becomes very easy.

Key words: forward gated-diode; R-G current; MOSFET; pocket or halo implant region; interface states; effective surface doping concentration

EEACC: 2530; 2560R; 1570D

CLC number: TN386   **Document code**: A   **Article ID**: 0253-4177(2001)07-0826-06

1 Introduction

It is well known that one of the aims of device research and development is to further scale down the feature size. However, when the transistor sizes shrink into the sub-micron or deep-sub-micron ranges, some especial physics issues will take place and severely obstacle the improvement in the device performance deduced from the proportionally scaling law.

On one hand, further decrease in the feature size leads serious short channel effects (SCE), which may lost control of the gate over the channel region to some extent. In order to avoid the short channel effects, the pocket or halo implantation is widely used in deep-sub-micron CMOS technologies[1, 2], which, however, will also result in large drain-induce V_T shift and low R_{out} that will greatly affect the analog circuit design and its performance. Therefore, the optimization of the pocket or halo design is of very importance for the maximum output resistance, while we maintain the acceptable SCE property. Therefore, the pocket or halo technology as the extension of the channel region, will complicate the extraction of the basic parameters of a device, and it is difficult to characterize this region effectively. As far as we know, no direct and effective method has been found to extract the surface doping concentration of the pocket or halo re-

gion for the optimal design of a device by far, though this parameter is very important.

On the other hand, as the transistor´ size shrinks into the sub-micron or deep sub-micron ranges, the lateral high electrical fields will induce the interface states. These interface states, mainly adjacent to the source and drain pocket or halo edges, will lead the degradation in device performance and deterioration of the used lifetime. For better understanding and to model the device performance, it is necessary not only to considerably reduce the interface states but also to effectively characterize them. Moreover, if the device sizes were scaling down into deep sub-micron region, many conventional characterizing methods, such as the C-V technique and parameter shifts of the MOSFET, would become insensitive and not applicable for the characterization of this especial region.

Recently, a refined gated-diode structure has been used to characterize the interface states and extract the bulk carrier recombination lifetime in a SOI device by measuring the recombination-generation (R-G) current, with some good results achieved[3, 4]. Based on the similar lateral SOI gated-diode configuration, we have analyzed the characteristics of the R-G current of the bulk traps, and a revised gated-diode method has been to presented to separate the interface states and bulk trap components from the total R-G current[5, 6]. The method has proved simple, sensitive, quickly applicable and nondestructive.

In this paper, the channel lateral pocket or halo region of NMOSFET has been characterized by using the interface state R-G current of a forward gated-diode for the first time. Through discrete numerical analysis with DESSIS-ISE[7], the interface states R-G current is demonstrated to be valid in the characterization of the interface state density and the surface doping concentration of the channel pocket or halo region. Since the channel region R-G current peak has been separated effectively from that of the especial surface doping region, the indi-

vidual characterization of the channel region interface state, the pocket or halo region interface state and the effective surface doping concentration becomes easy and feasible. In addition, the R-G current peak position and the peak amplitude are used as a direct and sensitive indicator to show the effective surface doping concentration and the average interface state density of the pocket or halo region, respectively, so as to evaluate the pocket or halo region.

2 Structure and Simulation

The device used in this study is a common NMOSFET. The simulated gated-diode structure is realized by the source and drain/body N^+P junction with a forward bias voltage of 0.3V, as shown in Fig. 1. The channel length, including the pocket or halo region, is chosen as $10\mu m$ in order to enlarge the effect of the interface states. The structural parameters concerned are given in Table 1.
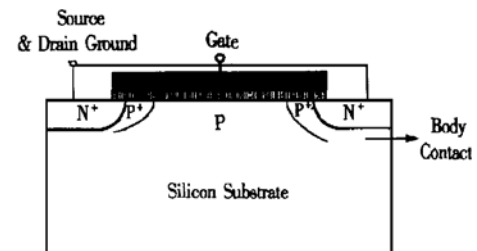

FIG. 1   Cross-Section of Simulated Gated-Diode

Table 1   Parameters Used in the Simulation

Parameter	Value	Type
N^{++} or P^{++} Concentration/cm^{-3}	1×10^{20}	Uniform
P^- Concentration/cm^{-3}	5×10^{16}	Uniform
Silicon Film Thickness/nm	800	
Gate Oxide Thickness/nm	10	N^+-Poly Contact

For the sake of convenience, we assume the interface states are located in the front interface, and the interface states of the channel and pocket or halo regions are evaluated by using the interface state density (N_{it}). The depth and width of the pocket or halo junction are fixed to be 0.2μm and

$3\mu m$, respectively. The source and drain junction is $0.15\mu m$. The main physics models used in the simulation are summarized in Table 2. Unless note especially, all the parameters are given the values in Table 1.

