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AlGaAs/GaAs Heterojunction Bipolar Transistors for Microwave Power Amplifier Application

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AlGaAs/GaAs Heterojunction Bipolar Transistors (HBTs) were designed for high power microwave application and their small signal and power chracteristics were investigated. It was found that an appropriate base-emitter d.c. bias voltage was required for HBTs to realize high output power as well as high power gain. Maximum output power of 1 W with 6 dB gain and 49 % collector efficiency at 5 GHz were obtained under CW class-C operation for the device with 640 μm total emitter periphery. Experimental resullts were analyzed with the aid of numerical simulation, highlighting the effect of base-emitter d.c. bias voltage on power characteristics.

1. Introduction

Heterojunction bipolar transistors (HBTs) have a great potential of ultra-high speed and high frequency operation. With up-to-date progress in material growth technology (such as MBE and MOCVD), as well as the self-alignment technique and design optimization, the performance of HBTs based on AlGaAs/GsAs heterostructure has been improved remarkably. A propagation delay time of 5.5 ps/gate in a CML ring oscillator [2], 105 GHz cut off frequency [3], and a maximum oscillation frequency of 105 GHz [4] have been reported.

However, most of these efforts have been devoted to logic applications, but HBTs are also prospective for microwave power application owing to their high operation frequency, high output breakdown voltage directly controlled by the epitaxial structure, applicability for class-C operation with high efficiency, and high current handling capability. In spite of these excellent characteristics, only resticted studies have been carried out for the power characteristics of HBTs. Using relatively small size devices, 320 mW CW and 500 mW pulsed output powers at 5 GHz [5], and 80 mW CW and 160 mW pulsed at 10 GHz [6] have been reported.

In this present paper, an AlGaAs/GaAs HBT with an output power of more than 1 W will be described, and its device performance will be analyzed with the aid of numerical simulation.

2. Design and Fabrication

Figure 1 shows the epitaxial wafer structure and cross-sectional view of the fabricated devices. All epitaxial layers were grown by MBE on Cr-doped semi-insulating (S.I.) GaAs substrates in order to reduce the parasitic capacitance associated with the bonding pads. The device structure is similar to that described previously except for the base and collector layers. The base layer thickness was increased up to 150 nm to reduce the base resistance. The collector layer thickness and the doping level were designed to realize a collector-base breakdown voltage of over 30 V.

Fabrication processes similar to that previously reported [7] were adopted.

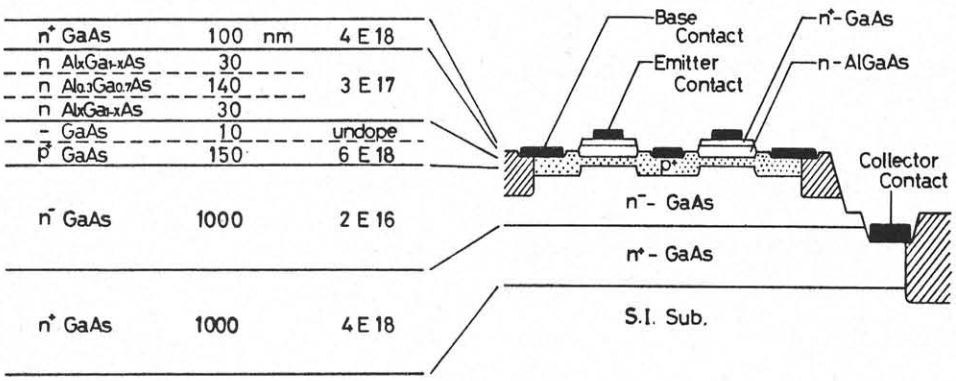

Fig.1: Epitaxial wafer structure and cross-sectional view of fabricated HBT.

Figure 2 shows a photomicrograph of the fabricated HBT with a total emitter periphery of 640 μm. The device consisted of eight unit cells , each having two emitter fingers placed between three base fingers. The collector fingers were placed between each of the unit cells. The dimension of the emitter finger was 4 x 20 μm with a 2 μm wide ohmic contact. The pitches of the emitter finger and cell were 8 μm and 17 μm, respectively. All bonding pads were placed on almost the same plane, and the interconnection for the base was crossed over that for the collector with CVD-SiO_2 as an interlayer insulator.

3. Results and Discussions

Figure 3 shows the current-voltage characteristics of the fabricated HBT with a 4 x 320 μm emitter area. A current gain of about 15 was obtained. The collector-base breakdown voltage was 27 V, as shown in Fig.3(b), which was slightly lower than the designed value probably due to the variation in collector doping density.

