Recent Development of GaAs Devices in Japan

Masumi Fukuta

FUJITSU LIMITED
1015 Kamikodanaka, Nakahara-ku, Kawasaki 211, Japan

Abstract

This paper describes the development status of the devices based on compound semiconductors especially on gallium arsenide (GaAs) in Japan.

In the area of the devices for handy phone, and PCS/PCN application, GaAs MESFETs, HEMTs and HBTs have been actively investigated to have low voltage operation and low power consumption. The market has started to expand and we can see many serious and practical studies in this area. In millimeterwave InP lattice matched HEMTs and GaAs pseudomorphic HEMTs have been developed as active devices for collision avoidance radar, wireless LAN, remote POS system and etc. For high rate optical communication systems, still GaAs MESFET ICs have been developed because the technology is matured today, though HBT ICs are studied for many functions. In the field of data processing, GaAs LSIs have established its position for the highest speed logic in a computer system.

1. Introduction

Now, the electronics industries in Japan has encountered with a turning point in the phase and is in a pregnancy period to make a new direction. This recession in Japan is essentially caused by a lack of effort to develop new products which customers really want, although it looked as a result of crush of the bubbled economy.

A GaAs device has an attractive performance that a Si device cannot achieve and is becoming inevitably necessary for the equipments we have to use in daily life such as for communication, broadcasting and data processing.

DBS, handyphone and wireless LAN in microwave /millimeterwave field will use GaAs FETs, HEMTs and MMICs. In the optical communication field they are also used as interface devices to electric signal in information infrastructure or multimedia. In the field of a super computer, GaAs LSIs have been used in high speed data processing and will be used widely in the near future.

Here the paper will review the development status of GaAs devices in Japan and shall describe what a realistic and hopeful device should be, which can contribute on electronics industries not only in Japan but in the would.

2. Mobile Communication: Handy phone, PCS, Wireless LAN

UHF - L-band is mainly used for these application. GaAs devices essentially indicate high gain, good linearity, low distortion and high efficiency. In addition, considering the advantages in low voltage operation, GaAs devices are the most suitable for mobile communication equipments such as handyphone. In this field a lot of steady studies are focussed on practical devices. Active devices such as MESFET, Junction FET, HEMT (or Hetero Junction FET), HBT, and their modifications have been investigated. There was a remarkable progress in the study to shrink passive elements.

L-band low power MMICs, LNA, mixer and SPDT switch, were developed using enhancement mode and depletion mode GaAs Junction FETs with insertion loss of 0.7 dB, isolation loss of 30 dB at 1.9 GHz [1] [2].

A new two-mode channel FET (TMT) for low noise and high power applications was reported for one chip transceiver. HEMTs and normal MESFETs operation are possible within a device for a low noise device and a power device respectively [3].

A 3V-operational L-band power device consists of double doped Heterojunction FET (HEMT) was investigated. It has two AlGaAs 2DEG supply layers and InGaAs channel layer. Output power of 1.4 W and power added efficiency of 61 % were obtained at 950 MHz [4].

An advantage of Unbalanced Bias Cascode Power Amplifier (UBIC-PA) using conventional GaAs MESFETs was demonstrated for high efficiency at low power level. [5].

The other active device for handyphone is a Hetero junction Bipolar Transistor(HBT). HBT achieved a power added efficiency of 70 % with an output power of two watt at 1.5 GHz with F-class using harmonic trap circuits from the simulated result [6].

Power added efficiencies of 74 %, 66 % and 61 % for 5 W, 8 W and 10 W respectively at 0.9 GHz with a V_{cc} of 6 V is reported using "Bump Heat Sink" technology to reduce a thermal resistance [7].

The key point for an HBT is to confirm its long life. Until now any complete life test result has not reported which confirms its MTTF as MESFET's.

Mobile communication system needs low voltage and low power consumption synthesizers. A 2 GHz prescaler at supply voltage of 0.8 V and power consumption of 0.9 mA using E/D HEMT IC process was developed. A low power synthesizer will be obtained by a 1V-CMOS PLL and a HEMT prescaler[8].