Table 2　Models Used in the Simulation

Recombination Models	Mobility Model	Transport Model
Avalanche	Doping	Diffusion-Drift
Auger	Dependence	
SRH	Phumob	
BGN	Enormal	

3　Simulation Results and Discussion

In this simulation, the pocket or halo doping concentration and the interface state density, as both independent variables, are intended to change. All the discrete simulated values are labeled. One simulation result of the structure is show in Fig. 2.
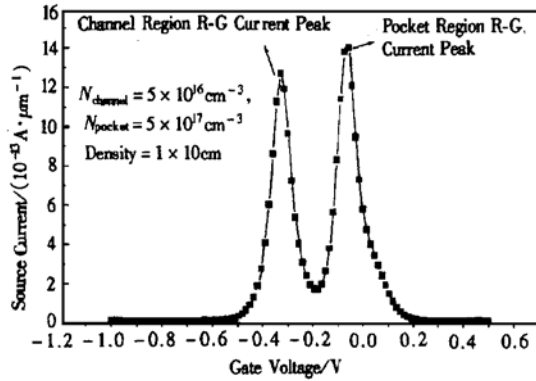

FIG. 2　R-G Current Characteristics of Gated-Diode with Pocket or Halo Structure

It can be seen that there are two R-G current peaks in this figure. The R-G current peak on the left of this figure is considered to correspond to the channel region interface states, the other the interface states of the pocket or halo region. Therefore. the R-G current peak position of the pocket or halo region is totally different from that of the channel region. According to the device physics, we draw a conclusion that the R-G current peak of the pocket or halo region will emerge when the gate voltage scans to the positive value so that the pocket or halo region becomes a depleted case.

The recombination-generation via interface state levels is known governed by SRH statistics. The recombination rate R for a single trap level at the intrinsic energy E_i is

$$R = \frac{n_1 p_1 - n_i^2}{\tau_{p0}(n_1 + n_0) + \tau_{n0}(p_1 + p_0)} \quad (1)$$

Based on SRH statistics theory, the maximum recombination rate is obtained when the surface and/or interface are in the intrinsic state, thus the R-G current shows a sharp increase peak in the scanning gate voltage axis. The relationship between the current peak value and the interface state density can be described simply as:

$$\Delta I_{peak} = \frac{1}{2} q n_i (c_n c_p)^{1/2} N_{it} A_G e^{\frac{q V_B}{2kT}} \quad (2)$$

where n_i is the intrinsic carrier density, N_{it} is the density of an interface trap, A_G is an individual R-G current peak corresponding to the gate area, and V_d is the small forward-voltage applied to diode. Here, $c_n = c_p = 10^{-8} cm^{-3} \cdot s^{-1}$ [5].

As a result, the interface state density of the pocket or halo region can be directly extracted from this expression at the corresponding R-G current peak.

According to MOS device physics, the critical gate voltage, under which the R-G current peak occurs, can be further expressed quantitatively.

$$V_g = V_{ox} + \frac{kT}{q} \ln\left|\frac{N_{eff}}{n_i}\right| + V_{FB} + \frac{Q_{interface}}{C_{ox}}$$
$$+ \frac{\sqrt{4\epsilon_{si} q N_{eff} \phi_F}}{C_{ox}} \quad (3)$$

where all symbols have the common meanings.

According to this expression, the R-G current peak position of the pocket or halo region can be derived from that of the channel region, besides, the amplitude of the doping concentration of the pocket or halo region can be calculated with equation (3) as well, due to the significant difference in the pocket or halo region doping concentration between it and that of the channel region.

Therefore, it is direct and simple to characterize the lateral lightly doping region of the pocket or halo NMOSFET by using the forward gated-

diode R–G current method considering the interface state and effective surface doping concentration. In practice, the interface state density and the effective surface doping concentration can be extracted directly from the measured R–G current peak and the corresponding gate voltage.

