GaAs a key RF technology - Industrialisation & competition

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Abstract

GaAs components in MESFET, HEMT and HBT technology are a valuable supplement to traditional Si RF technologies and cover 15 to 20% of all RF applications. Their major application potential is in power amplifiers for mobile communication as well as WLAN and WLL transceiver circuits. Moreover, at MMW frequencies new applications like radio links, SATCOM and car distance radar support the introduction of GaAs hetero devices.
Production quantities of about 100 million pcs and annual growth rates of about 30% clearly require large volume production strategies and cost positions well-known from Si counterparts.

1. Introduction

The wireless communication is the driving force of the TELECOM industry with the mobile telephone as flag ship and new services like SATCOM at the horizon. Production figures and growth rates in this area exceed in the meantime the traditional dominating markets of car production, tuner fabrication and even PC production.
All these applications require sophisticated RF components in silicon (Si) and GaAs. In this context, GaAs RF components often have key functions for the introduction of new innovative services because they contribute to the optimization of sensitivity, power consumption and efficiency as well as improved economy through overall system benefits.
This paper describes the roadmaps of rf technology, describes and compares the most enhanced GaAs and Si processes and finally presents major application areas of GaAs devices. A short report on industrialisation aspects completes the contribution.

2. RF Technology Roadmap

An enhanced wafer technology roadmap for the next 5 years (see Fig.1) should include both RF materials, Si and GaAs, a variety of discretes as well as Si and GaAs MMICs and Si BICMOS circuits. Hetero technologies in GaAs (HEMT, HBT) and SiGe (HBT) will complete the wafer process portofolio. Fundamental material and component differences and benefits together with the process maturity visible will result that all processes will be widely used in the next decade.
The basic Si bipolar process produced by Siemens since 1995 is called B6HF. This 0.5µm-process based on double poly self-aligned emitter/base (DPSA E/B) contacts is the worldwide leading edge with a transit frequency (f_T) of 25 GHz. The B6HF process is used for discretes and MMICs, the BICMOS version B6HFC has been released mid 1998.

The next step in the Si bipolar world is the SiGe hetero process. In the case of Siemens, the so called B7HF process will contain all established B6HF process steps, only the SiGe layer is new and further miniaturisation from 0.5 µm to about 0.3 µm is foreseen. The process with f_T > 60 GHz is expected to be in production mid 1999.
The Si RF technology portofolio has to be supplemented in the next two years by a 0.25 µm RF-CMOS process with about 20 GHz transit frequency especially suitable for low voltage/low current applications like cordless phones and GPS.
In the area of GaAs, the working horse is the MESFET process with transit frequencies of 15 to 20 GHz. The Siemens DIOM process (double Ge/Si contact implantation, one Ohmic/gate metal step) is an outstanding self-aligned gate process, costeffective with only 12 layers. The most important features of the MESFET DIOM processes are summarized in Table 1. The fundamental GaAs material advantages together with the benefits of a unipolar transistor result in very good low noise, high linearity and especially impressive power amplifier (PA) characteristics.
GaAs HEMT technology combines superior hetero material properties with sophisticated miniaturization, i.e. gate lengths of sub-0.2 µm. In the case of Siemens, 4 different process options have been realized for optimized applications in mobile communication (HEMT M30), radio links and SATCOM (HEMT LN60, P60) and for automotive radar (HEMT 110). Again major features demonstrating extraordinary performance have been summarized in Table 2. In comparison to competition, the Siemens process uses mainly standard production techniques, i.e. the critical gates are produced by i-line/phase shift stepper processes and self-aligned SiN spacer technologies.
The GaAs HBT finally based on MOCVD grown AlGaAs/InGaP/GaAs layers, non-alloying E/B-contacts and thermally optimized interconnect metals is described in major parameters in Table 3. The device is optimized for mobile communication PAs.
The second part of the RF technology roadmap covers the packaging strategy. In the area of GaAs devices, low-loss SMD packages up to 20 pins are required, and especially heatsink versions for PA's. This goes along with the general requirements of contineous miniaturisation and costeffective packaging materials and processes.
The Siemens GaAs MMIC SMD packages widely used are the MW 12 (SOT 223 derivate, PAs up to 2 W), the MW 16 (PAs up to 10 W), and MW 6 (SOT 23 derivate) for low noise applications. New packages to be introduced in 1998 are TSSOP-10 and TSSOP 16/20, both with heatsinks. A very attractive new package family is the SCT 595/598 (SOT 23 derivate) suitable for example for GSM and DECT PA's. These packages require only one forth of the TSSOP 16 body with excellent price/performance relation.
In addition everybody knows that RF module technologies including all active and passive components preferable in chip form are indispensable for certain applications as mobile communication PA's and MMW transmit/receive circuits.