A remarkable progress was reported in passive element. Ferroelectric material, BST ($Ba_xSr_{1-x}TiO_3$), was introduced to GaAs MMIC wafer process for the use of capacitor. The purpose of this work is to unify supply voltage by insertion of large capacitance in the source circuit. It enables to realize 50 times larger capacitance than the same size of usual MIM capacitor on GaAs. While various studies on active devices have been done, this study is thought to be excellent considering total product performance [9].

3. Millimeterwave Application

In Japan millimeterwave application study has been less active compared to Europe and US. Recently great demands for millimeterwave are raising up because it can handle large amount of data or graphic information.

The features of millimeterwave system are as follows:

(1) A high speed/capacity data transmission is possible because of its wide band width.
(2) Terminals can be shrunk because of its short wavelength.
(3) A repeatable use of a frequency is possible on account of the loss in the air.
(4) A high resolution sensor is available owing to its directional transmission.

Studies for Wireless LAN, Wireless Video Camera System, Collision Avoidance Rader for traffic are in progress using 60GHz band in Japan. Developments of millimeterwave devices also have become aggressive. For low noise applications HEMTs have apparent advantages. Among several material systems a lattice matched InAlAs/InGaAs HEMT on InP substrate indicates superior performance for millimeterwave application.

A 0.1 µm T-shape gate InAlAs/InGaAs HEMT was demonstrated with a noise figure of 1.35 dB with the associated gain of 10.2 dB at 50 GHz and NF of 2.7 dB, G_{as} of 5.4 dB at 94 GHz [10]. A 0.05 µm InAlAs/InGaAs/InP HEMT was fabricated and its short-channel effects were investigated. [11].

Developments of GaAs based HEMT are still active, because it is thought to have advantages in cost and in productivity compared to an InP based HEMT. A 0.15 µm T-shape gate HEMT with a NF of 1.6 dB and a G_{as} of 6.5 dB at 60 GHz was reported using InGaAs for channel layer and Si planer doped AlGaAs for 2DEG supply layer [12].

A GaAs based pseudomorphic HEMT with a InGaP 2DEG supply layer was proposed. The HEMT indicated a NF of 0.41 dB and a G_{as} of 13.0 dB at 12 GHz including the package loss. This approach is very unique and will be considered as a next commercially available device. [13].

HEMTs have advantages even for power application in millimeterwave. The HEMT with a gate length of 0.3 µm and gate width of 800 µm achieved an output power of 23.4 dBm with the associated gain of 4.1 dB and power add efficiency of 18 % at 55 GHz [14].

A 60GHz HEMT Mixer MMIC was studied. A conversion loss of 3.4dB was achieved at an input power of 2.5 dBm [15].

Radiation efficiency at 40 GHz was improved to be 89% by an MMIC aperture-coupled microstrip antenna (MSA) integrated with a mixer and an amplifier [16].

4. Optical Communication

In optical communication system 2.4 Gbps system has been spreading. To enhance data and image transmission rate, 10Gbps system development is in progress. In this high speed system GaAs devices will take very important role.

Adopting GaAs MESFET IC technology, a 10Gbps pre-amplifier with an equivalent input noise current of 12.6 pA/$\sqrt{Hz}$ over DC to 7.8 GHz, and transimpedance of 44 dB Ω was reported. Wafer process feature was 0.5 µm gate BPLDD MESFET [17].

A design technique for a high-gain amplifier module using 0.2µm gate GaAs ICs was investigated to expand bandwidth and maintain stability considering high transimpedance, high gain, package design [18].

BCTs (Ballistic Collection Transistor), advanced HBTs, demonstrated a 19 Gbps 2:1 multiplexer , a preamplifier with a transimpedance of 52 dB Ω with a 3-dB-down bandwidth of 18.5 GHz, a 40 Gbps selector IC and a 50 GHz dynamic frequency divider [19].