Owing to the band-gap-narrow (BGN) effect caused by the high doping concentration of the pocket or halo region, the R–G current of the pocket or halo region shows a higher peak than that of the channel even if they are at the same interface state density of 5×10^{10} cm^{-2}. Based on the basic SRH theory with BGN effects taken into account,
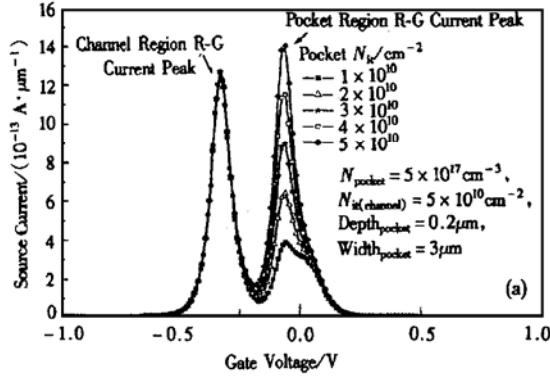
the interface states of the pocket or halo region with this effect can also be extracted from the value of R–G current peak.

Figure 3 illustrates the sensitivity of R–G current versus the interface state density of the pocket or halo region. The R–G current peak shows high sensitivity to the interface state density. The larger the interface state density is, the higher the R–G current peak would be. Furthermore, the critical voltage of the R–G current peak is found almost constant at different interface state density of the pocket or halo region.
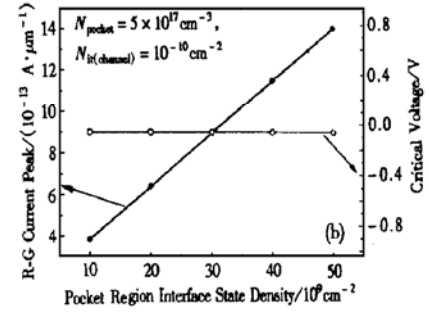

FIG. 3 (a) R–G Current Characteristics at Different Interface State Density for Gated-Diode with Pocket or Halo Structure; (b) R–G Current Peak and Critical Voltage Versus Interface State Density of Pocket or Halo Region for Gated-Diode with Pocket or Halo Structure

In Fig. 4, it is shown the R–G current characteristics at different doping concentration of the pocket or halo region. As we can see, both the position and amplitude of the R–G current peak of the channel region keep constant at the same channel doping concentration, while those of the pocket or halo region change with the pocket or halo's doping concentration. It is very interesting that the position of the R–G current peak is a direct and simple indicator of the doping concentration of the pocket or halo region. In other words, the doping concentration or ion-implantation dose of the pocket or halo region can be easily obtained from the R–G current peak. The R–G current peak position is a sensitive monitor of the change in the doping con-

centration of the pocket or halo region.

In practice, due to the influence of the sequent annealing and drive-in, it is difficult to measure or characterize the effective surface doping concentration of the pocket or halo region directly. Fortunately, it becomes easy by using the R–G current peak position method. As shown in Figs. 3 and 4, the surface doping concentration of the pocket or halo region can be directly extracted from the $V_{G\text{-peak}}$. The intrinsic theoretical voltage of the pocket or halo doping concentration in 1.1×10^{18} cm^{-3} region is calculated to be 0.195V according to the device physics, while that obtained by using the R–G current method is 0.18V, so they agree with each other very well.
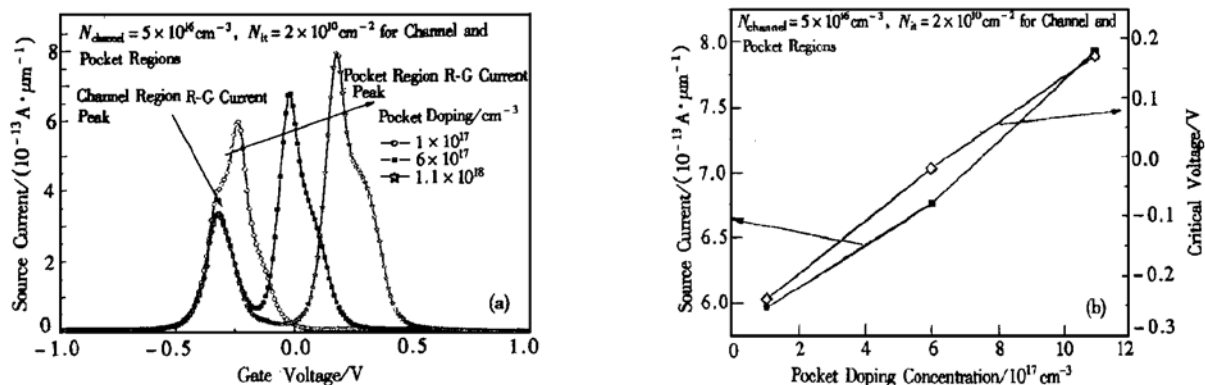
FIG. 4　(a) R-G Current Characteristics at Different Doping Level of Pocket or Halo Region; (b) R-G Current Peak's Position Versus Doping Level of Pocket or Halo Region

