Extended Abstracts of the 1999 International Conference on Solid State Devices and Materials, Tokyo, 1999, pp. 10-11 **A-1-2**

Leakage Mechanism of Local Junctions Forming Main or Tail Mode of DRAM Retention Characteristics

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1. Introduction

Recently, the low power applications demand the long retention cycle for DRAMs, though the electric field at the junction becomes high as the device is scaled. Therefore the retention time is one of the serious problems for the future DRAMs. In particular the tail distribution of the DRAM makes the retention time small and is formed only by the few leaky cells (<0.1%). To improve the retention characteristics, many studies have been reported[1,2,3]. However, the clear analysis based on the measured leakage characteristics has not been reported yet. This is because that our targets are local junctions and direct observation of the leakage characteristics is difficult. We have been developed the test pattern for measuring a small leakage current for a lot of local junctions[4]. In this paper, we present the leakage characteristics of the local pn junctions with our developed test system. The trap assisted tunneling mechanism controls the leakage current of the main mode cells. It is found that the current distribution of majority cells is strongly related to that of the active energy with the various trap concentrations and the trap levels. Moreover, the tail cells show the small dependence on the voltage even if the leakage current increases. We propose that two traps related leakage current with TAT can fully explains the tail leakage characteristics.

2. Experimental Result

We have been reported the TEG for analyzing the retention characteristics as shown in figure 1[4]. The small leakage current with local area is able to measure from the time dependence of the storage node voltage (figure 2). The storage node voltage is amplified to the PMOS drain current. Therefore the small leakage signal of the small junction is able to be observed. Moreover, the irregular leaky cells can be selected among arrayed local test junctions to analyze the leakage current of the tail cells with our TEG as shown in figures 2 and 3.

The majority cells show the leakage characteristics as shown in figure 3(a) which has the three features as follows. (1) The voltage dependence of the leakage current is larger than that assuming the SRH model. (2) The active energy of the majority cells are about 0.7 ~ 0.8eV (< energy gap) with the normal distribution. (3) The leakage current is increased with a decrease in the active energy.

The tail leakage characteristics is shown in figure 3(b), comparing with the normal characteristics of main cells. Six features can be seen. (4) The irregular leaky cells can be found at the rate of 0.1%. (5) The leakage current of the tail forming cells is about one order higher than that of the main forming cells. (6) The active energy is about 0.6eV. (7) The voltage dependence of the leakage current is smaller than that of main mode cells. (8) Some of the leaky cells show the kink. (9) Some show the variable leakage characteristics by 120°C annealing,

3. Discussion

At both the main and the tail mode, the active energy of the leakage current is below the band gap of Si (features 2 and 6). This means that the thermal emission is not the only mechanism of the leakage current. Moreover the leakage current shows the strong dependence on the voltage (features 1 and 7). This means that the tunneling works for increasing the leakage current. The trap assisted tunneling (TAT) is one of the well known mechanisms of trap related leakage current which explains the electron emission from the trap by combining both the thermal emission and the tunneling[5,6]. The leakage characteristic of local junctions is discussed base on the TAT mechanism.

[*main mode*]

The leakage currents of the majority cells form the normal distribution as shown in figure 2. The active energies also show the normal distribution and the strong relation can be seen between the leakage current and the active energy as shown in figure 4. Assuming the TAT mechanism, the active energy is decreased by closing the trap level to the mid-gap as shown in figure 5(a). Therefore the distribution of the active energy is made by that of the trap level. Moreover the active energy *vs* leakage current distribution is given not by the unique line buy by the region with area as shown in figure 4(a). This means that the some cells with the same active energy show the different leakage current. Increase of the trap concentration means increase of the path with the same leakage mechanism. Therefore the active energy has small influence even if the leakage current is increased as shown in figure 5(b). Therefore it is found that the leakage current of the majority cells are controlled by the TAT mechanism and the normal distribution of the leakage current is related to that of the trap concentrations and the trap levels.

[*tail mode*]

The variable leakage (feature 9) and the kink characteristics (feature 8) indicate that the tail leakage current also relates with the trap. The TAT mechanism is able to explain the large leakage current with the small active energy (features 5, 6). However small slope of $ln(I_{LEAK})$ for V_{LEAK} with large current (feature 7) cannot be explained. This is because that the TAT cannot make the leakage current large without increasing the contribution of tunneling current. The slope of $ln(I_{LEAK})$ for V_{LEAK} needs to increase when the leakage current increases as shown in figure 5.

