Extended Abstracts of the 1991 International Conference on Solid State Devices and Materials, Yokohama, 1991, pp. 20-22 **A-1-5**

A Study of Hot-Carrier-Effects in SOI-MOSFETs Using Photon Emission

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The hot-carrier effects of SOI-MOSFETs have been studied, for the first time, using photon emission from hot carriers. The emission of the SOI-MOSFETs is observed not only in the drain region but also the source region. The emission mechanism at the source region is possibly electron-hole recombination. The total photo intensity from a SOI-MOSFET indicates the strength of impact ionization. The relation between the hot-carrier-lifetime and the photo intensity in SOI-MOSFETs is similar to that between the lifetime and the substrate current in bulk MOSFETs. The photon emission is a good index for hot-carrier-degradation measurements in SOI devices.

1. INTRODUCTION

Many advantages of SOI-MOSFETs have been reported. However, there are still few reports on the hot carrier reliability in SOI-MOSFETs, mainly because the substrate current which indicates the strength of impact-ionization in bulk MOSFETs cannot be measured in SOI-MOSFETs, due to the floating substrate. In the bulk MOSFETs, the photon emission detection is a useful evaluation technique for hot carrier effects and CMOS latch up.[1)2)3)] In this paper, hot-carrier effects of SOI-MOSFETs have been studied, for the first time, using photon emission from hot carriers.

2. DEVICE FABRICATION

In the present experiment, two kinds of SOI MOSFETs were fabricated. One is both NMOSFETs and PMOSFETs on bonded SOI wafers having the SOI film thickness ranging from 0.15 um to 0.5 um and buried oxide thickness of 1 um. The impurity density of the channel is about 10^{15} cm^{-3} and the gate oxide thickness is 15 nm. The NMOSFETs are LDD with n^- dose of 10^{13} cm^{-2}. The other is conventional NMOSFETs on SIMOX wafers having 0.25-um-thick SOI film and 0.4-um-thick buried oxide. The impurity density of the channel is about $5x10^{16}$ cm^{-3} and the gate oxide thickness is 20 nm. Bulk MOSFETs were also fabricated with the same process condition as bonded-SOI MOSFETs as a reference. The photon emission was detected with EMMI(KLA).

3. RESULTS AND DISCUSSION

The emission images of MOSFETs on bonded SOI wafer and bulk wafer are shown in photo 1(NMOS) and photo 2(PMOS). It is clearly shown in these photos that the emission is observed in the source region of the SOI-MOSFETs for both NMOS and PMOS, while only in the drain region for bulk MOSFETs.

In order to clarify the origin of the emission in the source region of SOI-MOSFETs, the photon energy spectrum was taken on a bonded-SOI NMOSFET, as shown in Fig. 1. Photo intensity from the drain and source is separately measured for a MOSFET with a 7-um-long gate with a drain voltage of 8V, a gate voltage being a parameter. Assuming that the carrier distribution is a Maxwellian, the carrier temperature can be calculated from the slope in Fig. 1.[1)] The temperature as a function of the gate voltage is shown in Fig. 2. The temperature at the drain junction varies from about 4200 K (V_G=1V) to about 2500 K (V_G=4V). On the other hand, the temperature at the source junction is found to be constant with about 1800K. Therefore, it is concluded that the emission mechanism of the drain is probably bremsstrahlung from hot carriers, while the mechanism of emission at the source is possibly electron-hole recombination.

The photo intensity from SOI-MOSFETs and a bulk MOSFET as a function of gate voltage is shown in Fig. 3. The thickness of SOI film is 0.15, 0.25 and 0.5 um. The gate length is 3 um, and the drain voltage is 6V. The photo intensity of the thin film SOI-MOSFETs is stronger than that of the thick film SOI-MOSFETs. This is because of the stronger electric field at the drain junction of thin film SOI-MOSFET. Moreover, the peak of photo intensity shifts toward the lower gate voltage in the thin film SOI-MOSFETs. This may be caused by pinch-off voltage shift, not by threshold voltage shift, because the threshold voltage shift was measured to be small. The notable rebound characteristics for the gate voltage of less than -1 volt for the 0.15-um-thick SOI-MOSFET are probably due to the snap back and the latch caused by parasitic bipolar effect, which are the characteristic of the SOI-MOSFETs.

Figure 4 shows the gate voltage dependence of both degradation ratio and photo intensity of the SIMOX NMOSFET with 1-um-long gate. The degradation of transconductance was measured after 10^4 seconds stress by V_D=6.5V. In Fig. 4, it is found that, in spite of the strong emission, transconductance has no degradation at the lower gate voltage. To explain this phenomenon, the carrier generation distribution of a MOSFET with 1-um-long gate and 100-nm-thick SOI film is simulated, as shown in Fig. 5. The drain voltage is 3V, and the gate voltage is 0V for (a) and 3V for (b). The latch occurs in the bias condition of (a). In the latch state, the current does not flow on the front MOS interface, but flows in the silicon body by a parasitic bipolar effect. Therefore, the generation area of hot carriers is away from the MOS interface as shown in Fig. 5(a). So, the front oxide has no degradation as shown in Fig. 4. On the other hand, at the high gate voltage, most carriers are generated in the front MOS interface as shown in Fig. 5(b), and the transconductance is degraded as shown in Fig. 4.

