Extended Abstracts of the 1995 International Conference on Solid State Devices and Materials, Osaka, 1995, pp. 237-239

Anomalous Capture and Emission by Individual Si-SiO_2 Interface Defects in Advanced Self-Aligned Bipolar Transistors

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In studies of the degradation effect we observed random-telegraph-noise (RTN) for the first time in advanced self-aligned bipolar transistors. This phenomenon closely resembles that for MOS transistors, but the temperature and voltage dependences for the RTN are quite different. Based on tunneling transitions between a single border trap, interface states and the Si-band, a model is suggested to explain this anomalous capture and the emission behavior.

1. INTRODUCTION

High doping in downscaled advanced self-aligned bipolar transistors renders such devices susceptible to hot carrier degradation[1,2,3,4]. The degradation is observed as an increase in the base current and low-frequency noise[5]. Our previous work shows that the defect induced by the hot carrier degradation is situated near the Si-SiO_2 interface at the perimeter of the base-emitter junction[5]. In studies of the microscopic origin of the hot carrier degradation and the low-frequency noise, particularly when the interface of Si-SiO_2 plays a role as postulated, it is suggested that random-telegraph-noise (RTN) switching should be observed at low temperature, analogous to the MOS structure[6,7]. We have found RTN signals for the first time (to our knowledge) in degraded bipolar transistors[5]. They appear at the same forward bias as the excess current, which confirms the damage at the Si-SiO_2 interface. Recently, the RTN in bipolar junction transistors has been found independently also by another group[8]. We present a more detailed analysis of RTN in degraded bipolar transistors and propose a model to interpret the data in terms of properties of the defects created at/near the Si-SiO_2 interface.

2. EXPERIMENTAL PROCEDURE

The n-p-n bipolar transistors are fabricated using a 0.5 μm "double-poly", self-aligned technology developed by SIEMENS[5]. As shown in Fig. 1., the base-emitter (B-E) junction contacts the TEOS-SiO_2 sidewall spacer. In order to study the effect of hot carrier degradation, the experiments are carried out by applying a constant reverse bias (e.g. 3.5V) as a stress to the B-E junction at room temperature. The stress time ranges from 0 up to 10^6 s. The forward characteristics are measured before the constant bias stress and then after each stress, at different temperatures (4.2 K to 300K).

The 1/f noise measurements are performed using some components of HP3048 phase-noise measurement

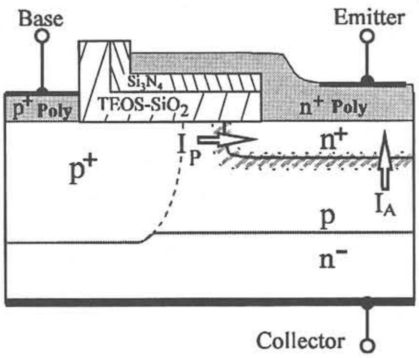

Fig. 1. The schematic cross-section of the bipolar transistor with the identification of perimeter and area current (I_P and I_A).

setup. A constant forward current is applied to the base. The collector voltage fluctuations of the transistor are displayed as spectral power density of the voltage fluctuations $S_υ(f)$.

The RTN characteristics are measured by a constant forward-voltage mode on the B-E junction, using the Keithley 236 and a low-noise current preamplifier. After appropriate filtering and subtraction of a constant-current offset, the temporal current fluctuations ΔI_B at the B-E junction are displayed with an oscilloscope and recorded also directly by measuring the base current I_B using the Keithley 236. The principal advantage of this approach to study degradation in bipolar devices lies in its direct link with microscopic properties of the defects.

3. RESULTS AND DISCUSSION

3.1 1/f NOISE

A typical 1/f noise is observed in our transistors as shown in Fig. 2. For devices without any stress the measured $S_υ(f)$ is that of the spectrometer. For degraded devices the $S_υ(f)$ rises typically to 20 dB above this background.

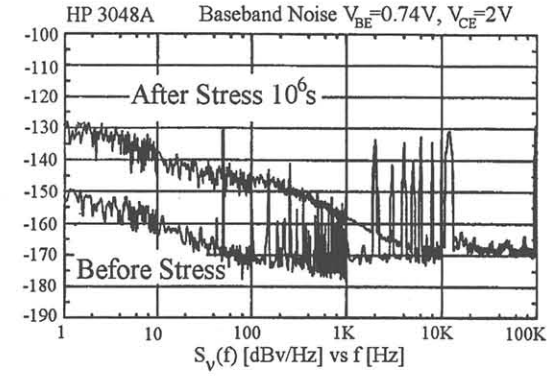

Fig. 2. Typical 1/f noise observed for an advanced self-aligned bipolar transistor

