MMIC CONSUMER APPLICATION AND PRODUCTION

Bertrand F. Cambou

Motorola, Inc.
Semiconductor Product Sector
Tempe, Arizona

ABSTRACT

Hand held radios and wireless telecommunication systems will represent in the near future a high volume market. The purpose of this paper is to discuss how GaAs can become a key technology for this application and how to leverage the expertise that we get from silicon processing.

INTRODUCTION

The development of a wireless communication network is now underway worldwide, everybody on earth will be able to stay in contact at any moment with his office or home. This revolution creates a pressing need for low cost hand held radios, pagers and other wireless telecommunication systems. GaAs technology has a unique opportunity to play a major role in this new development. At higher operating frequency mixed mode designs are very expensive on silicon. However, the effort placed on improving this technology during the past 20 years leads us to believe that silicon may be able to surpass other material for high volume applications. GaAs technologists need to take advantage of this effort in order to enter the consumer market.

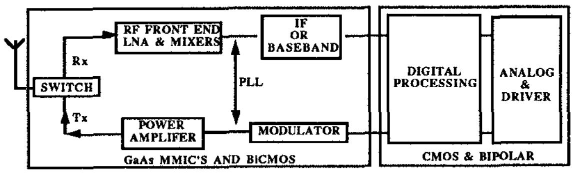
1. COMMERCIAL WIRELESS TELECOMMUNICATION

The wireless telecommunication market Ref [1] is growing very fast. For example, cellular phone sales worldwide are growing in the 30% range per year. Lower end cordless telephones and telepoint systems are gaining acceptance in Europe and Japan. Satellite based networks using 23 GHz frequency will allow people with portable cellular radios to communicate from any point on earth. The enabling factors of these emerging applications are cost, size, weight, features and high operating frequency.

1.1 Cost

The main drivers, in the cost reduction of hand held radios are the hyperintegration of the electronic components through assembly technology. Semi-insulator GaAs is a good material for Monolithic Microwave IC's and provides opportunities for the hyperintegration of systems. (Fig. 1). Multichip modules (MCM) combining Si, GaAs and passive components will be a low cost, manufacturable solution. The cost of RF Testing MCM is potentially less than individual devices.

Fig 1. System Partitioning vs Semiconductor Technologies



1.2 Size & Weight

The hyperintegration previously discussed positively impacts the reduction of the size and weight of the portable equipment, however now, the battery becomes the limiting factor. The user is extremely sensitive to the talk time of a phone between battery changes. GaAs offers multiple advantages in this regard. At 2 GHz the RF portion of the electronics can consume 70% of the total current drain. GaAs is more efficient and less noisy than silicon (Table 1). The low noise level of a GaAs PA reduces the number of filters in the system and then maximizes even more the total efficiency which is about twice that of a Silicon PA. SMART PA's with adjustable output power will be developed to improve the battery life even more.

Table 1

	Si-Bipolar	Si-NMOS	GaAs-FET
Typical Power added efficiency @ 1GHz (2 watt PA, 5.8 volt)	45%	45%	60%

1.3 Feature

New features such as, voice, data and image transmission, graphic, computing, storing and others are already available in current application. The electronics have become increasingly complex. For example, a pager in 1970 had 100 equivalent gates, 2,000 in 1980, 20,000 in 1990 and will have several million in the year 2000. The role of GaAs in this respect is still unclear. Low power embedded memories and well known design methodology will be an advantage for silicon. E/D GaAs may be useful for systems operating at low voltage (ex: 1.5 volt), and complementary GaAs has the potential to replace CMOS in selected applications.

1.4 Operating Frequency

The large number of users of sophisticated hand held radios saturate the communication network. The answer is digital technology and a higher operating frequency. In 1980, typical radio was working in the range of 100 MHz. Now it is 900 MHz for analog radios moving toward 1.8 GHz for digital systems. In that range GaAs MMIC become very efficient. The satellite communication network will require 1.6 to 23 GHz technology. In this last application GaAs is the only solution and the cost of the devices, is not properly reduced, could become a limiting factor of the expansion of the market. (see Ref [1])

2. PROCESS CONSIDERATION - UTILIZATION OF THE SILICON EXPERTISE

The comparison between silicon and GaAs is often unfair because the amount of resources dedicated in the past, on silicon, are overwhelming. For example, the gate density on Si increased by ten every three years. GaAs technologies are often based on processes developed in the laboratories 10-15 years ago and take small advantage of the newest equipment.