The relation between hot-carrier-lifetime and photo intensity is shown in Fig. 6. The lifetime is defined as a time for 10% transconductance degradation. The MOSFETs with variation of gate length (L<1um) were stressed under the condition that the latch does not occur. The negative proportional relation exists between logarithm of hot-carrier-lifetime and logarithm of photo intensity, showing that the photon emission is a good index for hot carrier degradation measurements in SOI devices.

4.CONCLUSION

The hot-carrier-effects have been studied using photon emission. The emission of the SOI-MOSFETs is observed not only in the drain region but also the source region. From the spectrum analysis, it is speculated that the mechanism of emission in the source region may be electron-hole recombination. The total photo intensity from a SOI-MOSFET increases with a decrease of the silicon film thickness, which indicates the strong impact ionization at the drain junction of the thin film SOI-MOSFET. The relation between the hot-carrier-lifetime and the photo intensity for SOI-MOSFETs is similar to that between the lifetime and the substrate current for bulk MOSFETs. The photon emission is a good index for hot-carrier-degradation measurements in SOI devices.

REFERENCES

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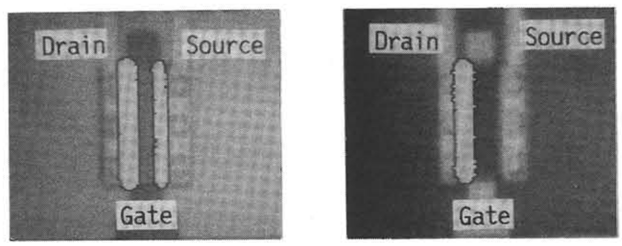
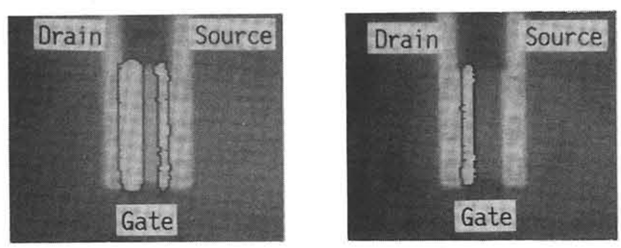


NMOS/SOI NMOS/bulk

Photo 1. Emission images of NMOSFETs on bonded-SOI and bulk wafers. L=5um, V_G=2V and V_D=7V.



PMOS/SOI PMOS/bulk

Photo 2. Emission images of PMOSFETs on bonded-SOI and bulk wafers. L=5um, V_G=-5V and V_D=-10V.

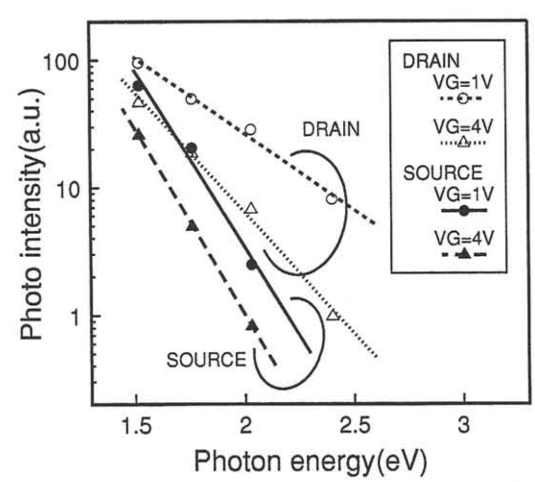


Figure 1. Photo intensity per unit energy of a bonded-SOI NMOSFET as a function of photon energy. L=7um, V_D=8V and T_{SOI}=0.25um.

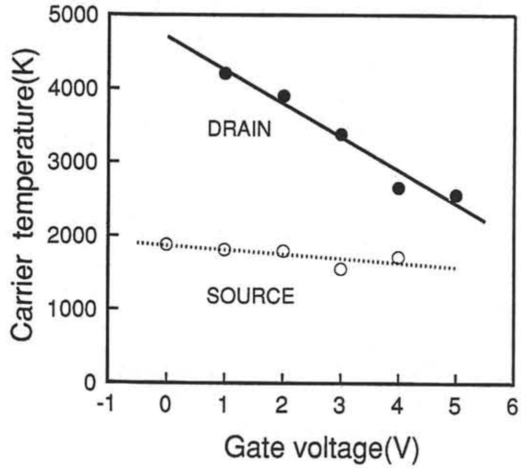


Figure 2. Carrier temperature as a function of gate voltage at both drain and source junction of the same NMOSFET in Fig. 1. V_D=8V.

