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A Micro-Crystal Emitter Heterojunction Bipolar Transistor

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Current transport and current gain degradation mechanisms of a-SiC hetero-emitter HBT are discussed by observing the I-V and other characteristics. In order to verify the model, micro-crystalline Si is introduced as hetero-emitter, after investigating its fundamental properties. Under such studies, current gain is remakably enhanced by using low resistance micro-crystalline Si, and current gain as high as 480 has been obtained.

1. Introduction

Since we have reported fundamental properties and effectiveness of wide band gap emitter by using amorphous SiC (a-SiC) emitter[1], hetero-emitter structures which can essentially reduce the base resistance are being widely investigated in Si field in order to realize future high speed bipolar transistor, power device and systems employing such devices.

This hetero-emitter has complete process compatibilities with high speed self-align bipolar transistors having poly-Si emitter, since the poly-Si emitter can be easily replaced by this emitter. Especially, it can be said that not only high emitter injection efficiency can be realized but also the low temperature process in fabricating emitter is much available for fabrication of heavily doped and very thin base region.

However, on this kind of transistor, there is a problem of the increase of emitter series resistance. This high emitter resistance will also become one of the causes to induce current gain degradation.

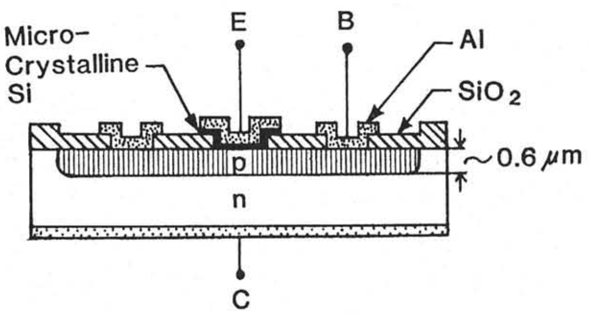
In this paper, the cause of lower current gain than the value theoretically expected from the energy band structure will be indicated by considering a current transport mechanism on the a-SiC/c-Si heterojunction. In order to verify this model, we will introduce a micro-crystalline Si as an example of hetero-emitter for the first time, which provides wide band gap as same as a-SiC in spite of much lower resistivity. Since a current gain as high as 480 was actually observed, we will discuss on the results in detail.

2. Devices Fabrication and Micro-Crystalline Si Films Preparation

Conventional Si process was used for fabrication of the HBTs.

A field oxide film was grown thermally on a chemically precleaned 7 Ωcm (111)n/n^+ Si substrate and a window was cut into it. Ion implantation (B^+, $8\times10^{12}cm^{-2}$, 80keV) was carried out for fabricating base region. A second oxidation (1025°C, 30min), base drive-in diffusion and activation anneal were

carried out simultaneously. An emitter window was cut into the oxide, the base surface was clean by RCA boiling again. Immediately after dipped in the HF solution in order to remove a chemical oxide, the sample was loaded into the discharge chamber of plasma CVD system wherein a micro-crystalline Si film was prepared. Then, the micro-crystalline Si film was etched by CF_4 RIE etching except emitter region. After Al electrodes were fabricated, treatment such as thermal or H_2 anneal was not applied.
A cross-section of the transistor and deposition condition of micro-crystalline Si are shown in Fig.1.



Deposition Conditions

Sub. Temp.	:350°C
Depo. Method	:L-coupled PCVD
R.F. Power	:60W
Gas Sources	:SiH_4, 5% He diluted PH_3, 1% He diluted (Added Ar of 20%)
Depo. Rate	:40 Å/min
Film Thickness	:100nm (for emitter)

Fig.1. Cross-section of the transistor and deposition condition of micro-crystalline Si.

3. Resutls and Discussions

3.1 Characterization of Micro-crystalline Si Films

Micro-crystalline Si films were deposited by using inductive coupled plasma CVD system which is the same apparatus for deposition of a-SiC films. It is significant here that the gas sources had to be mixed by 20% Ar to obtain micro-crystallized film. If not, the film was in amorphous phase. This phenomena were occurred regardless of whether He or H_2 diluted gas sources.