3. Si versus GaAs & Hetero Devices

In general, the situation visible today will not change with about 15 to 20% of all RF applications covered by GaAs. No fundamental change can be expected as far as applications are dominated by wireless systems up to 3.5 GHz, i.e. cellular and cordless phones, WLAN, WLL, GPS etc.
In simple words, Si dominates the receiver market up to 2 GHz, whereas GaAs is the preferred material for PA's above 0.5 W output power due to better PAE at low supply voltages.
From cost point of view, the process costs of a 4"-GaAs MESFET wafer is comparable to that of a 6"-Si Bipolar wafer. This is somewhat compensated as a result of the better integration ability of GaAs, i.e. die cost should be considered instead of area cost. Finally the user should know that normally the die contributes only to about 1/3 to the total device cost and that smaller dies can result in lower assembling cost (see SCT 595/598).

Another discussion is that of the application and substitution potential of the new hetero devices in GaAs and Si. This can be summarized as follows:

- SiGe will result in only minor improvements concerning the known cellular and cordless phone systems, i.e. will not substitute any Si Bipolar circuit due to higher cost. A key question is whether the material benefits justify the realization of 1-chip UMTS transceivers. Moreover, the main potential is for receivers at higher frequencies (2-20 GHz).
- GaAs HEMT technology is the best MMW material up to 100 GHz. It combines the advantages of unipolar transistors with outstanding performance down to 1.5 V supply but with a factor 2 higher wafer cost compared to GaAs MESFET.
- The GaAs HBT process is a candidate for mobile communication PA's with good PAE and the advantage of a single supply voltage. Disadvantages to GaAs MESFET and HEMT are reduced shrink potential due to thermal problems, reduced linearity of a bipolar transistor and cost levels comparable to HEMT.

4. Application Areas

The most important application areas for GaAs devices with market size and technology choice is shown in Table 4. In the following only some selected application examples will be considered in detail.

Mobile Telephones

The largest GaAs market available is that of cellular and cordless phones with in most cases digital standards, i.e. GSM and DECT in Europe, AMPS/DAMPS, TDMA, CDMA and PCS in USA, and PDC, PHS in Japan.
GaAs PA's are widely used due to the above described performance advantages. The GaAs PA roadmap of Siemens covering the 1996 to 1998 time frame is shown in Fig. 2. A description of the state-of-the-art includes MESFET based GSM PA's with typical PAE of 55% at 3 V supply (CGY 93, 96), PCN PA's with PAE of 45% (CGY 181, 184), TDMA/CDMA PA's with 40/35% PAE (CGY 81,191) and DECT PA's with 40-45% PAE (CGY 180, 195).
New highlights in this area are the introduction of GaAs MESFET PA's for dual mode GSM/ PCN or even trimode for CDMA/TDMA/AMPS as single chips to allow multi system use.
The introduction of the GSM/PCN PA CGY 98 in enhanced MESFET process D18 LVM is a milestone in miniaturisation (SCT 595, factor 4 compared to TSSOP 16), performance (PAE = 60%) and also cost.
In the case that the system needs even better performance, the HEMT counterpart CGY 98H with 65% PAE will be offered. Another alternative is the GaAs HBT PA, where Lab samples showed 62% PAE in the PCN band.
Other GaAs devices produced in large quantities are VGA drivers, high-IP3 mixers, and switches.