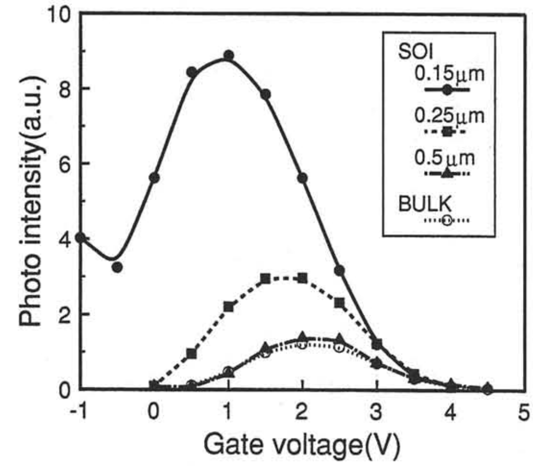


Figure 3. Photo intensity of bonded-SOI and bulk NMOSFETs as a function of gate voltage. L=3um, V_D=6V.

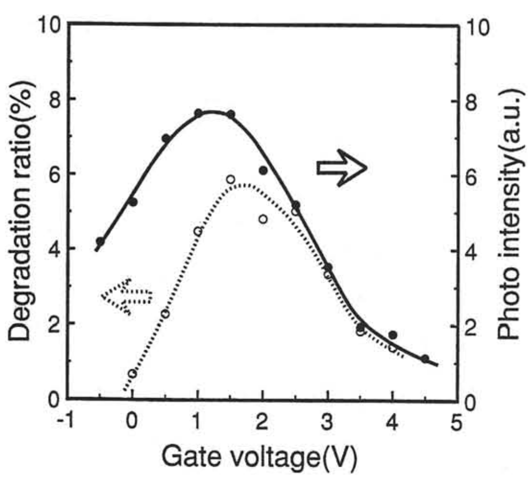


Figure 4. Transconductance degradation ratio after 10^4 seconds stress and photo intensity as a function of gate voltage in a SIMOX NMOSFET. L=1um, V_D=6.5V.

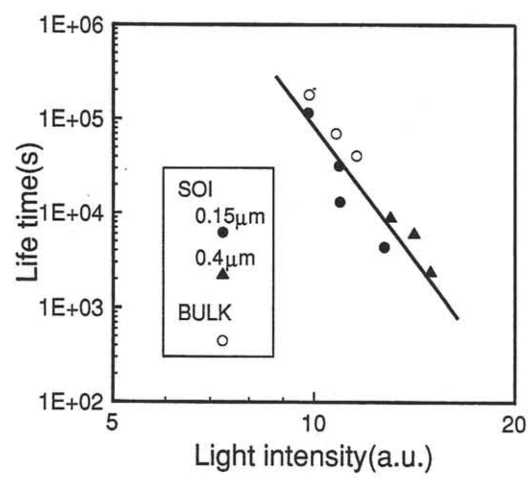
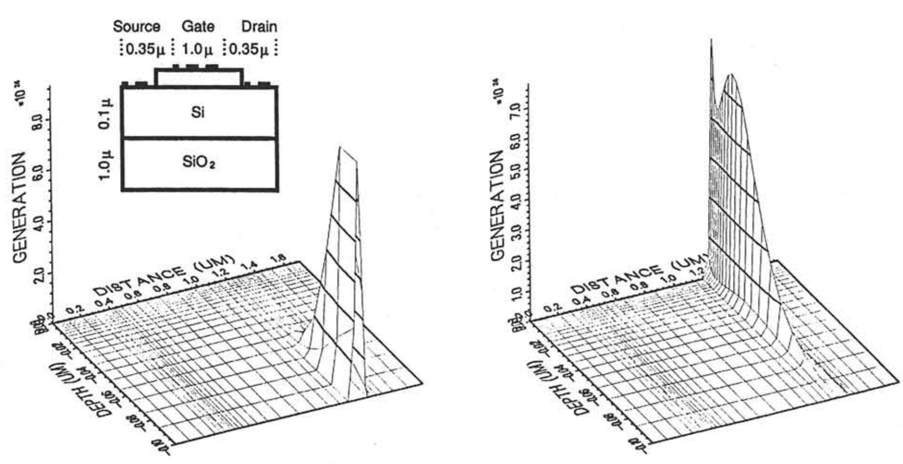


Figure 6. Hot-carrier-lifetime for both bonded-SOI and bulk NMOSFETs as a function of photo intensity. The bias conditions are V_D/V_G=6/1V for 0.15-um-thick SOI and V_D/V_G=7/2V for others.

Figure 5. Distribution of carrier generation in a SOI NMOSFET. L=1um, V_D=3V. (a) V_G=0V, (b) V_G=3V.



(a) V_G=0V, VD=3V

(b) V_G=3V, VD=3V