Optical band gap and average grain size of micro-crystalline Si films were measured by photo absorption method and X-ray diffraction pattern as shown in Fig.2. Because the optical band gap is rather wide, this film would be applicable to wide band gap hetero-emitter as well as a-SiC.

Electrical properties were also investigated. I-V measurements using Al electrodes deposited in vacuum showed good ohmic contact characteristics without any treatments. The conductivity was evaluated to be 7.1 S/cm from the measurments. Hall mesurements were carried out, resulting in carrier concentration of 5.5×10^{19} cm^{-3} and electron Hall mobility of 0.81 $cm^2/V\cdot s$.

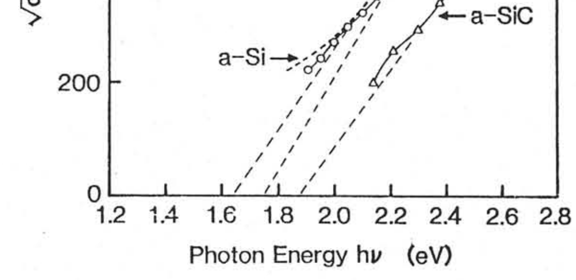


Fig.2. Photo absorption and X-ray diffraction properties of micro-crystalline Si.

3.2 Current Gain Degradation Mechanism

On the a-SiC emitter HBT, the current gain was not so large as expected value from the band structure[2]. The current density was also rather small. In order to clarify the mechanisms, the characteristics of emitter currents and current gains were measured as the function of V_{BE} as shown in Fig.3. It is observed that the current gain degradation starts at the same point at which emitter currents start saturate for the a-SiC emitter HBT. This behavior could be interpreted by a current transport model at an a-SiC/c-Si heterojunction as shown in Fig.4. A current flowing through the emitter is in drift-current-limited even at low current level because resistivity of the a-SiC film is so high. On the other hand, the interface recombination current and the defect-assisted current (This current might be explained by capture tunneling model[3].) flowing via localized states are still in the exponetial increase region. Furthermore, it is noted that electric field due to the emitter series resistance enhances the defect-assisted current component. On the contrary, for the case of micro-crystalline Si emitter, such degradation would not be appeared, since emitter series resistance could be very low in comparison with a-SiC film.

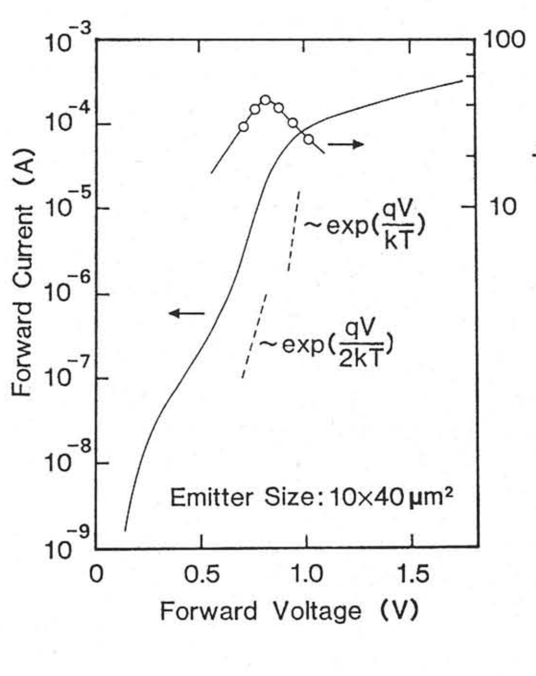


Fig.3. Emitter base diode current and current gain dependences on V_{BE}.

