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


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 \(R_{on}\) 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-

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HE Jin  male, 33, post-doctoral researcher. His current research interests focus on the deep sub-micron SOI device optimum and characterization and new MOS-based power devices.

ZHANG Xing  male, 35, professor. He has been working in the area of sub-micron CMOS/SOI process, simulation and design of ASICs since 1986.

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region 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-4 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.\textsuperscript{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 presented to separate the interface states and bulk trap components from the total R-G current.\textsuperscript{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\textsuperscript{37}, 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 special surface doping region, the individual 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 10μm in order to enlarge the effect of the interface states. The structural parameters concerned are given in Table 1.

![Cross-Section of Simulated Gated-Diode](image)

**Table 1** Parameters Used in the Simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>N' or P' Concentration/cm\textsuperscript{3}</td>
<td>1×10\textsuperscript{20}</td>
<td>Uniform</td>
</tr>
<tr>
<td>P Concentration/cm\textsuperscript{3}</td>
<td>5×10\textsuperscript{16}</td>
<td>Uniform</td>
</tr>
<tr>
<td>Silicon Film Thickness/μm</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>Gate Oxide Thickness/μm</td>
<td>10</td>
<td>N' -Poly Contact</td>
</tr>
</tbody>
</table>

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 ($N_a$). The depth and width of the pocket or halo junction are fixed to be 0.2μm and...
3 μm, respectively. The source and drain junction is 0.15 μm. The main physics models used in the simulation are summarized in Table 2. Unless noted especially, all the parameters are given the values in Table 1.

<table>
<thead>
<tr>
<th>Recombination Models</th>
<th>Mobility Model</th>
<th>Transport Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avalanche</td>
<td>Doping</td>
<td>Diffusion-Drift</td>
</tr>
<tr>
<td>Auger</td>
<td>Dependence</td>
<td></td>
</tr>
<tr>
<td>SRH</td>
<td>Plumbob</td>
<td></td>
</tr>
<tr>
<td>RGN</td>
<td>Enormal</td>
<td></td>
</tr>
</tbody>
</table>

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

$$R = \frac{n_1 p_1 - n_2^2}{\tau_0 (n_1 + n_0) + \tau_1 (p_1 + p_0)}$$  \hspace{1cm} (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:

$$\Delta I_{\text{peak}} = \frac{1}{2} q n_i (c_i c_p)^{1/2} N_{\text{sh}} A e^{-\phi_f}$$  \hspace{1cm} (2)

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

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.

$$V_g = V_{th} + \frac{kT}{q} \ln \left( \frac{N_{\text{sh}}}{n_i} \right) + V_{th} + \frac{Q_{\text{interface}}}{C_{ox}}$$

$$+ \frac{\sqrt{4 \pi e q N_{\text{sh}} \phi}}{C_{ox}}$$  \hspace{1cm} (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 $5 \times 10^{10} \text{cm}^{-2}$. 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.

![Graph](image)

**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 concentration 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 $V_{\text{G-peak}}$. The intrinsic theoretical voltage of the pocket or halo doping concentration in $1.1 \times 10^{19} \text{cm}^{-3}$ 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.
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.

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References


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 黄亚华 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 DESSIS-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

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何 进 男, 33 岁, 博士后, 目前研究方向为深亚微米 MOS 器件、功率 MOS 器件、深亚微米 MOSFET 新结构的设计和表征等。
张 兴 男, 35 岁, 教授, 博士生导师, 研究方向为深亚微米 MOS 器件、工艺和 ASIC 设计。
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