Short Distance Radio & SATCOM

Radio link applications in the MMW frequency range (18-40 GHz) include different short distance point-to-multipoint systems and also the 38 GHz PCN intercell communication networks. This is clearly a domaine of broadband HEMT MMICs, i.e. LNA's, driver and PA's up to 1 W output power are required as well as mixer and VCO MMICs.

This application which traditionally is restricted to only some thousand component sets will receive a push by new SATCOM services to be realized in the same frequency range. The specifications for satellite equipment, home/business/corporate terminals and interlinks with special emphasis on high data transport are in progress.

Car Distance Radar

After about 3 years intensive R & D work, a complete 77 GHz FMCW RF frontend has been realized. The chip set consists of 3 different GaAs HEMT MMICs (VCO, driver, H-mixer) and a double-balanced Si diode mixer. The complete multichip RF module includes ceramic boards with the described chip set, patch antennas and all passive components. The performance achieved show that active VCOs can replace Gunn elements and cost-effective planar production techniques can be realized.

5. Industrialisation & Commercial Aspects

For the first time the GaAs suppliers are confronted with a real global volume market and an extraordinary dynamic business, that of mobile telephones. The specific features of this business are generation changes on an annual base, steep ramp-ups from zero to several million, permanent performance improvements, and price levels of a consumer market.
The only chance of longterm success is to copy the silicon model, i.e. 100% production orientation and large-volume flexible production facilities based on 7 days/21 shifts working models.
Today, Siemens and a handful suppliers in USA and Japan realize a production volume of 40 K wafer starts per year. All three GaAs wafer processes (MESFET, HEMT, HBT) use the 4"-wafer process. This corresponds to a production volume of 80 million devices in 1998, of which 50% are MMICs.
To meet the requirements of tomorrow, Siemens will open a new 6"-wafer Fab. The R & D program will be started in Oct. 1998, full production is foreseen for Jan. 2000.
This wafer production strategy will be accompanied by an enhanced multiband and inline packaging concept altogether with the target to achieve performance and cost leadership.

6. Conclusions

GaAs MESFET discretes and MMICs are in volume production for tuner, DBS, cable TV, WLAN, MIL & space, and especially mobile telephones. The currently most important product segment is that of GaAs MESFET PA's where excellent power densities and PAE even at low voltage supply can be achieved.
GaAs hetero MMICs (HEMT, HBT) are now also ready for production in the area of mobile phone and all MMW applications (radio link, SATCOM, car distance radar). Excellent noise figures and power amplifier capabilities open applications up to 100 GHz.
Major emphasis is currently directed to establish fast and flexible volume production facilities.

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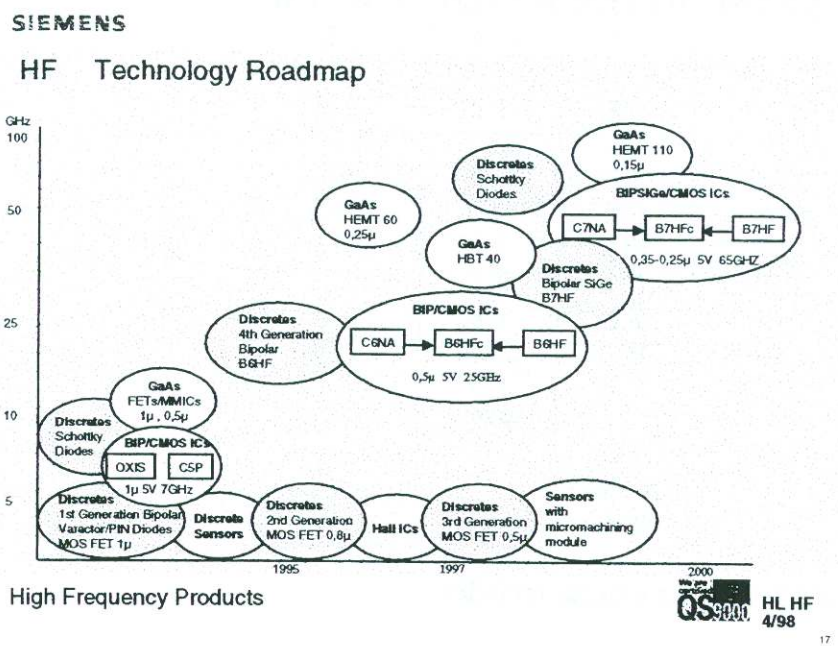

