Extended Abstracts of the 22nd (1990 International) Conference on Solid State Devices and Materials, Sendai, 1990, pp. 1153-1154

The Effects of Nitridation and Re-Oxidation on Drain Leakage Current in n-Channel MOSFETs

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Subthreshold leakage current is an important factor when MOSFETs are used in computer memories (DRAMs) since such devices must be able to store charge for long periods [1]. The effects of nitridation and re-oxidation on gate oxides have been studied for some years in the expectation that the resulting dielectrics will improve some of the properties of SiO_2 when devices are scaled to ULSI dimensions. It would therefore seem of great importance to examine the effects of these processing conditions on leakage current. In the present work we have systematically investigated, for the first time, the effects of nitridation and re-oxidation on the subthreshold drain leakage current in n-channel MOSFETs. As an alternative to rapid thermal processing (RTP) we have studied low partial pressure nitridations with dilutions of 1:10 (10% ammonia : 90% nitrogen) and 1:20 (5% ammonia : 95% nitrogen). Figure 2 includes details of the processing conditions. Devices had both a channel width and a channel length of 20 μm, and a gate dielectric thickness of 10 nm. Subthreshold characteristics were measured in a pure nitrogen ambient under light-proof and shielded conditions using an HP4145B Semiconductor Parameter Analyzer. Drain current (I_D) versus gate voltage (V_G) curves were extracted (for V_{DS}=50 mV) and the threshold voltage (V_T) was taken to be the value of V_G at $I_D = 10^{-7}$ A.

Figure 1 shows typical results for the sample with the heaviest nitridation (with no re-oxidation) as well as for the pure oxide. The gate voltage was normalized to gate drive (V_G-V_T) to eliminate the effects of threshold voltage change between samples, and the leakage current was determined at a gate drive value of -2 V. The results presented here were averaged over eight locations on the wafer. Figure 2 shows drain leakage current for different nitridation conditions with no re-oxidation. The heavier the nitridation, the higher the leakage: for example, the drain leakage current increased from 8.54×10^{-13} A in the pure oxide to 9.4×10^{-10} A with the 60 minute, 1:10 dilution (RONO4). It is apparent that the dilution factor had little or no effect in the case of the 15 minute nitridation, whereas for the 60 minute nitridation the change in dilution increased the leakage current by one order of magnitude. This can be explained since in the former case (15 minutes) the product of ammonia percentage and time, which can be taken as an indication of the level of nitridation, increased by 75, but in the latter case (60 minutes) the increase was 300. The effects of re-oxidation can be seen in Figure 3. The trend may be observed that re-oxidation reduced leakage current: for each sample tested, 60 minutes of re-oxidation reduced the leakage current by about one order of magnitude. Thus the sample with the lightest nitridation and the heaviest re-oxidation had a leakage current approaching that for pure oxide. Shown in Figure 4 is the impact of nitridation and re-oxidation on drain leakage as a function of drain voltage. It can be seen that nitridation increased I_D by 100 times while the following re-oxidation suppressed it. A plot of log (I_D/V_{DG}) vs $1/V_{DG}$ suggests that this enhanced drain leakage is due to a tunnelling mechanism [2] as indicated in Figure 5. However, the energy barrier is much lower than that for band to band tunneling [3].

It is known that nitridation introduces a high density and larger capture cross-section of interface states [4]: consequently, these interface states can serve as centres for carriers with much lower energies to tunnel indirectly, as shown in Figure 6, causing leakage current to increase. Subsequent re-oxidation, which has been found to reduce the density of interface states [5], would result in a reduction of the drain leakage current.

Therefore, it is suggested that this enhanced drain leakage is due to interface-state-induced indirect tunnelling. Hence, as the drain leakage appears to be strongly dependent on both nitridation and re-oxidation, an optimum fabrication procedure is warranted.

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[3] A.T. Wu et al., Tech. Digest of IEDM, p.271, 1989.
[4] Z.H. Liu and Y.C. Cheng, IEEE Trans. on Electron Devices, vol. 36, No.9, p.1629, Sept. 1989.
[5] Z.H. Liu et al., J. Electrochem. Soc., vol.137, No.6, p.1871, June 1990.

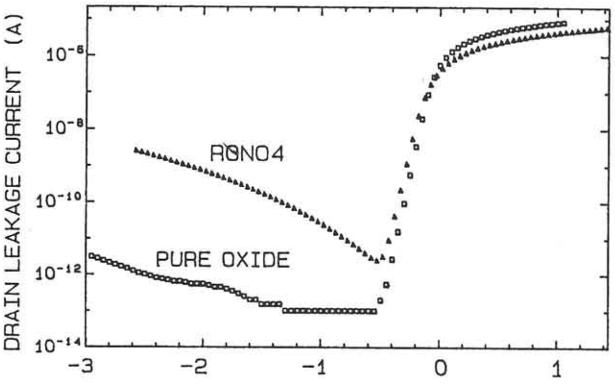

Fig.1 Typical curves of drain leakage current against gate voltage for the case of the pure oxide (thickness 10 nm) and RONO4 (950 C, 60 minutes at 1:10 dilution, no re-oxidation).