The small slope with a large current (figure 3b) means that the leakage current increases not by the tunneling but by the thermal emission. Therefore, two traps are assumed as shown in figure 6 to explain the tail leakage characteristics. Figure 7 shows the emission probability as a function of the electric field from the simple analytical equations shown in the table 1. It can be seen that the two traps related leakage mechanism with TAT is able to explain the small slope with a large current as the tail cells show (feature 7).

4. Conclusion

The leakage characteristics of the local pn junctions are discussed based on the measurement results. It is found that the trap assisted tunneling mechanism controls the leakage current of the main mode cells. The current distribution of majority cells is related to that of the active energy with the various trap concentrations and the trap levels. Moreover, the irregular tail cells show the small dependence on the voltage with the large leakage current. It is found that the two traps related leakage current with TAT can fully explains the tail leakage characteristics.

Acknowledgments

The authors would like to thank Dr. Kamakura and Dr. Sonoda for their valuable discussions.

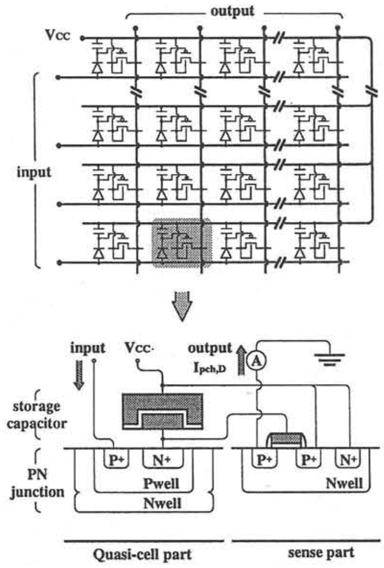


Figure 1 : The proposed test structure for detecting a large amount of fA level leakage current of local area PN junction.

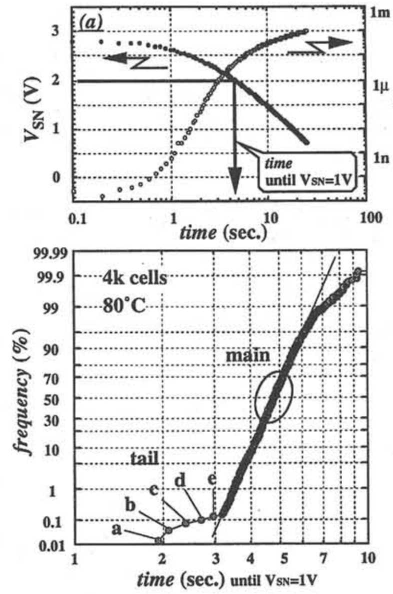


Figure 2 : Distribution of the time until storage node voltage = 2V shown in figure 2(a).

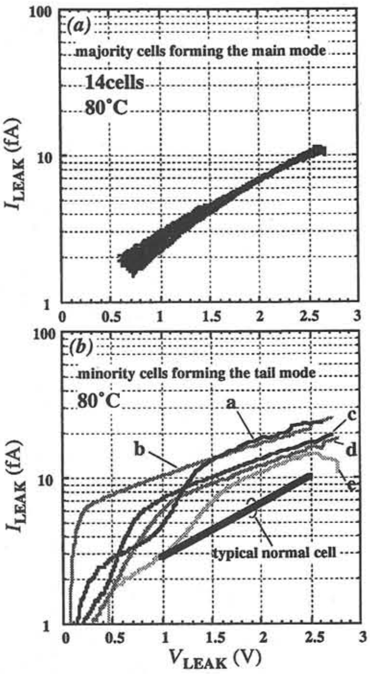


Figure 3 : Leakage characteristics of the 14 normal cell s (in main mode) and 5 leaky cells (in tail mode). Signals of a to d in figure 3 (b) are corresponding with figure 2