4　Conclusion

In this paper, the characterization of the lateral lightly doping region of a pocket or halo of NMOSFET with forward gated-diode R-G current method has been studied numerically by using DESSIS-ISE, an advanced semiconductor device simulator. The relationships between the R-G current peak amplitude and the interface state density of the pocket or halo region, R-G current peak position and the pocket or halo doping concentration, respectively, have been revealed.

The simulation results show the dependence of pocket or halo region's R-G current on the scanning gate voltage. It is also demonstrated that significant difference in characteristics exist between the R-G current of the pocket or halo region and that of the channel region. With the method proposed, the interface state density and the effective surface doping concentration of the pocket or halo region can be evaluated easily. Moreover, this method is numerically sensitive to the variation in the interface state density and the effective surface doping concentration of the pocket or halo region.

References

[1]　Bin Yu, H. J. Wann Clement, Edward D. Nowak et al., Short-Channel Effect Improved by Lateral Channel-Engineering in Deep-Submicrometer MOSFET's, IEEE Trans. Electron Devices, 1997, **ED-44**: 627—633.

[2]　Akira Hiroki, Shinji Odanaka and Atsushi Hori, A High Performance 0.1μm MOSFET with Asymmetric Channel Profile, IEDM '95, 1995, 439—443.

[3]　T. Ernst, S. Cristoloveanu, A. Vandooren et al., Carrier Lifetime Extraction in Fully Depletion SOI Devices, Proceeding of 1998 IEEE International SOI Conference, Oct., 1998, 21—22.

[4]　T. Ernst, S. Cristoloveanu et al., Recombination Current Modeling and Carrier Lifetime Extraction in Dual-Gated Fully-Depleted SOI Devices, IEEE Trans. Electron Devices, 1999, **ED-46**: 1503—1509.

[5]　He Jin, Huang Ru, Zhang Xing and Wang Yang-yuan, Numerical Analysis on Characterized Interface Trap of SOI Devices by R-G Current, Chinese Journal of Semiconductors, 2000, **12**: 1146—1151.

[6]　He Jin, Huang Ru, Zhang Xing, Huang Ai-hua and Wang Yang-yuan, Gated-Diode R-G Current: A Sensitive Tool for Characterizing the Back Traps of SOI Devices, Chinese Journal of Electronics, 2001, 2.

[7]　User's Manual of DESSIS-ISE 6.0, Integration System Engineering, Inc., 2000.

正向栅控二极管的 R-G 电流直接表征 NMOSFET 沟道 pocket 或 halo 注入区*

何 进 黄爱华 张 兴 黄 如

(北京大学微电子学研究所, 北京 100871)

摘要: 使用半导体器件数值分析工具 DESSISE-ISE, 对正向栅控二极管 R-G 电流表征 NMOSFET 沟道 pocket 或 halo 注入区进行了详尽的研究. 数值分析表明: 由于栅控正向二极管界面态 R-G 电流的特征, 沟道工程 pocket 或 halo 注入区的界面态会产生一个独立于本征沟道界面态 R-G 电流特征峰的附加特征峰. 该峰的幅度对应于 pocket 或 halo 区的界面态大小, 而其峰位置对应于 pocket 或 halo 区的有效表面浓度. 数值分析还进一步显示了该附加特征峰的幅度对 pocket 或 halo 区的界面态变化的敏感性和该峰的位置对 pocket 或 halo 区的有效表面浓度变化的敏感性. 根据提出的简单表达式, 可以用实验得到的 R-G 电流的特征直接抽取沟道工程的 pocket 或 halo 注入区的界面态和有效表面浓度.

关键词: 正向栅控二极管; R-G 电流; NMOSFET; pocket 或 halo 注入区; 界面态; 有效表面浓度

EEACC: 21560R; 2560F; 0590

中图分类号: TN386   **文献标识码**: A   **文章编号**: 0253-4177(2001)07-0826-06