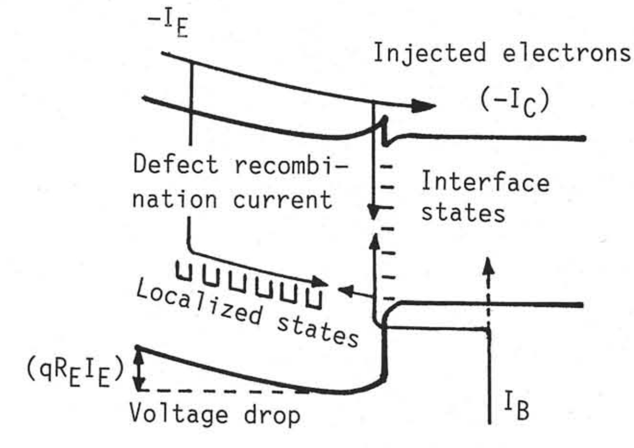


Fig.4. Current transport model for a-SiC/c-Si heterojunction.

3.3 Improvement of Current Gain by Micro-Crystalline Si Hetero-Emitter

In order to verify the above speculation, HBTs were fabricated using micro-crystalline Si for hetero-emitter. The h_{FE}-I_C characteristics of the HBT are shown in Fig.5. As

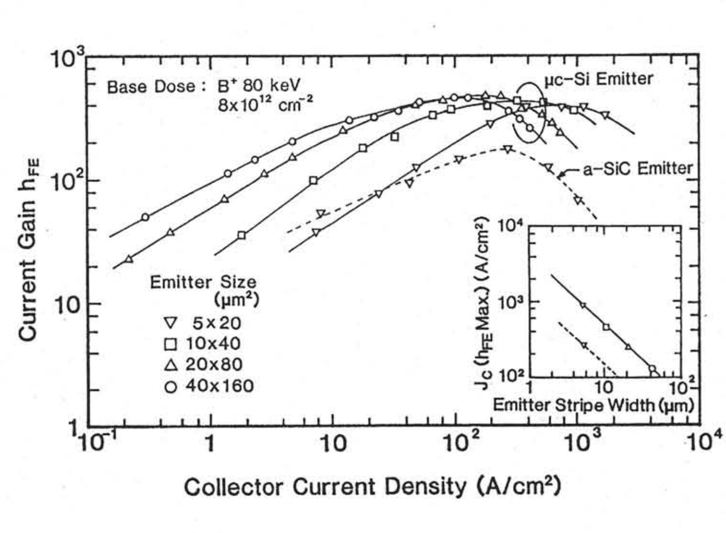


Fig.5. h_{FE}-I_C characteristics and current densities of micro-crystalline Si and a-SiC hetero-emitter transistors.

can be seen in this figure, the current gain as high as 480 is achieved. This value is from 2 to 3 times larger than that of a-SiC emitter, also improving current densities. However this improvements might be occurred by high doping in emitter. Let us estimate the current gain when the emitter is homojunction.

The current gain is approximately given by the next equation;

$$h_{FE}= \frac{\int_0^{W_E} N_E(x)dx \; D_p}{\int_0^{W_B} N_B(x)dx \; D_n} \cdot \exp(-\Delta E_g/kT) \qquad (1)$$

where N_E, N_B, W_E, W_B, D_n and D_p is carrier concentration, thickness and diffusion coefficient for electrons and holes in the emitter and base region respectively. ΔE_g is the band gap narrowing for heavily doped Si. Using following values as reasonable ones estimated from our experimental conditions:

$N_E=5.5\times10^{19}cm^{-3}$, $\int N_B(x)dx=8\times10^{12}cm^{-2}$
$W_E=100nm$, $D_n=17cm^2/s$, $D_p=1.2cm^2/s$ 4),
$\Delta E_g=100meV$ 5)

the h_{FE} is calculated to be about 20.

Since obviously, we can see that higher current gains than those in the conventional homojunction transistors are realized, this high current gain is reduced to the wide band gap emitter effect.

Therefore we can say that these experimental results confirm the validity of above considerations.

4. Conclusion

We have discussed the current transport mechanisms and current gain in a-SiC and micro-crystalline Si emitter Si-HBT. We can conclude that the current gain degradation in a-SiC emitter HBT is occurred due to low current supply capability of emitter rather than interface problem.

These interpretations and the structures for hetero-emitters are expected to be useful for realizing future high speed Si-HBT.

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