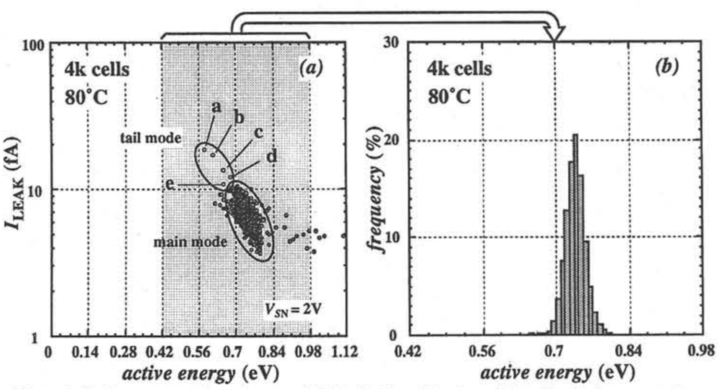


Figure 4 : Leakage current dependence on (a) distribution of the slope of logarithm leakage current for voltage and (b) distribution of active energy.

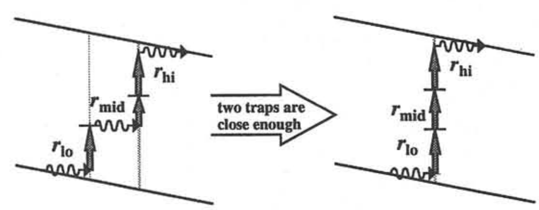
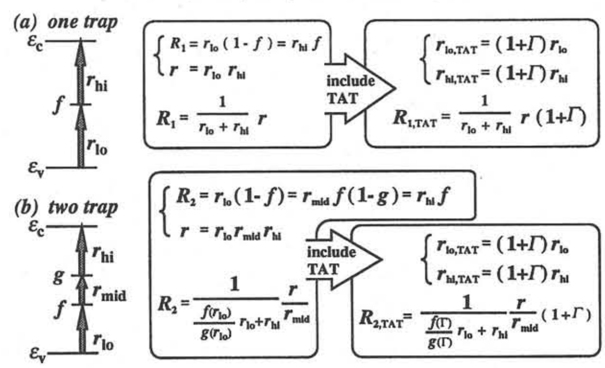


Figure 6 : Schematic drawing of double trap related TAT.

Table 1 : Simple analytical equations of double trap related TAT.



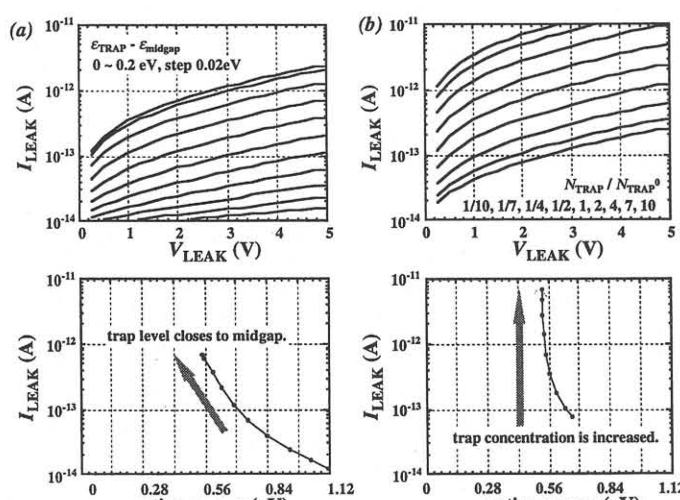
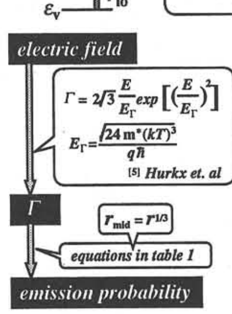


Figure 5 : Leakage current dependence on the active energy with (a) variable trap level and (b) variable trap concentration.



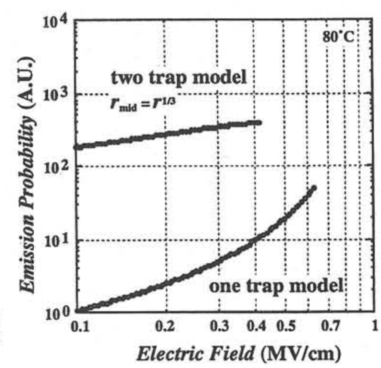


Figure 7 : Comparison between two trap and one trap related TAT current with simple analytical equations in table 1

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