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A−2−5 Dependency of Channel Hot-Electron Injection on MOSFET Structure

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Hot carrier injection into a gate oxide, and subsequent trapping, are most important when considering reliability of miniaturized n-channel MOSFETs in VLSIs. We have been investigating the dependence of hot-electron injection upon MOSFET structures, in the search for structures suitable for scaling down to the submicron level.

We have tested various kinds of structures. Drain junction structure and channel doping proved to be significant when optimizing device structure. Several structural parameters were also varied over a wide range in our studies. For example, channel length was varied over a range of 0.5-5 μm.

All these devices were evaluated for gate current due to hot-electron injection, under the biasing conditions $V_D = V_G$. Figure 1 shows gate current for conventional As-diffused drain structure as a function of bias $V_D = V_G$, with effective channel length as a parameter. We define the highest applicable voltage, $BV_{DC}$, which represents the resistance of a device against hot-electron injection, as the bias $V_D = V_G$ which causes a gate current of $1x10^{-15}$ A/μm. In this determination, we took an extrapolated shift of 10 mV in threshold voltage over ten years, which would be caused by an injection current of $1x10^{-15}$ A/μm, as being allowable.

It can be seen in Fig.1 that shrinking of effective channel length drastically lowers $BV_{DC}$. The scaling-down of other structural parameters, such as gate oxide thickness, junction depth for source and drain diffusion layers, substrate resistivity and channel implant dose, also intensifies the injection of hot electrons. An example of this dependence is shown in Fig.2, which shows that increase in channel impurity density appreciably lowers $BV_{DC}$.

Figure 3 shows the limits placed by several physical mechanisms, such as punchthrough, avalanche multiplication and hot-electron injection, on the highest applicable voltage, which is given as a function of effective channel length. It can be clearly seen that hot-electron injection imposes the severest limit. It should be noted that, for a device having an effective channel length of 1.0 μm, the highest applicable voltage limited by hot-electron injection, $BV_{DC}$, drops below 5 V. This demonstrates the urgent need for improving the resistance of devices against hot-electron injection.

In order to determine a device structure optimum for relaxing hot-electron constraints, we have used a numerical model of hot-electron injection for arbitrary impurity doping profiles. As a result, we have fabricated three kinds of devices, having structures such as graded drain junctions (P-diffused drain or As-P double-diffused $n^+$-$n^-$ drain junctions), offset-gates and buried channels.

Figure 4 shows $BV_{DC}$ for these devices, as a function of effective channel length. A 2-volt improvement in $BV_{DC}$, as compared with the conventional As-drain device, is obtained for devices having graded junctions, and a 1-volt improvement for devices having offset-gates or buried channels. A 1-2 volt increase in highest applicable voltage, $BV_{DC}$, is quite appreciable in attempt to realize VLSI compatibility in supply voltage with the existing systems enviroment. The feasibility of these devices at the VLSI integration level, from the viewpoint of fabrication and operation, will be discussed.

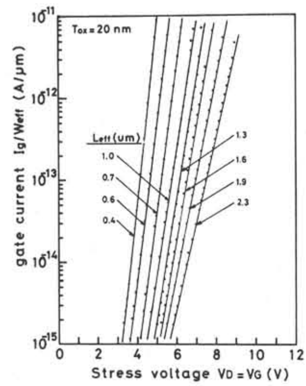


Fig.1 Dependence of gate current, given as a function of the bias $V_D$=$V_G$, on effective channel length

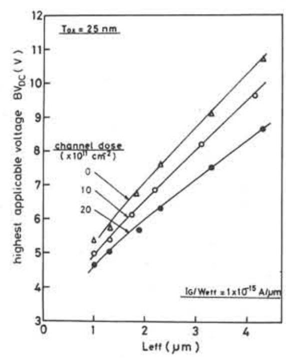


Fig.2 Dependence on channel dose of highest applicable voltage, $BV_{DC}$, which is limited by hot-electron injection

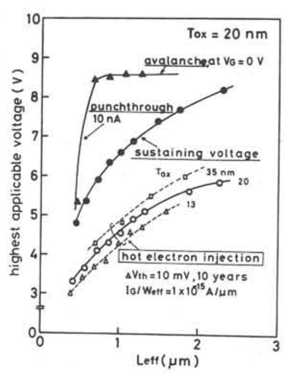


Fig.3 Comparison of the effects of several physical mechanisms on the highest applicable voltage

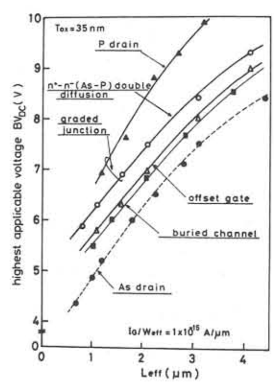


Fig.4 Comparison for various kinds of MOSFET structures of highest applicable voltage, $BV_{DC}$