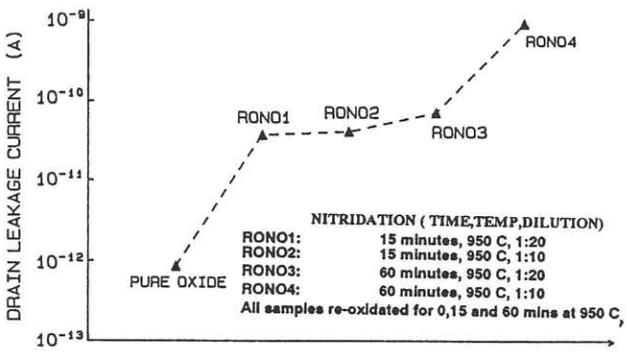

Fig.2 Drain leakage current at a gate drive of -2V for the four nitridation conditions with no re-oxidation. The x-axis is not to scale. Also included are details of the processing conditions.

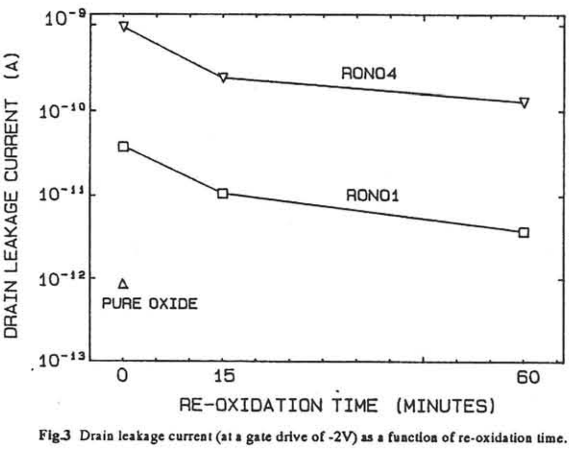

Fig.3 Drain leakage current (at a gate drive of -2V) as a function of re-oxidation time.

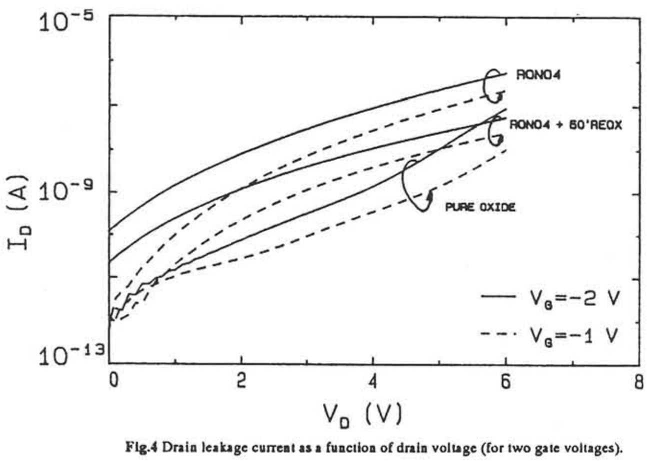

Fig.4 Drain leakage current as a function of drain voltage (for two gate voltages).

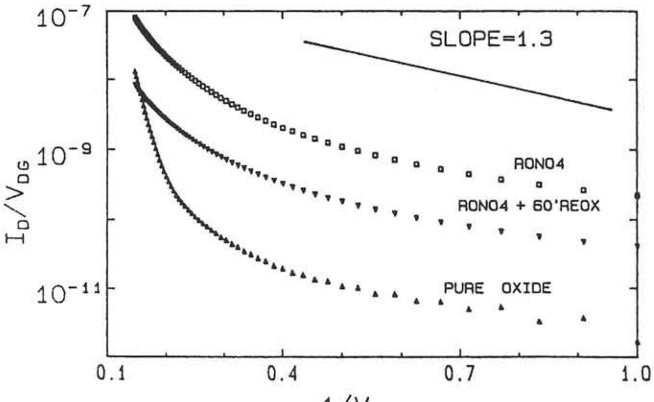

Fig.5 A plot of log (I_D/V_{DG}) against $1/V_{DG}$, where V_{DG} is the voltage difference between the drain and the gate. The linear region of the curves indicates a tunnelling mechanism.

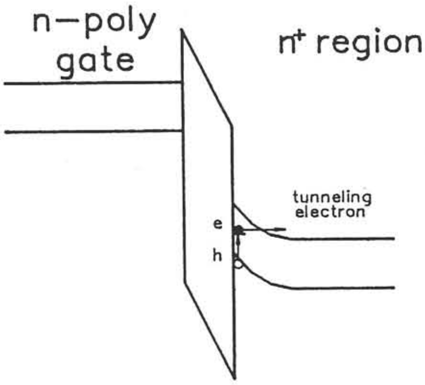

Fig.6 Energy band diagram illustrating interface-state-induced indirect tunnelling.