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A — 3 — 6 New Observation of Hot-Carrier Injection Phenomena

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We have observed new hot-carrier injection mechanisms in MOS transistor by directly measuring the gate current in devices having sub-micron gate lengths and very thin oxides. The new mechanisms, rather than the already reported channel hot-electron injection mechanism, are more responsible for the hot-carrier related device degradation, which constitutes the most stringent limitation on submicron MOS transistors.

The devices used in the present study were n-channel silicon gate MOS transistors. Structural dimensions are summarized in table 1. The injection processes were investigated by mesuring the gate current, I_G, for each devices under various bias conditions.

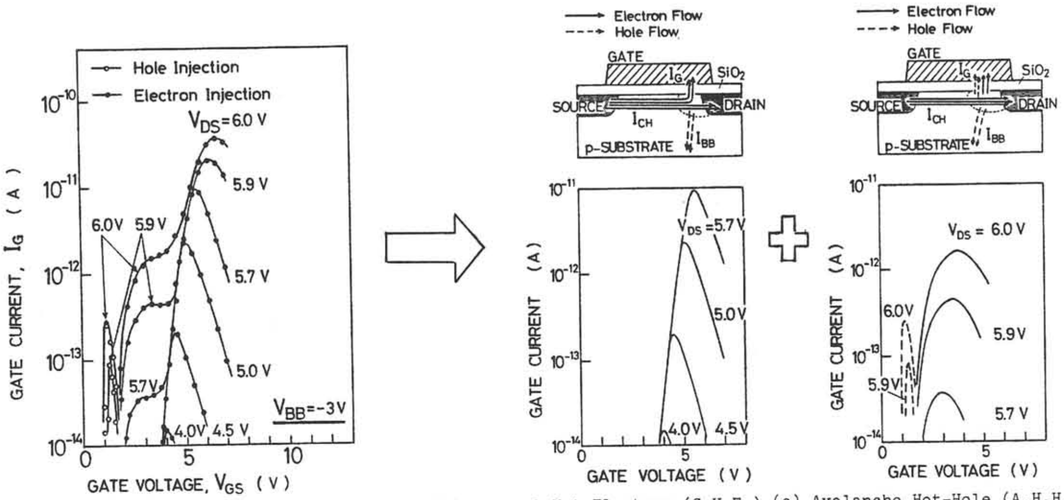
Figure 1 (a) shows the gate current, I_G, for device A as a function of the gate voltage, V_{GS}. I_G was classified as one of two types based on bias condition dependency. For bias condition $V_{DS} \leqslant 5.0$ V, a single peak was observed when $V_{GS} \simeq V_{DS}$ (Fig.1 (b)). This was determined to be channel hot-electron injection, as in previous works$^{1)}$. However, for bias condition $V_{DS} > 5.5$ V, two additional peaks were observed, one at $V_{GS} \simeq 1.2$ V and one at $V_{GS} \simeq 3.5$ V (Fig.1(c)). These peaks correspond to hole and electron injection, respectively. This experiment is the first observation of the hot-hole and hot-electron injection due to drain avalanche plasma which has been predicted theoretically by Hara$^{2)}$ and Fair et al.$^{3)}$. These new phenomena are named Avalanche Hot-Hole (A.H.H.) and Avalanche Hot-Electron (A.H.E.), respectively.

The gate current characteristics for device B are shown in Fig.2. For bias condition $V_{DS} \leqslant 5.0$ V, a single I_G peak is observed when $V_{GS} \simeq 3.5$ V. This also corresponds to electron injection. This injection can be clearly distinguished from channel hot-electron or avalanche hot-electron injection, by its strong dependency on substrate bias voltage, V_{BB}. As V_{BB} decreases, I_G increases and its dependency on V_{GS} becomes similar to that of substrate current, I_{BB}.

We decided that this injection is caused by substrate hot-electrons. A schematic illustration of the injection process is shown in Fig.3. Holes generated in the drain avalanche region and accelerated towards the substrate, can induce secondary impact ionization$^{4)}$. Some of the electrons generated by this ionization are injected into the gate oxide by the strong electric field close to the surface. To confirm our explanation of this injection mechanism, we performe a simulation with a simple, one-dimensional model. From this simulation, we determined that this kind of injection really does occur when channel doping is as high as 1×10^{17} cm^{-3}. Therefore, we call this injection " Secondary Ionization Induced Substrate Hot-Electrons (S.I.H.E.)".

The mechanisms of hot-carrier injection in n-channel MOS transistors with sub-micron dimensions can clearly be classified using these results. Two new kinds of injection modes were observed. Consequently, hot-carrier injection phenomena that can take place under practical bias conditions are as follows:

1) Channel Hot-Electron (C.H.E.) Injection;
2) Avalanche Hot-Hole (A.H.H.) and Electron (A.H.E.) Injection;
3) Secondary Ionization Induced Substrate Hot-Electron (S.I.H.E.) Injection.



(a) Measured raw data of gate current.

(b) Channel Hot-Electron (C.H.E.) injection.

(c) Avalanche Hot-Hole (A.H.H.) and Electron (A.H.E) injection.

Fig.1 Gate current characteristics observed in device A

REFERENCES

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Table 1 Structural data of the devices investigated

Device		A	B
Channel Length	(μm)	0.8	1.0
Channel Width	(μm)	14.0	
Junction Depth of S&D	(μm)	0.2	
Gate oxide thickness	(nm)	10.2	6.8
Peak Acceptor Concentration	(cm^{-3})	1×10^{17}	2×10^{17}

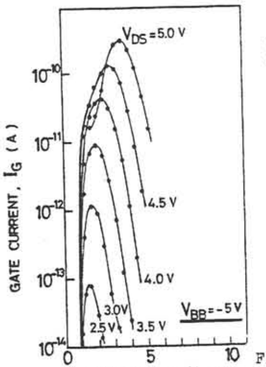

Fig.2 Gate current characteristics observed in device B.

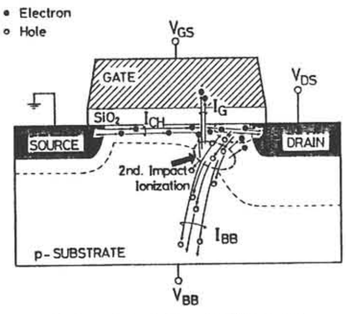

Fig.3 Schematic illustration of a secondary ionization induced substrate hot-electron (S.I.H.E.) injection process.