To evaluate the high frequency characteristics, small signal S-parameters of the device with a total emitter finger area of 4 x 40 μm, which coresponds to the unit cell described in the previous chapter, were measured from 1 GHz to 26 GHz with on-wafer probing system. The short circuit current gain H21 and maximum available power gain Gamax calculated from the S-parameters ,under a 2 V V_{CE} and 32 mA Ic bias condition, were plotted as a function of frequency, as in Fig.4. A cut off frequency fT of 19 GHz and a maximum oscillation frequency fmax of 26 GHz were obtained.

The power characteristics were evaluated with a 4 x 320 μm emitter area device. After the wafer was lapped to 100 μm in thickness,

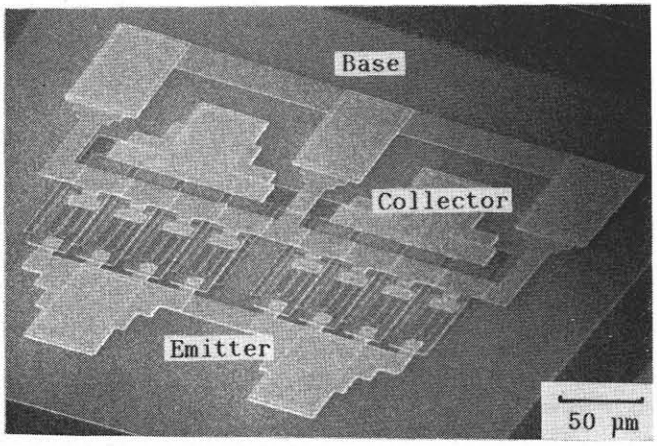

Fig.2: Photomicrograph of fabricated HBT with total emitter finger periphery of 640μm

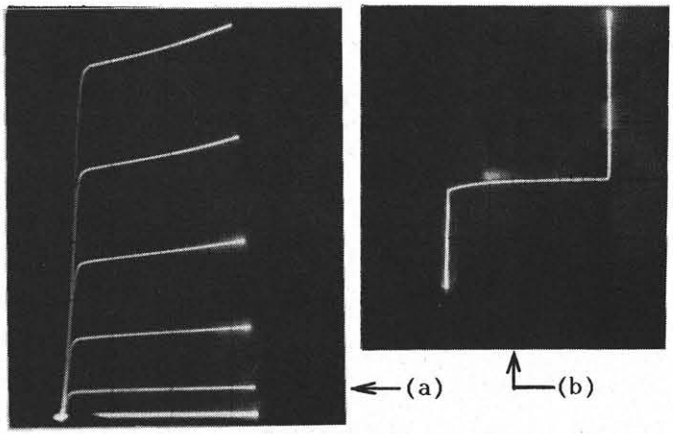

Fig.3: D.c. characteristics of fabricated HBT with total emitter periphery of 640 μm.
(a)Emitter grounded I-V characteristics Ic:20mA/div, Vc:2v/div, Ib:2mA/step
(b)Base-collector junction characteristics. I:50uA/div, V:10v/div

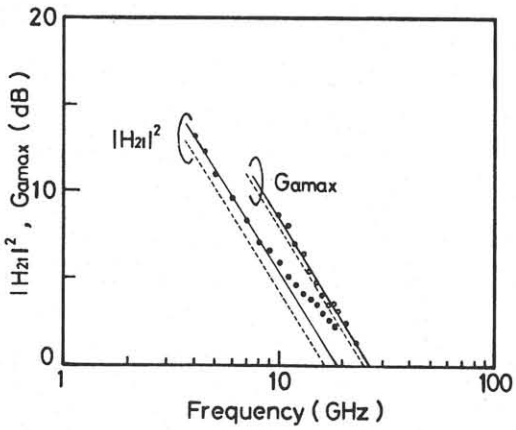

Fig.4: Short circuit current gain H21 and maximum available power gain Gamax vs. frequency of 4 x 20 μm two emitter finger device at 2 V V_{CE} and 32 mA Ic condition. Open and solid circles are experimental results and broken lines are calculated ones.

the transistor chip was mounted on a Cu based ceramic package together with a prematching circuit. The output chracteristics were measured in a common-base configuration under CW class-C operation. Figure 5 shows the output power and collector efficiency obtained at 5 GHz as a function of input power with the d.c. base-emitter bias voltage V_{BE} as a parameter. As shown in the figure, the output power strongly depends on V_{BE} . At 1.5 V V_{BE} , a maximum output power of 1 W with 6

