Extended Abstracts of the 18th (1986 International) Conference on Solid State Devices and Materials, Tokyo, 1986, pp. 355-357 **C-5-3**

The New High Speed Device: The TEG-base Transistor

C.Y. Chang, W.C. Liu, M.S. Jame and Y.H. Wang

Semiconductor and System Laboratories
National Cheng Kung University

1, University Rd., Tainan, Taiwan, R.O.C.

We present a new high speed transistor, the V-grooved TEG-base transistor (TEG BT) which is a majority carrier (hot) transport device with a modulation of the barrier directly by the V_{EB} bias. By using a two dimensional electron gas as the base, the structure is n^+GaAs/graded i-AlGaAs/i-GaAs(TEG base)/i-AlGaAs/n^+GaAs, which has revealed high gain ($\alpha \approx 0.96$) and ultra high speed (~1ps).

Recently, molecular beam epitaxy (MBE) becomes one of the important technologies due to its good crystal quality and it is capable of producing ultra-thin layers. In this paper, a MBE grown two dimensional electron gas base transistor (TEG BT) will be presented. The device possesses a conceptual similarity to the well-known metal base transistor (MBE) with a base of two-dimensional electron gas (TEG) instead of metal. The TEG base charges are produced at a heterojunction interface by an electrical field caused by collector-base field and by carriers are injected from the emitter to the base by a bias. The concept of this device was proposed by Chang[1], and a theoretical analysis has also been presented by Luryi[2]. The presented TEG-BT preserves the main attractive feature (high speed) of a MBT, while avoiding its inherent drawback of a low common-base current gain, α.

Compared to other hot-electron transistors, the key new idea of the TEG-BT is that the base can be fabricated as thin as 100Å or smaller without a loss in its sheet conductance. The TEG is in the undoped GaAs quantum well (~100Å). In order to make a contact to the base layer easily, a V-groove etch technique is used.

The TEG-BT was grown by the molecular beam epitaxy technique. A cross section of this device is schematically shown in Fig. 1. The structure investigated consists of a 1.0μm n^+GaAs buffer layer, a 0.18μm undoped $Al_{0.4}Ga_{0.6}As$ collector barrier, a 100Å undoped GaAs Q.W. base, a 0.15μm undoped $Al_xGa_{1-x}As$ graded barrier ($x=0.4 \rightarrow 0$) emitter and a 0.3μm n^+GaAs cap layer. Emitter and base regions were delinated by a selective etching technique. A mesa structure was then formed along the emitter periphery by the V-groove etch technique with the etching solution of $H_2SO_4:H_2O_2:H_2O$(1:8:10).

The simplified conduction band diagrams for the TEG-BT are shown in Fig.2. In equilibrium as shown in Fig.2(a), the Fermi level is below the bottom of the lowest subband E_o of the Q.W. base, so the base is not conducting. When a positive bias V_{CB} is applied to the collector, a sheet of conducting electrons is induced in the base. If $V_{BE}=0$, and V_{CB} is increasing, the energy level E_o moves downward with respect to the Fermi level E_F as shown in Fig.2(b), and the number of electrons in the Q.W. base increases. When the TEG base starts conducting, the electron charge sheet density σ in the base is a function of V_{CB} and V_{EB} and can be expressed as,

$$\sigma = \frac{\varepsilon}{d_2} (V_{CB}-V_T)[1+e^{-qK_E V_{EB}/kT}] \quad (1)$$

The "1" in the bracket is due to V_{CB} which induces electron charges in the quantum well base, while the exponential-term $e^{-K_E V_{EB}/kT}$ is due to the charge injection from the emitter. K_E is the proportional constant. The threshold voltage V_T for the base conduction is a function of device geometry (d_1, d_2, ℓ) and the doping levels in the emitter and the collector.

When a set of positive bias V_{BE}'s are applied between the thin base and the emitter. The band diagram is shown in Fig. 2(c). A transistor action is occurred. In this case, the barrier height in the emitter side is lowered by $K_E V_{BE}$ and $K_C V_{CE}$. The current-voltage characteristics of the TEG-BT are shown in Fig.3. The base-emitter bias is changed 0.2V per step from zero. The I_C versus V_{CE} curves are shifted to higher currents with the increasing V_{BE} bias. This is due to the reduction of the barrier height for thermionic emission into base.