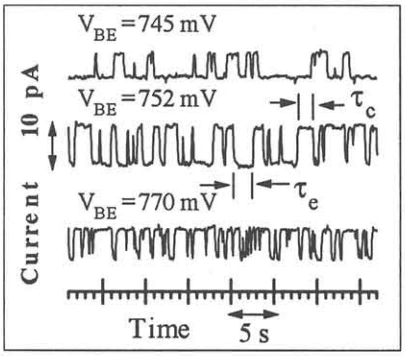

Fig. 3. Typical RTN signals observed in the base-emitter junction of an advanced self-aligned bipolar transistor

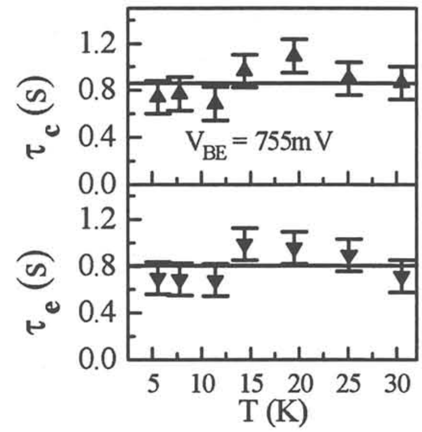

Fig. 4. The constant capture and emission times at different temperatures indicate a non-thermal process.

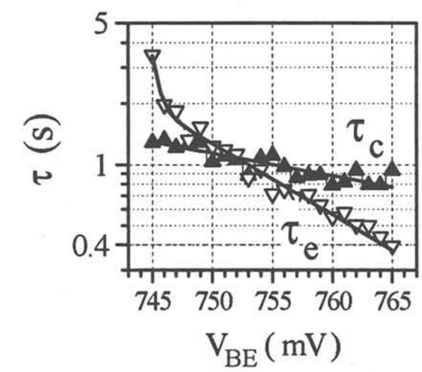

Fig. 5. Capture and emission times as a function of forward bias V_{BE} at low temperature.

3.2 RTN NOISE

The RTN signals can be observed only in the lower forward bias region and their features differ from device to device. A typical result is shown in Fig. 3, where the mean times in high- and low-current states are denoted τ_c and τ_e, respectively. This RTN closely resembles that of MOS transistors[6,7], but the temperature and voltage dependences have different behaviors.

Fig. 4 shows that the τ_c and τ_e are nearly *independent* of the temperature (T) when the T is low. It is also observed that they decrease very fast with increasing T when T > 50 K.

The bias dependence of τ_c and τ_e is shown in Fig. 5. With increasing forward bias V_{BE} both τ_c and τ_e decrease.

As an example shown in Fig. 6a), the amplitude of the current switching ΔI_B is about 1% of the base current I_B. The ratio ΔI_B / I_B has a peak near V_{BE} ~ 0.752V. Another feature occurs in the region 0.655 - 0.675V.

3.3 DISCUSSION

Formally the RTN signals resemble those studied in MOS transistors, but their microscopic origin is different because the current regime where they are observed is dominated by tunneling through interfacial defect states. In MOS transistors above threshold the drain current I_D is a drift current. The capture or release of an electron in a slow trap, located physically in the oxide at some distance from the interface, changes the carrier density and scattering in the channel. The switching observed in I_D is the result. Particularly big switching signals near threshold are thought the reflect changes in the filamentary distribution of current in the fluctuating surface potential[9]. For MOS devices, there is an exponential T-dependence in the times τ_c and τ_e. Their relative value is a function of the position of the Fermi-energy[6].

Using the accepted thermal activation process model[6], which predicts that the τ_c and τ_e have a strong temperature dependence in the form $\frac{\tau_c}{\tau_e} = g\exp(\frac{E_t - E_F}{kT})$, it is possible to explain our results at higher T. It does not explain the capture and emission at lower T.

The very different dependences on T and V_{BE} that are found for the RTN in Fig. 4 and 5, indicate that T-independent tunneling is involved at least of low T. We suggest that the capture and emission at low T are temperature independent electron tunneling processes

