A-3-1 (Invited) A SIPOS-Si Heterojunction Transistor

Takeshi Matsushita, Hisao Hayashi, Norikazu Oh-uchi and Hisayoshi Yamoto
Semiconductor Division, SONY Corporation
4-14-1 Asahi, Atsugi 243, Kanagawa, Japan

A heterojunction transistor is normally one in which the emitter material is of wider energy band gap than the base and collector material. Although many attempts have been made to fabricate heterojunction transistors, a transistor with very high current gains has not been developed so far due to high recombination velocity at the interface between the two materials[1].

We have used SIPOS(Semi-insulating polycrystalline silicon) doped heavily with phosphorus as the material of wide energy band gap and developed an npn SIPOS-Si heterojunction transistor showing 50 times the current gain of a silicon homojunction transistor with the same base Gummel number[2),3)]. P-doped SIPOS ($Si_xO_yP_z$) is deposited from SiH_4, N_2O and PH_3 with N_2 as a carrier gas at 650°C. The energy band gap, resistivity and mobility of $Si_{54}O_{45.1}P_{0.9}$ annealed at 1,000°C for 1 hour is about 1.5 eV, 10 ohm-cm and 0.6 $cm^2V^{-1}s^{-1}$, respectively. The resistivity of P-doped SIPOS has also been found to be reduced to about 1/10 of the initial value by low-temperature annealing in hydrogen.

An npn heterojunction transistor has been fabricated by forming p-type base into a (111) n-type Si epitaxial layer and depositing double layers which are composed of P-doped SIPOS of 1,000 Å thickness and then P-doped polysilicon of 1,500 Å thickness onto the base region. P-doped polysilicon is formed in order to obtain a good ohmic contact between an Al electrode and P-doped SIPOS. As P-doped SIPOS acts also as a diffusion source of phosphorus into silicon in high-temperature treatments such as 900°C for 60 min. or 1,000°C for 10 min., the surface region of p-type base can be converted into n-type emitter. The cross section and energy band diagram of the isotype (n-SIPOS)-(n-Si) heterojunction transistor is shown in Figs. 1 and 2, respectively. Figure 3 shows base currents I_b and collector currents I_c of the isotype heterojunction and a conventional transistor with the same emitter area as a function of forward base-emitter voltages V_{BE}. I_b-V_{BE} characteristics of the heterojunction transistor show that the non-ideality factor "n" is 1 at middle injection level, which indicates that the diffusion component is the dominant mechanism in the isotype heterojunction.

On the other hand, the wide-gap emitter transistor using an anisotype (n-SIPOS)-(p-Si) heterojunction has been fabricated by annealing of 900°C for 10 min. Capacitance-voltage characteristics of the anisotype heterojunction are shown in Fig. 4. The value of the diffusion voltage is 1.03 V, as shown in Fig. 4.

The difference in energy of the valence band edges ΔE_V in SIPOS and Si was estimated to be about 0.2 eV, based on the Anderson theory of heterojunctions. The anisotype heterojunction transistor shows also high current gains. However, we discovered degradation of current gains in the whole collector current region as a result of avalanching the emitter-base junction of the anisotype heterojunction transistor. This phenomenon is different from degradation of current gains at low collector currents originating from breakdown of the emitter-base junction of conventional transistors. The anisotype heterojunction is, therefore, inferior to the isotype heterojunction in respect of reliability.

Using a model which takes band gap narrowing caused by high impurity concentrations and Auger recombination for Si into account, calculated emitter Gummel numbers of the isotype heterojunction transistors are shown in Fig. 5 as a function of impurity concentrations in the n-Si emitter of 1,000 Å thickness with interface recombination velocities S as a parameter, where ΔE_V is 0.2 eV. Emitter Gummel number of the fabricated transistor was measured to be 2×10^{15} s/cm^4. As the impurity concentration in the n-Si emitter of the transistor was about 2×10^{18} cm^{-3}, it is estimated that the SIPOS-Si interface recombination velocity is about 100 cm/s from Fig. 5. Therefore, the SIPOS-Si heterojunction transistor has the potential of surpassing the present performance of silicon homojunction transistors.

References:1)A.G.Milnes and D.L.Feucht,Heterojunctions and Metal-Semiconductor Junctions(Academic,New York,1972).
2)T.Matsushita et al.,Appl.Phys.Lett.35,549(1979).
3)N.Oh-uchi et al.,IEDM Technical Digest 522(1979).

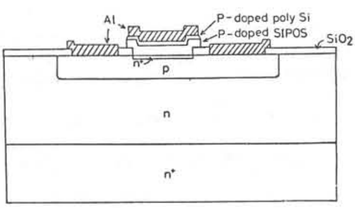

Fig. 1

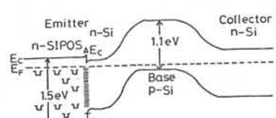

Fig. 2

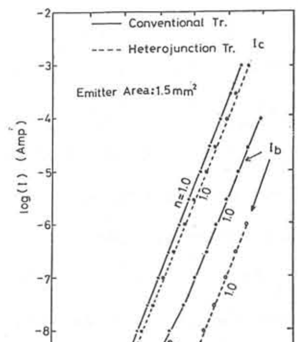

Fig. 3

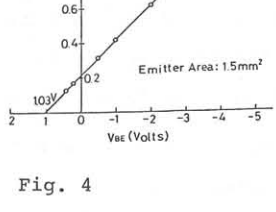

Fig. 4

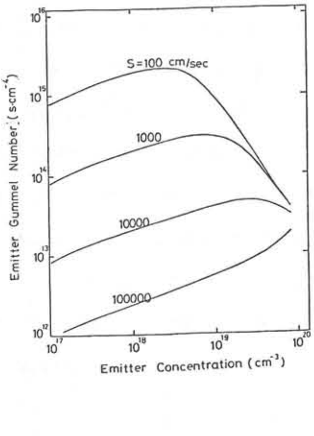

Fig. 5