Extended Abstracts of the 1999 International Conference on Solid State Devices and Materials, Tokyo, 1999, pp. 240-241

Hot Electron Transport in Si-MOSFETs

Toshitsugu Sakamoto, Hisao Kawaura, Takahiro Iizuka[1], and Toshio Baba

Fundamental Research Labs., NEC, 34 Miyukigaoka, Tsukuba, Ibaraki 305-8501, Japan
Phone: +81-298-50-1111 Fax: +81-298-56-6139 e-mail: sakamoto@frl.cl.nec.co.jp
[1]ULSI Device Development Labs., NEC, 1120 Shimokuzawa, Sagamihara, Kanagawa 229-1198, Japan

1. Introduction

The gate length of MOSFETs continues to be scaled down while keeping the operating voltage constant over several device generations. Therefore, the electrical fields in the channel have tended to increase and hot carriers are increasingly generated. Ballistic transport of the hot electrons can cause velocity overshooting, which increases the operating speed in small-feature-size MOSFETs [1]. To forecast future MOSFETs, it is thus important to investigate hot electron transport in decanometer-gate-length regimes. We have investigated hot electron transport in Si-MOSFETs and derived the characteristic length of hot electrons for the first time. This was accomplished by using a lateral hot-electron transistor (LHET) with two potential barriers.

2. Device structure and fabrication

The LHET consists of an upper gate, two lower gates (an emitter and a collector gate), and four ohmic contacts (Fig. 1). When a positive voltage is applied to the upper gate, n-channels that are self-aligned with the lower gates are induced in the Si surface and effectively work as the emitter (E), base (B), and collector (C) [2,3]. By biasing the emitter gate voltage (V_{ge}) and the collector gate voltage (V_{gc}), we can control the barrier height of the emitter barrier that acts as a hot-electron injector and of the collector barrier that acts as a spectrometer. The resistance between two base contacts is monitored to ensure that the base is not depleted of carriers for the gate voltages used in the experiments.

The LHET fabrication was identical to the conventional n-MOSFET process except for the gate fabrication. The poly-Si lower gates were fabricated by electron-beam lithography with a high-resolution resist (Calixarene) and reactive-ion etching with CF_4 (Fig. 2). The base length (l_B) between the emitter and the collector gate is an important parameter when examining the ballistic nature of hot electrons. We fabricated LHETs with l_B = 72 and 131 nm. The width of the lower gates was 0.15 μm, which was larger than those of our previously reported devices [4]. This doubled the current amplitude of the collected hot electrons and enabled us to observe hot electrons in a device with $l_B > 100$ nm.

3. Results and discussion

The measured collector current for the LHET with $l_B = 72$ nm is shown in Fig. 3. Measurements were made at 100 K. When I_E of -2 nA was applied to the emitter and V_{ge} was biased at -1.0 V (curve A), I_C remained finite below the threshold voltage of the collector gate (note that I_C was cut off for $V_{gc} < 1.8$ V in curve D). This finite current originated from hot-electron transport. When a negative I_E and a negative V_{ge} are biased simultaneously, a negative V_E is induced and electrons with energy above $-eV_{EB}$ are injected via the emitter barrier into the base. The hot electrons with enough energy to overcome the collector barrier can cause a positive I_C.

When $V_{BC} > 0$ V (curves B and C), only the hot electrons can be collected at the collector since the electrons with low energy cannot flow into the collector due to the potential gradient (inset of Fig. 3). The maximum I_C (I_{max}) of curve B was 0.1 nA, which is 5% of the injected current. The fraction γ ($= |I_{max}/I_E|$) increased with increasing $-V_{ge}$ (*i.e.* $-V_{EB}$) (Fig. 4). Moreover, the fraction γ depended strongly on l_B. When $-V_{EB} \simeq 1.3$ V and $V_{gu} = 8$ V, $\gamma = 0.07$ for $l_B = 72$ nm and $\gamma = 0.007$ for $l_B = 131$ nm. From the l_B dependence of γ (Fig. 5), the characteristic length L_C could be estimated by fitting into the equation:

$$\gamma = |\frac{I_{max}}{I_E}| = exp(-\frac{l_B}{L_C}). \tag{1}$$

The resulting length L_C is summarized in Table I. For $V_{gu} = 8$ V, L_C was 25 nm and decreased with increasing V_{gu}. This reduction in L_C may have been caused by either surface roughness scattering, which is stronger for higher vertical electric-fields, or by electron-electron scattering, which depends on the carrier density.

Table I: Characteristic length of hot electrons

V_{gu} (V)	L_C (nm)
8	25
10	23
12	21

4. Conclusions

We have investigated hot electron transport by using LHETs with a 10-nm gate-length emitter gate. Up to 7% of the injected current was due to hot electrons at an emitter-base voltage of -1.3 V. We estimated that the characteristic length of hot electrons ranges from 21 to 25 nm at this emitter-base voltage. These results show that hot electron transport will play a crucial role in future MOSFETs with gate lengths of 20 nm or less.

This work was performed under the management of FED as a part of the MITI R&D of Industrial Science and Technology Frontier program (Quantum Functional Devices Project) supported by NEDO.