Due to the low fraction of electron loss in transporting the base and low probability of quantum mechanical reflection when electron passing over the triangular barrier, the common base current gain, $\alpha \approx 0.96$(V_{CE}=2.5V, I_E=3mA) has been achieved. It is much higher than the reported metal-base transistors, e.g., the $Si/CoSi_2/Si$ structure MBT with $\alpha \lesssim 0.2$[3].

The transit delay time in the collector is $\tau_c = d_2/V_S$, where V_S is the saturation velocity. In this device τ_c is about 1ps. However, at room temperature the device is mainly limited by the $R_b C_{eb}$ constant. This becomes negligible when operated at very low temperature (e.g., 4°K). Moreover, a velocity overshoot may be prevailed in such a thin layer of base and collector when it is comparable to the electron scattering mean free path[4].

The relationship between the TEG base sheet resistance, $R_\square$, and the applied collector-base voltage, V_{CB}, is illustrated in Fig.4. When the emitter is floating and V_{CB}<0.5V, $R_\square$ is very large due to the subthreshold regime. As V_{CB}>0.5V, $R_\square$ decreases with increasing the V_{CB}, on account of the increasing of induced TEG density in the base as discussed in Eq.(1). The induced TEG is limited by the breakdown field in the AlGaAs barrier. If a negative base-emitter bias, V_{EB}, is applied as shown in Fig.2(c), the barrier height of the triangular emitter barrier is reduced, which enhances the carrier injection from emitter to base, and the base sheet resistance is reduced. When the polarity of the V_{EB} is changed, the base sheet resistance is increased due to the reduction of the base TEG density.

In conclusion, a novel hot-electron transistor with TEG base has been fabricated successfully. The ultrathin base is made by using an undoped GaAs quantum well. A V-groove etch technique is used to make contact to the base layer. The main attractive feature of metal-base transistor, high speed operation, and high common-base current gian, $\alpha(\approx 0.96)$ have been obtianed, simultaneously. Charges in the quantum well base are "inducted" from the collector-base field and of "injected" from the emitter-base bias.

References:

1. C.Y. Chang, Y.H. Wang, W.C. Liu, S.A. Liao and K.Y. Cheng, Appl. Phys. Lett., Vol.46, 1084, (1985).
2. S. Luryi, IEEE. Electron. Device. Lett., EDL-6, 178, (1985).
3. E. Rosencher, S. Delage, Y. Campidelli, and F.A. d'Avitaya, Electron. Lett., 20, 762 (1984).
4. S.M. Sze, Physics of Semiconductor Devices, 2nd Ed., New York: Wiley, 1981, p340.

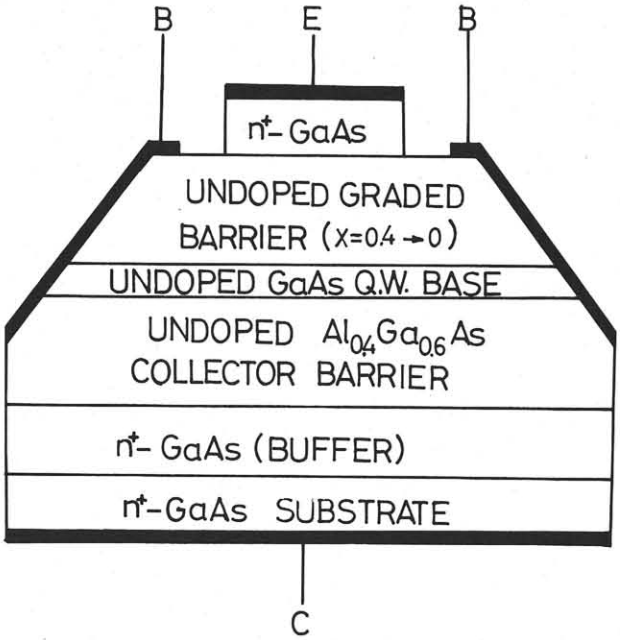

Fig.1. The cross section of the TEG base transistor.

