Study on Maximum Electric Field Modeling Used for HCI Induced Degradation Characteristic of LDMOS Transistors

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Supported by MoDeCH Inc.
OUTLINE

- Introduction

- Our Research
  - HCI Degradation Modeling
  - Maximum Electric Function Equation

- Conclusion
OUTLINE

■ Introduction

■ Our Research
  ➢ HCI Degradation Modeling
  ➢ Maximum Electric Function Equation

■ Conclusion
Background and Object

Reliability Test Problem in Circuit Design

<table>
<thead>
<tr>
<th>Test Items</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Temperature Operating Life</td>
<td>$Ta=125^\circ C$</td>
</tr>
<tr>
<td></td>
<td>$V_{op_max}, 1000h$</td>
</tr>
<tr>
<td>Temperature Humidity Bias</td>
<td>$Ta=85^\circ C$</td>
</tr>
<tr>
<td></td>
<td>$85%RH$</td>
</tr>
<tr>
<td></td>
<td>$V_{op_max}, 1000h$</td>
</tr>
</tbody>
</table>

Our object

Circuit design considering with reliability simulations
Research Purpose

- Degradation modeling by HCI of n-channel LDMOS’
- Maximum electric field modeling for reliability circuit simulations

HCI: Hot Carrier Injection, LDMOS: Laterally Diffused MOSFET
Degradation by Hot Carrier Injection

Important parameters

- Threshold voltage
- Carrier mobility
Degradation of LDMOS Devices

Cross view section view of an the LDMOS [1]

Electric field distribution of n-channel LDMOS [2]

High lateral electric field at the gate edge 😞

Maximum Electric Field Model should be developed !!
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HiSIM-HV Model for Modeling Vehicle

- Hiroshima-University STARC
- IGFET Model - High Voltage
- International Industry Standards Model
- Based on Surface-Potential

[1] HiSIM-HV 2.2.0 User's manual
HiSIM-HV Model used for LDMOS

Drift region

- Voltage drop at drift region
- Represent as an internal variable $R_{drift}$

[1] HiSIM-HV 2.2.0 User's manual
Model Parameter Extraction and Simulations

- Used measured data

Cross section view of an n-channel LDMOS [3]

Process data [3]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>process size</td>
<td>0.18 um</td>
</tr>
<tr>
<td>gate length</td>
<td>0.4 um</td>
</tr>
<tr>
<td>gate width</td>
<td>20 um</td>
</tr>
<tr>
<td>oxide thickness</td>
<td>11.5 nm</td>
</tr>
</tbody>
</table>

Analysis of Stress Measurement Results

**Ids-Vgs characteristics**

- Vth is not changed
- Decreasing Ids

**Ids-Vds characteristics**

- Ids in saturation region is Not changed
- Ids in pinch-off region is decreased

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Parameter Selection of HiSIM-HV

\[ R_{\text{drift}} = (R_d + V_{ds}R_{DVD}) \left( 1 + \frac{RDVG11}{RDVG12}V_{gs} \right) \]

\[ (1 - V_{bs}RDVB) \left( \frac{LDRIFT1 + LDRIFT2}{DDRIFT - W_{dep}} \right) \]

\[ R_d = \frac{R_{d0}}{W_{eff,LD}NF} \left( 1 + \frac{RDS}{(W_{gate}10^6L_{gate}10^6)^{RDSP}} \right) \]

\[ R_{d0} = (RD + R_{d0,\text{temp}})f_1f_2 \]

[1] HiSIM-HV 2.2.0 User’s manual
RD Degradation Model

RD : Before 1.1mΩ  After 1.4mΩ

Increased $R_{on}$ by decreasing carrier in drift region
Maximum Electric field for the Degradation Model

\[
\frac{\Delta R_{\text{on}}}{R} = A_1 \cdot \ln\left(1 + \frac{t}{\tau}\right) + A_2 \cdot \ln\left(1 + \frac{t}{\gamma\tau}\right)
\]

\[
\tau = \alpha \cdot W \cdot \frac{\phi_b}{I_D} \cdot \frac{\phi_b}{E_m \lambda} \cdot e^{E_m \lambda}
\]

Electric field distribution of n-channel LDMOS [2]

Referred by “An LDMOS hot carrier model for circuit reliability simulation”
Problems of the Referred Model

The maximum electric field is fitting functions, so far.

We developed maximum electric field model equations.

Electric field distribution of n-channel LDMOS [2]

Peak electric field of n-channel LDMOS [4]
Maximum Electric Field Function Equation

Function Eq.

\[ E_m = A \cdot \exp[-\exp(-z) - z + 1] \]

Amplitude

\[ A = \alpha \frac{(V_{DS} - V_{DSAT})}{L_{\text{eff}}} \]

Peak location

\[ z = \frac{(V_{GS} - V_{TH} - V_{GS_{\text{max}}})}{\beta} \]

\( \alpha, \beta \) : fitting parameter, \( V_{GS_{\text{max}}} \) : maximum \( V_{GS} \), \( V_{TH} \) : threshold voltage

- Lateral electric field depends on \( V_{ds} \)
- Flexible peak value and location
The peak value of electric field agrees with T-CAD simulation.
The shape of calculated curves is close to T-CAD simulation.
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Conclusion

- We have characterized fresh and stressed n-channel LDMOS with measurement and simulations.

- We have derived the maximum electric field model equations and demonstrated the effectiveness.

References

[1] HiSIM-HV 2.2.0 User’s manual
Thank you for your kind attention

謝謝
発表に使っているLDMOSのプロセスはどこのものか
→ 論文のデータなので、詳細は不明です

電界モデルは、SPICEに入れる予定なの？
（のようなことを聞かれたと思う）
→今後の課題として取り組みます。
（上手く伝わりませんでした）