2.1 Substrate & Isolation

The semi-insulator property of GaAs eliminates several steps in the processing of the wafers. A 0.5 micron BiCMOS technology requires epitaxy, double buried layer, trench isolation, planarization, P and N wells, local oxidation and sometimes a dielectric isolation (SiMOX or Direct Wafer Bonding). A basic E/D 0.5 micron GaAs MESFET process needs only a field isolation with N and P co-implantation for the channel control. A complementary GaAs process is more complex with the addition of an epitaxy and an extra implantation for isolation, however, it remains simpler than a silicon technology - see table 2. Now a 100mm GaAs substrate costs about $250, a projection of $100 is realistic five years from now. A 100mm silicon wafer costs about $15, SOI wafer is in the $100 range, which is close to GaAs. For sub 0.25um dense digital GaAs processes, the semi-insulator property of the material may not be appropriate and trench isolation processes similar to silicon could be the solution.

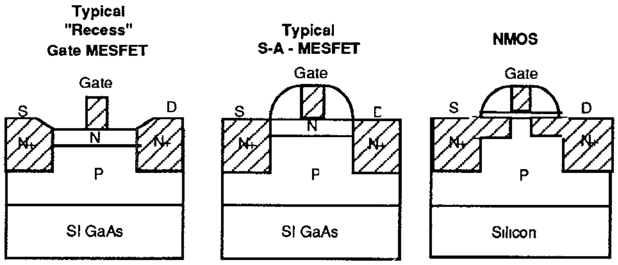
Table 2
Process Complexity for GaAs vs Si

PROCESS COMPLEXITY	GaAs		SILICON	
BEFORE METAL	E/D	C	BIPOLAR	0.5um BiCMOS
•NUMBER OF MASKS	4	6	15	20
•NUMBER OF STEPS	24	30	70	97
PERFORMANCE				
•Ft (GHz)	35	45	16	25
•COMPLEMENTARY	N	Y	N	Y

2.2 Active Device Formation

The cross section of an NMOS Device and a refractory gate MESFET are similar (see fig 2), while the traditional recess gate MESFET is quite different. The controlled by of the NMOS is mainly dependent on the Pwell implantation, the cleanliness of the interface silicon - gate oxide and the gate length. In a similar way, the performance of the GaAs MESFET is mainly controlled by the implantation of the N channel implantation, the cleanliness of the interface GaAs - gate and the gate length. The set of equipment capable of processing VLSI silicon is then appropriate for GaAs: 1% controlled ionic implantors, RTA, automatic cassette to cassette acid processors, 1% controlled PECVD reactors, dry etchers, 1% controlled sputtering reactors, and I line steppers. In Motorola, we successfully developed an E/D MESFET process using the same set of equipment as our VLSI silicon factory, and obtained tight device performance.

Fig. 2. Active Device Formation



2.3 Interconnect

The direct transfer of a multilevel metal (MLM) process developed for silicon on GaAs is possible with a non-gold refractory ohmic process. In Motorola, we demonstrated the feasibility of transferring the MOSAIC (Motorola Oxide Isolated Self Aligned Integrated Circuit - Ref [2]) MLM process on GaAs. Hard dielectric, aluminum and refractory barriers are used to produce 3-4 levels of interconnect. Such a methodology allows a full leverage of the resources spent on silicon processing. It is important to note that on current VLSI technologies the MLM part costs about 50% of the final cost of the wafer.