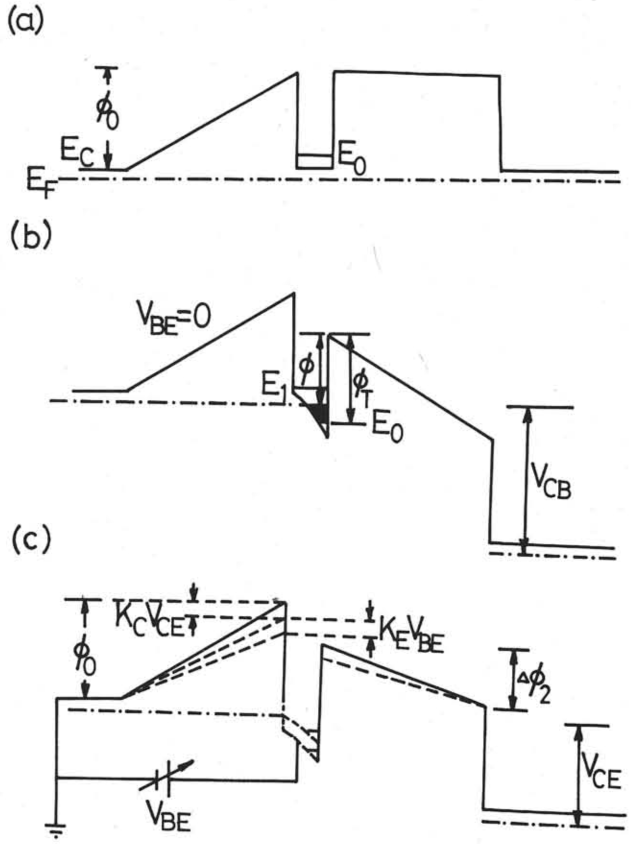

Fig.2. Conduction band diagram of the TEG-BT device.
(a) equilibrium
(b) a positive bias V_{CB} is applied to collector
(c) a positive bias V_{BE} is applied to emitter

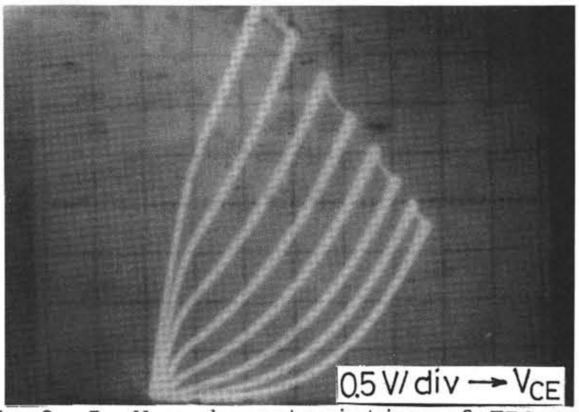

Fig.3. I_C-V_{CE} characteristics of TEG-BT with V_{BE} as parameters (from right to left 0.2V per step from zero.)

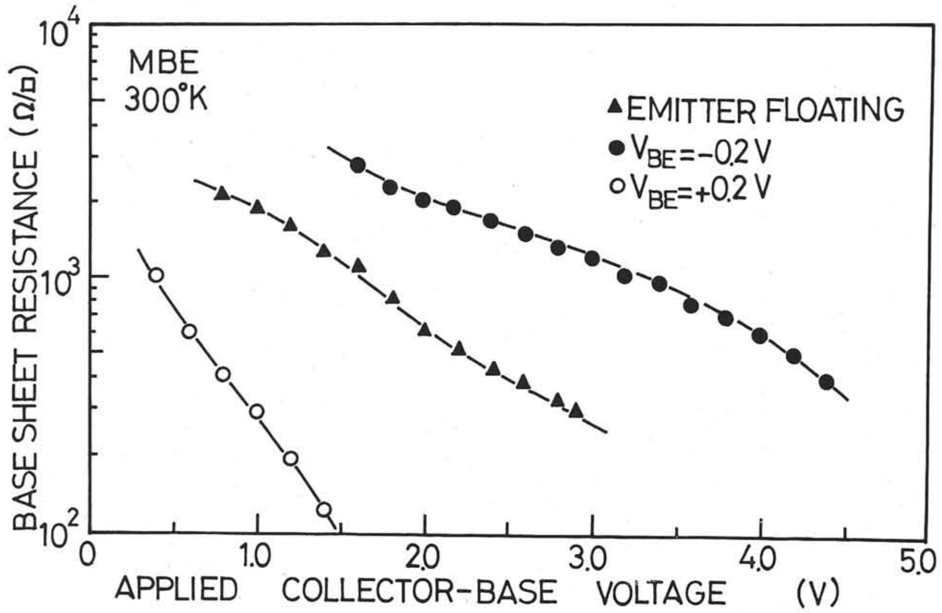

Fig.4. The relationship between the base sheet resistance and the applied collector-base voltage.