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Auger Recombination Enhanced Hot Electron Programming in Flash EEPROMs

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Abstract

A hot electron programming method by taking advantage of Auger recombination is proposed. Faster programming rate and higher electron injection efficiency than conventional channel hot electron programming (CHE) are obtained. In contrast to CHE, this technique shows excellent temperature stability from T=25C to T=125C.

Introduction

In conventional HE programming, the major electron energy gain mechanism is field acceleration. Electrons can acquire sufficient energy either from a lateral channel field (CHE) or from a vertical substrate field (SHE [1] and CHISEL [2]). Based on the lucky electron concept, the gate current injection decreases drastically as the voltage drop in Si substrate approaches the Si/SiO_2 barrier height, i.e., 3.2eV. In addition, conventional HE programming efficiency degrades severely at an elevated temperature due to increased phonon scattering. These two factors make it difficult to operate in low voltage and high temperature condition.

In this work, we propose a new HE programming technique by utilizing Auger recombination assisted hot electron process. This method is particularly significant at lower drain bias as electron energy obtained from channel field is not sufficient to surmount the SiO_2 barrier. As opposed to the negative temperature effect in field accelerating process, the Auger recombination assisted hot electron process exhibits positive temperature dependence.

Operational Principle

The biasing scheme and operational principle of the *A*uger *E*nhanced *C*hannel *H*ot *E*lectron (AECHE) programming are illustrated in Fig. 1. A positive substrate bias is applied in a n-channel EEPROM. Holes are injected from the substrate to the channel, which provide recombination with electrons in the channel and transfer excess energy to other electrons. The Auger recombination rate [3] and lateral electric field in the channel are shown in Fig. 2 from 2D device simulation. The energetic electrons created by Auger process near the source are then accelerated by a lateral electric field.

A stack-gate EEPROM cell and a conventional gate dummy cell are used in this study. The tunnel oxide thickness is 100Å and the drawn gate length is 0.7μm. The dummy cell has a gate width of 20μm.

Results and Discussion

(a) Conventional gate MOSFET characteristics

The dependence of hot electron gate current on substrate bias in a conventional gate nMOSFET is shown in Fig. 3(a). The drain voltage is 3.5V. When V_b increases, the gate current first decreases due to body effect and then increases with V_b. The I_g-V_g characteristic at V_b=1.5V is quite different from that at V_b=0V. The I_g-V_g at V_b=0V has a peak around V_g=3.5V while the gate current at V_b=1.5V increases monotonically with V_g. The drain bias dependence of the hot electron gate current is shown in Fig. 3(b). Hot electron luminescence and emission spectra are measured to analyze the hot electron distribution (Fig. 4). The light intensity is normalized to the drain current to compensate for the different carrier flux in the channel. The result shows that the high-energy tail of channel electrons is indeed increased by the application of a positive substrate bias. In addition, Fig. 4 reveals that the emission spectrum has a small hump around 1.6eV (≈1.5E_g) with positive substrate bias. Because the most probable electron energy transition in Auger process is about 1.5E_g [4,5], the appearance of the hump is possibly related to the Auger effect.

The temperature dependence of conventional CHE and AECHE is examined (Fig. 5). The CHE current has negative temperature dependence while AECHE gate current exhibits slightly positive temperature dependence. This excellent temperature stability of AECHE is particularly useful in applications which require high temperature operation.

The injection efficiency (I_g/I_s') of AECHE is evaluated (Fig. 6), where I_s' is defined as $I_d+I_b(V_b/V_d)$ to account for the voltage difference at the substrate and at the drain. It should be noted that although a parasitic BJT current exists in AECHE operation, the programming efficiency of AECHE is still much better than CHE. In addition, diminishing temperature instability in programming efficiency is obtained in AECHE.

(b) EEPROM characteristics

The programming characteristics in a EEPROM cell by CHE and AECHE are compared (Fig. 7). V_{cg} is 12V and V_b is 1.5V in AECHE. The V_{cg} in CHE is selected such that I_g has a maximum value. The drain bias is 3.5V. Positive temperature dependence of hot electron programming speed is observed for the first time in AECHE. As compared to CHE, 5x programming speed enhancement is obtained at T=25C. The speed enhancement factor is even greater at 125C. Besides, since a higher V_{cg} is allowable in AECHE programming, a larger threshold voltage window between the programmed state and the erased state is achieved.

Conclusion

A new channel electron energy gain process by taking advantage of Auger recombination is proposed for flash EEPROM operation. Improved hot electron injection efficiency and temperature stability have been obtained.