2.4 Packaging

The flip chip technology on GaAs is important for the following reasons:

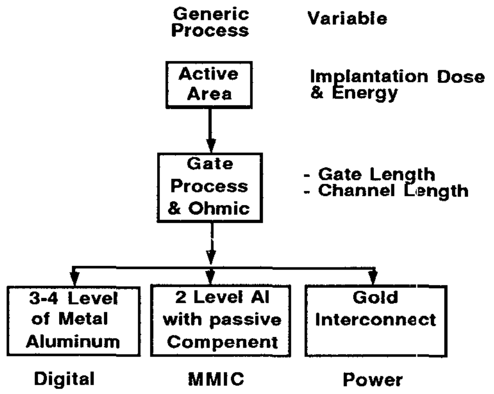
- Eliminate the need of via holes for ground.
- Thermal dissipation on active components.
- Reproducibility of electrical parameters.
- Multichip module (MCM).

The processes developed for silicon are directly applicable on GaAs. Successful implementation was reported (Ref [3]). The thermal expansion mismatch of GaAs and Si is a challenge. The usage of soft solder bump with underfill has the potential to fix this last problem and then authorize hybrid MCM including GaAs, Si and passive devices.

3.0 MANUFACTURING AND FACILITIES

The nature of the market requests small wafer lot size with high diversity of devices. ASIC's like manufacturing organization has to be selected with an emphasis on short cycle time, and flexibility. Up-front identification of the process options become critical for the design of the factory. We demonstrated that refractory gate processes (Ref. [4]) can be efficient for power, analog and digital application. A modular process identified in table 3 is optimum for the manufacturing.

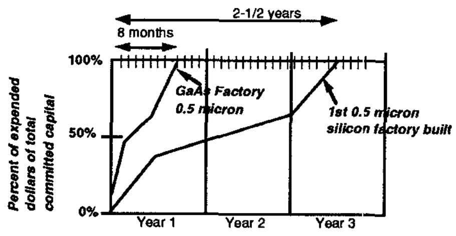
Fig. 3 Modular Process



3.1 Equipment & Facilities

The equipment and facility technology developed for silicon devices is applicable to GaAs. Class 10 cleanroom and 0.5 micron capable equipment was successfully put together in our facilities in less than 8 months thanks to the availability of internal knowledge (see fig. [4]). In fact, the absence of diffusion equipment and related gases in a GaAs factory greatly simplified the construction of the facilities.

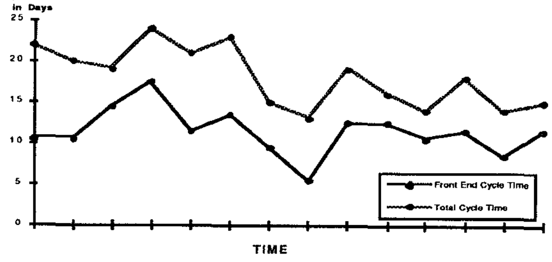
Fig. 4 - Time to Build a Factory and Install Equipment



3.2 Manufacturing Management

GaAs technology as described in table 2 has lower theoretical cycle time. Using a constant work in process technique, high uptime cassette to cassette equipment and small wafer lot a short cycle time was demonstrated in the processing of GaAs wafers (see Fig. 5). The training of the operators was done in advance in well established wafer fabs using the same set of equipment. All specifications, routine maintenance schedule and process control was transferred at the same time.

Fig. 5 Cycle Time Chart After Start Up



CONCLUSION

GaAs MMIC's will play a key role in the high volume wireless communication market. The utilization of the silicon expertise is very useful for the selection of the equipment, the construction of the factory, the design of the processes and the management of the manufacturing line.

REFERENCES

[1] High Volume GaAs MMIC Application, Hugh R. Malone & All - 1991 GaAs IC Symposium, p 135-138.

[2] A Four Metal Layer High Performance Interconnect System for Bipolar & BiCMOS Circuit, Syd Wilson and All, Nov. 1991 - Solid State Technology, p 67-71

[3] Manufacturing Technology Program for Transmit/Receive Module, John Woolridge and all - 1991 MANTECH - p 26-27

[4] Complementary Heterostructure Insulated Gate FET Circuits for High Speed, Low Power VLSI, RR Daniels & All - IEDM 86, p 448-451