References

[1] T. Mizuno, *et al.*, *Appl. Phys. Lett.* **69**, 106 (1996).
[2] A. Palevski, *et al.*, *Phys. Rev. Lett.* **62**, 1776 (1989).
[3] H. Kawaura, *et al.*, *SSDM Ext. Abst.*, 25 (1998).
[4] T. Sakamoto, *et al.*, *Ext. Abst. of the 46th Spring Meeting of Jpn. Soc. of Appl. Phys.*, 28p-G-4 (1999) (in Japanese).

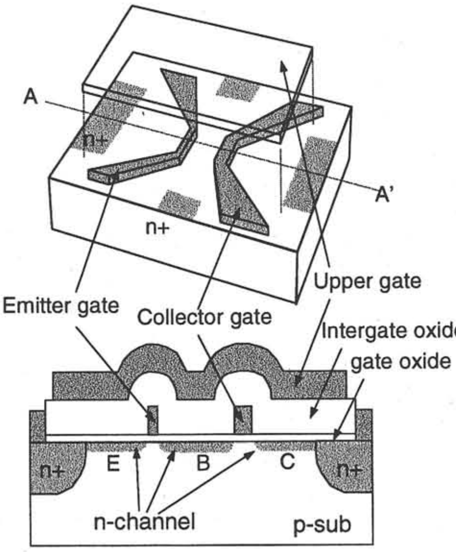

Figure 1: Device structure of a lateral hot electron transistor (LHET): top view and cross-sectional view along A-A'. Boron concentration of the substrate was 2×10^{18} cm^{-3}. The gate oxide was 5 nm thick.

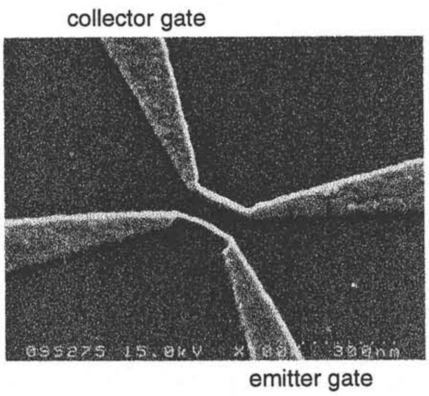

Figure 2: SEM photograph of the emitter and the collector poly-Si gate after the upper gate and intergate oxide were removed.

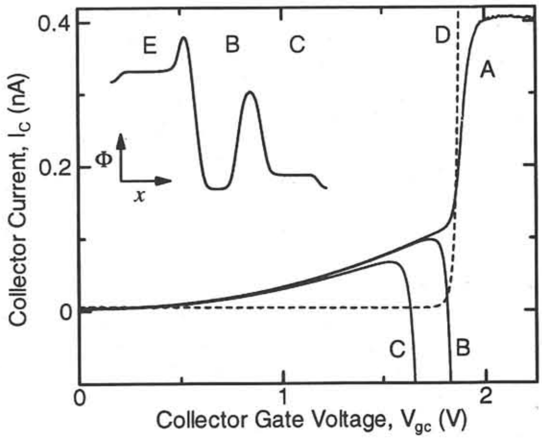

Figure 3: Collector current (I_C) versus collector gate voltage (V_{gc}) for the LHET with l_B = 72 nm. For curves A, B and C, $V_{ge} = -1.2$ V, $I_E = -2.0$ nA, and V_B = 1 V. V_{EB} was induced at -1.27 V. V_C was varied at 1 V (curve A), 0.99 V (B) and 0.9 V (C). Curve D shows the cutoff characteristics of the collector gate when V_{ge} = 0 V, $V_E = V_B$ = 1 V and V_C = 1.01 V. V_{gu} was fixed at 10 V for all curves. Inset: Potential profile of LHET at the biasing condition of curve C.

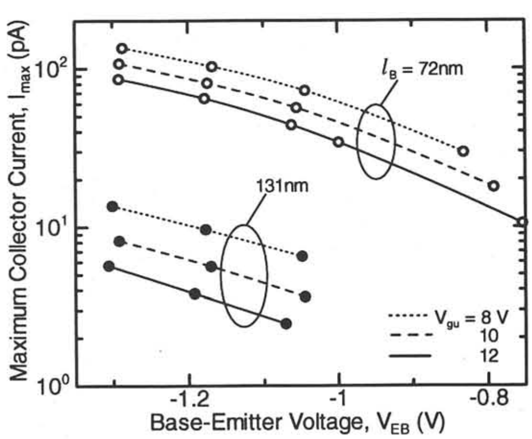

Figure 4: Maximum I_C (I_{max}) at V_C = 0.99 V as a function of V_{EB} for V_{gu} = 8, 10, and 12 V. Open (solid) circles show I_{max} for l_B = 72 (131) nm.

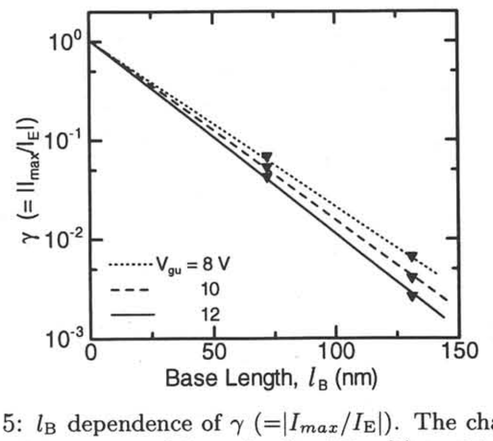

Figure 5: l_B dependence of γ ($=|I_{max}/I_E|$). The characteristic length is extracted from the fit of Eq. (1) to this data.