HBT ICs have been reported by another group [20], [21]. But still there should be a confirmation in reliability or improvement of device structure has to be done for getting a long life. As HBT ICs have not been admitted for long term operation until now, HEMT ICs will take over MESFET ICs in high bit rate application

5. Data Processing

As remarkable progress, 355 GFLOPS super computer using 0.8 μm-GaAs MESFET LSIs has been released. The LSI consists of 25k-gate BDCFL gate array with a differential push-pull ECL I/O. The basic delay times are 45 ps for 0.75 mW DCFL gates and 60 ps for 1.2 mW BDCFL gates. Using 90% of internal gates, the total dissipation power is 25 W [22]. At present GaAs 250k gate SOG (Sea Of Gate) LSIs by 0.5 μm-BPLDD MESFET have been provided.

Recent progress in GaAs LSI production status are thought as followers:

(1) GaAs chips with integration density up to 120KG have been available.

(2) The chip cost has been competitive to Bi-CMOS owing to improved chip yield.

(3) The TAT (Turn Around Time) becomes also competitive.

(4) The circuit design system has been established.

GaAs LSIs have been expected to take the place of Si Bipolar LSIs and it comes true. As for the next stage GaAs LSIs should be developed taking CMOS into account as not only a competitor but a cooperator.

6. Conclusion

The most important thing when we develop a new device is that we have to think a definite application and to fefine what are the advantages and disadvantages when the device is used. Its inherent characteristics in reliability and cost are also important. We should not make efforts on only performance improvement without the above thinking.

References

[1] S. Kusunoki, T. Ohgihara, M. Wada and Y. Murakami, "SPDT Switch MMIC Using E/D-mode GaAs JFETs for Personal Communications", GaAs IC Symposium Digest, pp.135-138, 1992

[2] T. Ohgihara, S. Kusunoki, M. Wada and Y. Murakami, "GaAs JFET Front-End MMICs for L-Band Personal Communications", IEEE 1993 Microwave and Milimeter-Wave Monolithic Circuits Symposium, pp. 9-12

[3] M. Sawada, D. Inoue, K. Matsumura, Y. Harada, "A New Two-Mode Channel FET(TMT) for Super-Low-Noise and High-Power Applications", IEEE Electron device letters, pp. 354-356, July 1993

[4] N. Iwata, K. Inosako, M. Kuzuhara, "3V Operation L-Band Power Double-Doped Heterojunction FETs", IEEE MTT-S digest, pp. 1465-1468, 1993

[5] M. Muraguchi, M. Nakatsugawa and M. Aikawa, "A Novel MMIC Power Amplifier for Pocket-Size Cellular Telephones", IEEE MTT-S Digest, pp. 793-796, 1993

[6] N. Goto, N. Hayama, H. Takahashi and K. Honjo, "Application of AlGaAs/GaAs HBT's to Power Devices for Digital Mobile Radio Communications" IEICE TRANS. ELECTRON, vol. E76-C, No.9 pp. 1367-1372, 1993

[7] H. Sato, M. Miyauchi, K. Sakuno, M. Akagi, M. Hasagawa, J. K. Twyram, K., Yamamura and T. Tomita, "Bump Heat Sink Technology - A Novel Assembly Technology Suitable for Power HBTs", GaAs IC Symposium Digest, pp. 337-340, 1993

[8] Y. Nkasya, T. Miyata, Y. Watanabe, S. Kuroda and M. Takikawa, "A 0.7-mW/2-GHz Dual Modulus Prescaler IC", in press.

