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Identification of Generation-Recombination Centers and Traps among Interface States by Cryogenic Charge Pumping Technique

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Low temperature charge pumping (CP) current measurements were carried out on $100\mu m/10\mu m$ NMOS transistors to investigate the interface state density. Interface states comprise traps and generation-recombination (g-r) centers. By measuring the CP current at different pulse frequencies at low temperatures, where the emission time constant of the traps is larger, the distribution of traps is determined distinct from that of the g-r centers.

1. INTRODUCTION

Charge pumping (CP) current measurement technique is useful in determining the interface state density[1)-3)] in MOS transistors. By varying the pulse frequency and/or the OFF period, the distribution of interface states as a function of time constant can be determined[4)]. Interface states in a MOS transistor can act as carrier traps or generation-recombination (g-r) centers. They act as traps if they can interact only with electrons or only with holes. If they can interact with both electrons and holes with comparable probability then they act as g-r centers. We present in this paper, results of low temperature charge pumping measurements that enable the identification of traps and g-r centers in the interface states.

2. EXPERIMENTAL

The devices used in this study were bulk non-LDD nMOS devices with device dimension W/L equal to $100\mu m/10\mu m$. The experimental setup for the CP measurement consists of a HP8112A pulse generator used to supply the gate voltage pulse, a HP4140B picoammeter to supply bias voltage for the source/drain and measure the CP current through the substrate, and a personal computer to control both pulse generator and picoammeter for automatic measurement. The CP current was measured using the constant pulse height with varying base level technique[1)]. The duty-cycle of the gate pulse was kept at 50 % and the CP current was measured at different pulse repetition frequencies from 100Hz to 5MHz.

3. RESULTS AND DISCUSSION

Fig.1 shows the variation of normalized CP current with the pulse base voltage for a constant pulse amplitude of 4V measured at 77K for different frequencies. The CP current is proportional to the pulse frequency. In order to compare the CP results at different frequencies, the CP current is divided by the pulse frequency to obtain the charge pumped per cycle. In Fig. 1 the ordinate is the normalized CP current i.e., charge per cycle. This figure shows the effect of interface states with different time constants. As seen in Fig. 1, there is a component of current that is frequency dependent and another that is frequency independent. The frequency dependent component arises due to interface states which interact with the majority carriers in the substrate with a characteristic time constant and the component of current that is not dependent on frequency is due to the contribution of g-r centers. In Fig.1, the shoulder of the plot which is frequency independent is the CP current due to g-r centers. For the samples used in this work, this represents an average density of $3.1 \times 10^{10} cm^{-2}eV^{-1}$. The average density for the traps with time constant less than 5 milliseconds is $6.8 \times 10^{10} cm^{-2} eV^{-1}$.

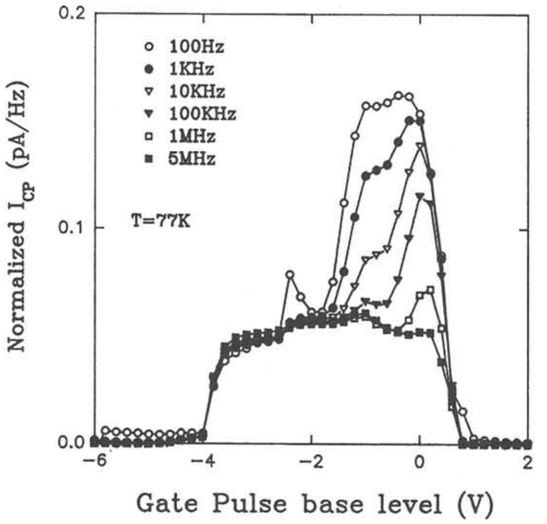

Fig.1 Plot of normalized CP current as a function of gate pulse voltage at 77K for different frequencies.

The g-r centers contribute to CP current by capturing electrons during the ON period and by capturing holes during the OFF period. On the other hand the traps contribute to CP current by capturing electrons during the ON period and by emitting the electrons into the bulk during the OFF period where they subsequently recombine with holes. As the frequency is reduced, more and more traps are able to contribute to CP current because of the increase in the OFF period. The portion of the CP current that does not change with frequency is due to g-r centers and the rest is due to traps. The curve at 5MHz in Fig.1 represents the contribution to the CP current of traps with time constant less than the OFF period which at this frequency is 0.1 μ second and of g-r centers.

This result was also confirmed by varying the duty-cycle of the gate pulse while keeping the pulse frequency constant. As shown in Fig.2, the component of CP current that corresponds to traps increases as the duty-cycle decreases, while the remaining portion is essentially unchanged. With the frequency kept constant at 100KHz, the increasing duty-cycle corresponding to decreasing OFF period suggests that there is less and less time allowed for the trapped electrons to be emitted. This result is consistent with the results obtained from varying the pulse frequency.