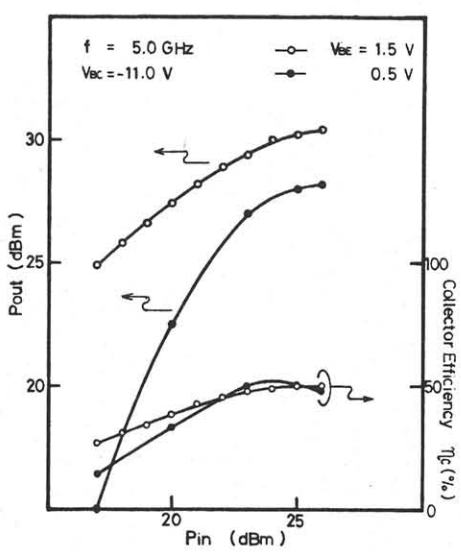

Fig.5: Output power and collector efficiency vs. input power at 5 GHz with base-emitter d.c. bias as a parameter obtained from total emitter periphery of 640 μm device.

dB gain and 49 % collector efficiency were obtained. The collector voltage and the collector current were 11 V and 186 mA, respectively.

Circuit modeling for large signal operation was carried out to investigate the dependence of output power on base-emitter d.c. bias voltage, which seems peculiar to HBTs compared with Si bipolar transistors. Figure 6 shows the equivalent circuit model of an HBT class-C amplifier. This model consists of an intrinsic transistor, external base diode, internal resistances, pad capacitances, and lead inductances, including both input and output matching circuits each approximately represented by a capacitance and an inductance. SPICE parameters were extracted from 1-dimensional numerical analysis. The matching circuit conditions were optimized by using our own model with direct SPICE linkage[8], where the initial values were derived from small signal S-parameters. Then, the power characteristics were calculated by applying large signals to the input terminal of the matching circuit.

In Fig 4, the H21 and Gamax predicted by the simulation are plotted together with those from experiment, verifing a reasonable agreement between them. The simulated power characteristics are demonstrated in Fig.7. As shown in the figure, the output power increases with an increase in V_{BE} . This phenomenon is attributed to the inherent large emitter-base turn-on voltage of the

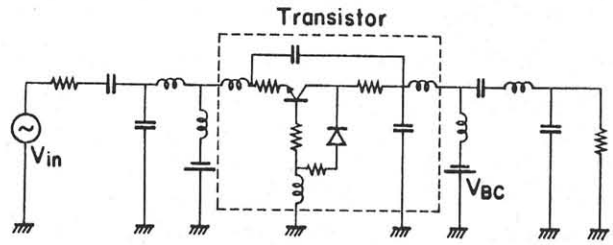

Fig.6: Equivalent circuit model of an HBT class-C amplifier

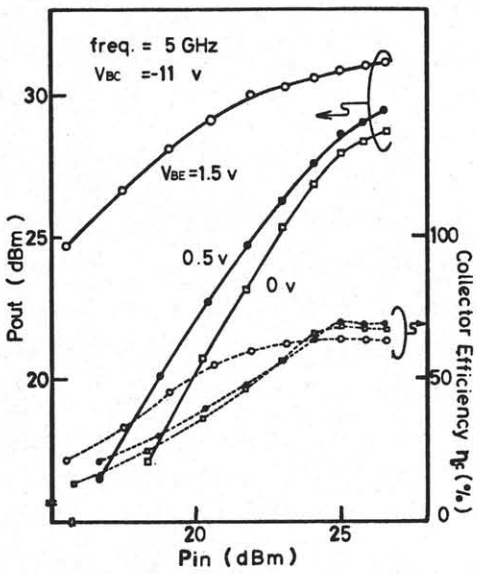

Fig.7: Simulated output power and collector efficiency vs. input power at 5 GHz with base-emitter d.c. bias voltage as a parameter.

HBTs. A large dv/dt current for charging and discharging the emitter capacitance couples with the emitter and base resistances resulting in a large input power loss compared with the conventional silicon transistors. The base-emitter d.c. offset voltage is considered to be useful for reducing the dv/dt current. However, the application of too high bias voltage enough to turn on the base-emitter junction will increase the d.c. collector current, resulting in a degradation of the collector efficiency. Therefore, an appropriate d.c. bias voltage is required to realize the high performance of the HBTs.

4. Conclusions

An AlGaAs/GaAs HBT was designed for microwave power amplifier application and its power characteristics were investigated.

It was found that an appropriate base-emitter d.c. bias voltage is required for HBTs to realize high output power as well as high power gain.

A maximum output power of 1 W with 6 dB power gain and 49% collector efficiency at 5 GHz were obtained under CW class-C operation for a device with 640 μm total emitter periphery.

Circuit modeling was carried out to investigate this phenomenon. The calculation revealed that this phenomenon is inherent in AlGaAs/GaAs HBTs with a higher base-emitter built-in voltage compared with silicon transistors.

These results indicate that the HBT will be very prospective for microwave power application, though some different circuit configuration from that for silicon technology may be required.

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