[9] S. Nagata, T. Ueda, A. Noma, H. Koizumi, K. Kanazawa, H. Ishida, T. Ueda, T. Tanaka, D. Ueda, M. Kazumura, G. Kano and C. Paz de Araujo, "A GaAs MMIC Chip-Set for Mobile Communications Using On-Chip Ferroelectric Capacitors", Digest of Technical Papers, 1993 IEEE International Solid-State Circuits Conference, pp. 172 -173, Feb. 1993

[10] H. Kawasaki, F. Sasaki, T. Kikuchi, M. Kawano, B. Abe and H. Tokuda, "W Band Low-Noise HEMT", Technical report of IEICE, pp. 51-56, 1992

[11] T. Enoki, Y. Umeda and Y. Ishii, "0.05um-Gate InAlAs/InGaAs HEMT and Reduction of Its Short-Channel Effects", Extend Abstracts of the 1993 International Conference Solid State Devices and Materials, Makuhari, 1993, pp. 1080-1082

[12] T. Katoh, N. Yoshida, H. Minami, T. Kashiwa and S. Orisaka, "A 60GHz Band Ultra Low Noise Planer-Doped HEMT", IEEE MTT-S Digest, pp.337-340, 1993

[13] M. Takikawa and K, Joshin, "Pseudomorphic N-InGaP/InGaAs/GaAs High Electron Mobility Transistors for Low-Noise Amplifiers", IEEE, ELECTRON DEVUCE LETTERS, vol. 14, No. 8, pp. 406 - 408, 1993

[14] S. Arai, H. Kojima, K. Otsuka, M. Kawano, H. Ishimura and H. Tokuda, "U-Band 200mW Pseudomorphic InGaAs Power HEMT", GaAs IC Symposium Digest, pp. 105-108, 1991

[15] T. Saito, N. Hidaka, Y. Ohashi, T. Shimura and Y. Aoki, "HEMT-based MMIC Single-Balanced Mixers

for 60 GHz Indoor Communication Systems", GaAs IC Symposium Digest, pp57-60, 1993
[16] H. Ohmine, T. Kashiwa, T. Ishikawa, A. Iida and M. Matsunaga, "An MMIC Aperture-Coupled Microstrip Antenna", PROCEEDINGS OF ISAP '92, SAPPORO, Japan, pp. 1105 - 1108
[17] M. Miyashita, K. Maemura, K. Yamamoto, T. Shimura, M. Nogami, K. Motoshima, T. Kitayama and Y. Mitsui, "An Ultra Broadband GaAs MESFET Preamplifier IC for 10Gb/s Optical Communication System", IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, vol 40,NO.12, pp. 2439-2444, 1992
[18] N. Ishihara, E. Sano, Y. Imai, H. Kikuchi and Y. Yamane, "A Design Technique for a High-Gain, 10-GHz Class-Bandwidth GaAs MESFET Amplifier IC Module", IEEE JOURNAL OF SOLID-STATE CIRCUITS, vol.27, No.4, pp. 554-562, 1992
[19] Y. Matsuoka S. Yamahata, S. Yamaguchi, K. Murata, E. Sano, T. Ishibashi, "IC-Oriented Self-Aligned High-Performance AlGaAs/GaAs Ballistic Collection Transistors and Their Applications to High-Speed ICs", IEICE TRANS. ELECTRON. vol.E76-C, NO.9, pp. 1392 -1401, 1993
[20] K. Honjo, N. Hayama, N. Nagano, H. Takahashi, S. Tanaka and H. Shimawaki, "Hetero-Guardring Fully Self-Aligned HBT (HG-FST) for Microwave and High-Speed Digital Applications", NEC Res. & Develop. vol. 33, No.3, pp. 324 - 334, July 1992
[21] H. Hamano, T. Ihara, I. Amemiya, T. Futatsugi, K. Ishii and H. Endoh, "20 Gbit/s AlGaAs/GaAs-HBT 2:1 Selector and Decision ICs", Electronics Lett., 27, pp. 663-664, 1991
[22] Y. Kaneko, H. Shimizu, K. Nagata, M. Koyanagi, M. Okamoto, M. Suzuki, S. Yokokawa, S. Shimizu, T. Maejima, J. Wada, H. Kawada, S. Ueno, M. Minamizawa and I. Yaegashi, "A 25k-Gate BDCFL G/A with a Differential Push-Pull ECL I/O", GaAs IC Symposium Digest, pp. 141-144, 1993