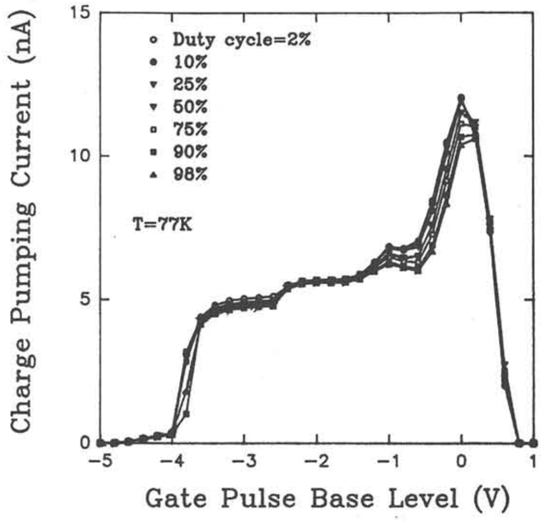

Fig.2 Plot of CP current as a function of gate pulse voltage at 77K for different duty cycles with pulse frequency equal to 100KHz.

The distribution of traps with different time constants can be derived from the plots in Fig. 1. The difference in the value of the current measured at two different frequencies is due to the traps having emission time constants in the range between the OFF periods of the two frequencies. For example, the difference between the curve at 5MHz and the one at 1MHz represents the contribution to the CP current from states whose emission time constant is approximately in the range between 0.1 μ second and 0.5 μ second. Fig. 3 gives the plot of total N_{it} having time constant less than the specified value on the abscissa.

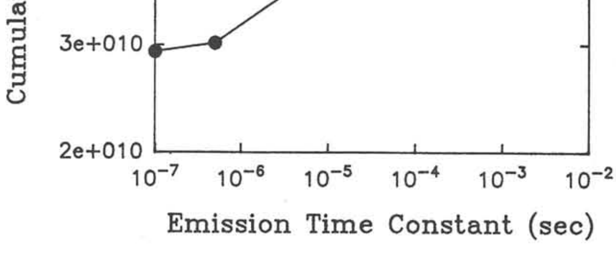

Fig.3 Plot of cumulative interface trap density (N_{it}) as a function of emission time constant of traps.

At room temperature all the traps have small emission time constant and hence all of them contribute to the CP current. As shown in Fig. 4, the room temperature plot shows no difference with frequency.

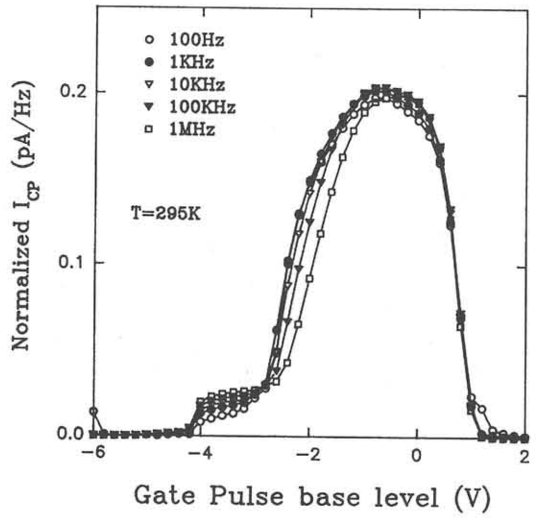

Fig.4 Plot of normalized CP current as a function of gate pulse voltage at 295K for different frequencies.

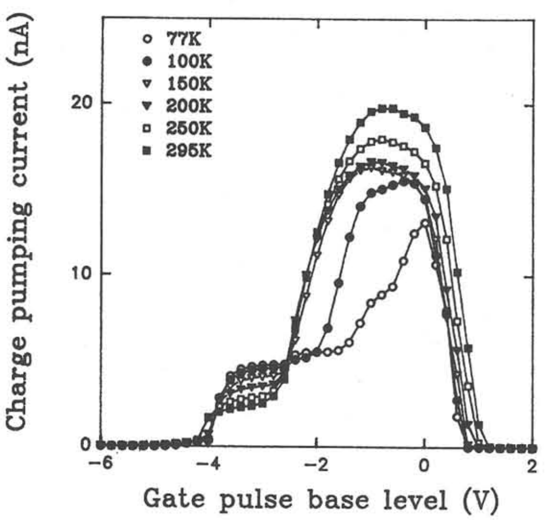

Fig.5 Plot of CP current for different temperatures at 100KHz pulse repetition frequency.

Fig. 5 gives a plot of CP current at different temperatures at 100KHz pulse repetition frequency. The portion corresponding to g-r centers decreases with temperature while that due to traps increases with temperature. The former occurs due to the fact that at low temperature the CP technique addresses a larger region of the bandgap. As temperature increases, the emission time constant for traps decreases. With the same OFF period, there are more and more traps contribute to the CP current as temperature increases due to the decreasing emission time constant.

4. CONCLUSION

In conclusion, we have used charge pumping technique at cryogenic temperatures to distinguish g-r centers from traps in the interface states. By varying the pulse frequency and duty-cycle, we can determine not only the distribution of g-r centers or traps within the bandgap but also the population distribution for traps with various emission time constants. The technique can be employed to study interface degradation mechanism resulting from hot-carrier or Fowler-Nordheim (F-N) stress.

5. REFERENCES

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