References

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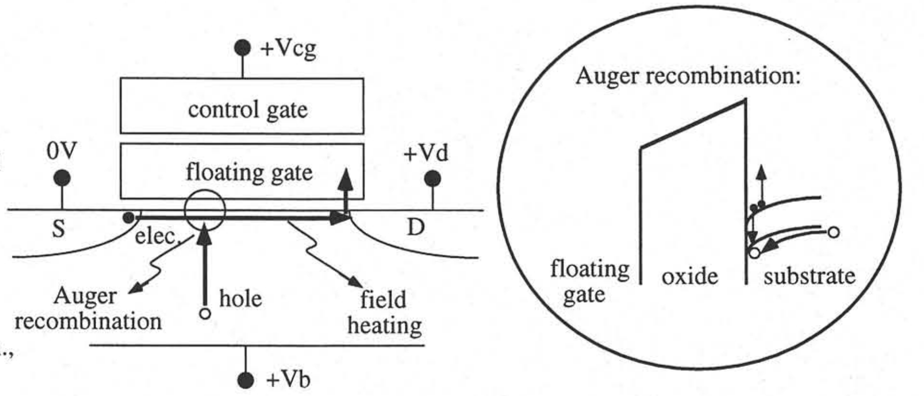

Fig. 1 Illustration of Auger recombination assisted hot electron programming in a stacked gate n-channel EEPROM.

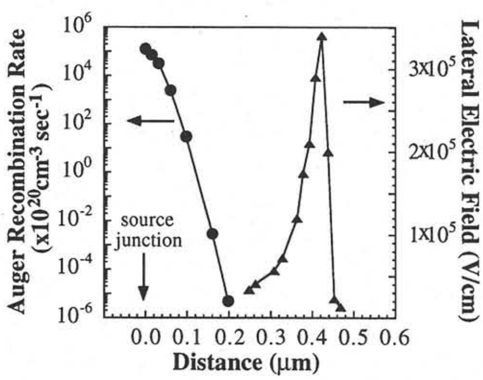

Fig. 2 Simulated Auger recombination rate and lateral electric field along the channel. V_d=3.5V, V_g=5.0V and V_b=1.5V.

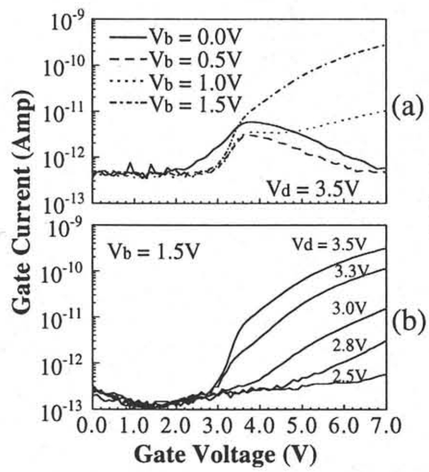

Fig. 3 The dependence of hot electron gate current on substrate bias and drain bias. The threshold voltage of the device is about 1.5V.

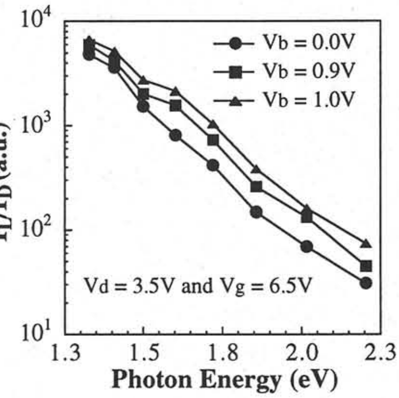

Fig. 4 Hot electron light emission spectrum in a n-MOSFET with different substrate biases. I_L is the light intensity.

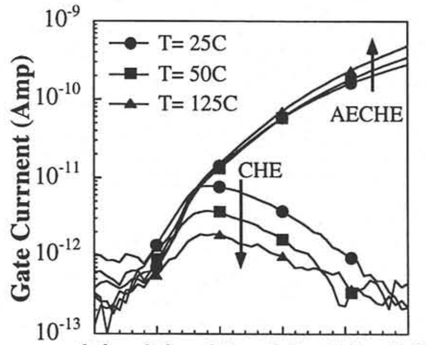

Fig. 5 Temperature dependence of hot electron gate current at V_b=0V and 1.5V. The drain bias is 3.5V.

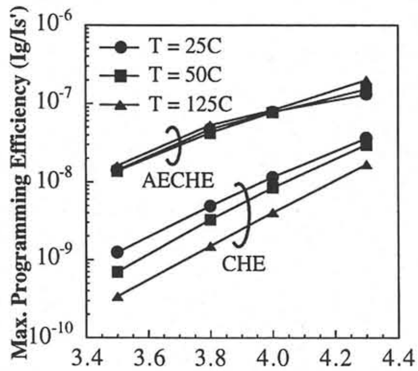

Fig. 6 Max. programming efficiency in a range of $0V \leq V_g \leq 7V$ versus drain bias. I_s' is defined as $I_d+I_b(V_b/V_d)$.

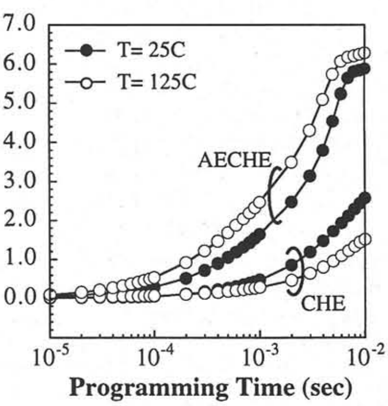

Fig. 7 Programming characteristics of CHE and AECHE at T=25C and 125C. V_d=3.5V.