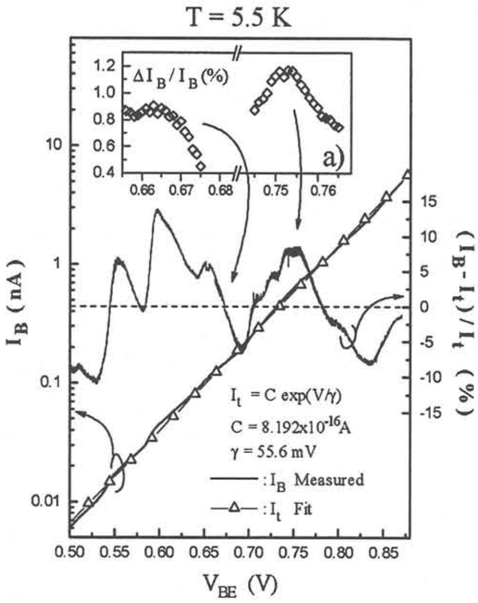

Fig. 6. Typical I-V characteristics at 5.5 K for degraded devices. The curve $(I_B - I_t)/I_t$ vis V_{BE} shows the deviation between the measured data and fit data. The insert Fig. a) shows the amplitude of RTN signals ΔI_B as a function of forward bias V_{BE}.

associated with a single border trap. The latter is situated in the oxide near the interface of Si-SiO_2 on the low doped p-base side of the B-E junction (see Fig.1).

Because the border trap is situated in the SiO_2, the electron tunneling through the border trap is a much slower process than that through the interface states. Therefore we note that in the small forward bias condition, where RTN is observed in degraded devices, the tunneling through the interface states dominates the base current I_B. This tunneling I_B rises exponentially with V_{BE} in Fig. 6. It is accounted for in terms of two factors. Both the rise in tunneling probability with forward bias (barrier reduced) and the change in the density of interface states must be considered to produce the fit in the figure. There are distinct "fingerprint" - type of current fluctuations around the exponentially rising I_B. The differences $(I_B - I_t)$ fluctuate as the density of interface states changes nonuniformly with rising V_{BE}. This is the static part and is analogous to the "fingerprint" I_D-fluctuations of MOSFETs. RTN signals are observed superposed on the $(I_B - I_t)$ as a temporal change.

The anomalous behavior of the RTN traps is linked to the dominance of the tunneling current contribution to I_B. We attribute the RTN to the electron capture and emission, into and out of a single border trap, respectively. Carriers available to be captured in the border trap state exist at the interface and also at n^+-Si in the tunneling states that account for I_B. Their charge can be transferred via tunneling to the trap location. When this occurs, the changed Coulomb potential alters all the tunneling trap energies and their interface states assited-band-to-band tunneling rates such that there is a measurable change in the current I_B. With regard to the physical properties of RTNs, such as their amplitude vs V_{BE} (Fig. 6), also the times τ_c and τ_e in their dependence on T and V_{BE}, both the predominance of the tunneling current processes through the interface states and the single border trap, and the nonuniform change of the density of interface states with rising V_{BE}, must be considered. This will account for the anomalous dependences.

The total 1/f noise spectrum, just as for MOS devices, can be explained as a summation of RTN sources corresponding to a set of border traps with appropriate distribution of switching times.

4. CONCLUSION

The RTNs have been observed in advanced self-aligned bipolar transistors. It has been shown that our model based on the tunneling transitions between a single border trap, interface states and Si-band can account for the anomalous capture and emission behavior. This study of RTN provides a direct information about the microscopic origin of the hot carrier degradation and the low-frequency noise.

ACKNOWLEDGMENT

The authors would like to thank Dr. T. Felgentreff for his help to measure the 1/f noise.

REFERENCES

1) S. P. Joshi, R. Lahri, and C. Lage: *IEDM Tech. Dig.* 1987, p. 182.
2) D.D.-L. Tang, and E. Hackbarth: IEEE Trans. Electron Devices, **35** (1988) 2101.
3) G. P. Li, T. C. C. Chen, C. T. Chuang, J. M. C. Stark, D. D. Tang, M. B. Ketchen, and L. K. Wang: IEEE Electron Device Lett. **EDL-8** (1987) 338.
4) J. D. Burnett and C. Hu: IEEE Trans. Electron Devices, **35** (1988) 2238.
5) J.-Q. Lü, S. Schöttl, E. Stefanov, F. Koch, R. Mahnkopf and H. Klose: *Defect- and Impurity-Engineered Semiconductors and Devices*, edited by S. Ashok, J. Chevallier, I. Akasaki, N.M. Johnson and B.L. Sopori (*Proc. Mat. Res. Soc. Symp.* **378**, San Francisco, April 1995), in press.
6) M.J. Kirton and M.J. Uren: Adv. Phys. **38** (1989) 367; and therein references.
7) M. Bollu, F. Koch, A. Madenach and J. Scholz,: Appl. Surface Sci. **30** (1987) 142.
8) D. Pogany and J.A. Chroboczek: Microelectronic Engineering **28** (1995) 83.
9) H.H. Mueller, U. Schirl and M. Schulz: Microelectronic Engineering **28** (1995) 163.