Fig.1 : **RF Wafer Technology Roadmap**

	Market/Pcs		Components			
	1994	2000	MOS	Bip	Dio	GaAs
1. Tuner & Cable TV	163'	190'	x		x	x
2. Mobile Telephones	50'	170'		x	x	x
3. WLAN & WLL	0'5	20'		x		x
4. MMW Radio Links & SATCOM	-	0'5			x	x
5. Car Distance Radar	-	2'			x	x
6. Mil. Radar (PAR)	M	0'5				x
7. Smart Sensors						
- Surface Micromachined	20'	80'	x	x		x

Table 4 : **GaAs Application Survey**

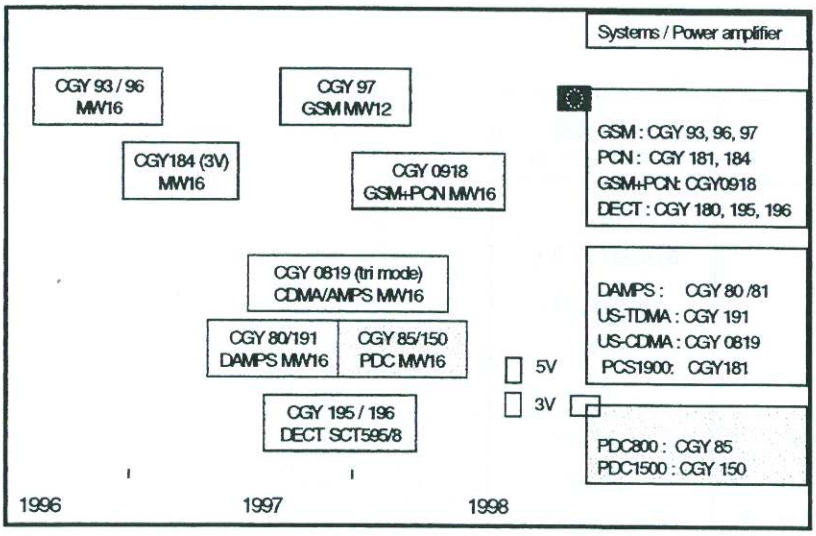

Fig. 2: **GaAs Mobile Com Power Amplifier Roadmap**

	Unit	D15HPM	D15LN	D20LN	D18LVM
Gate Length	μm	0.8	0.8	0.5	0.8
f_t / f_{max}	GHz	15 / 30	15 / 30	20 / 40	18 / 36
V_p	V	-2.7	-0.8	-1.2	-1.0
g_m	mS/mm	125	140	180	160
Idss	mA/mm	230	75	120	90
Idsat	mA/mm	340	200	300	250
V_{break}	V	>20	>15	>6	>15
NF @ 2 GHz	dB	1.5	0.7	0.6	0.6
NF @ 12 GHz	dB	-	2.2	1.8	2.0
Psat @ -3dB/3V	mW/mm	150	100	200	150
Min. Supply	V	2.5	2.0	1.5	1.5
Products		CGY93/96/ 81/191	CGY195 /196 CMY91/ 210	CFY35	CGY98

Table 1: GaAs DIOM MESFET Process Characteristics

	HEMT M30 (Mobile Comm.)	HEMT LN60 (Low Noise)	HEMT P60 (Power)	HEMT 110 (Millimeter Wave)
Gate Length L_G	ca. 500 nm	ca. 180 nm	ca. 180 nm	ca. 130 nm
Cut-Off Frequencies f_T / f_{max}	30 GHz / ca. 60 GHz	60 GHz* / ca.120 GHz*	60 GHz / ca.120 GHz	110 GHz / ca. 210 GHz
Threshold Voltage V_T	-0.5 V	-0.5 V	-0.5 V	0
Transconductance g_m	400 mS/mm	450 mS/mm*	500 mS/mm	700 mS/mm
Drain Current at $V_{GS} = 0$ I_{DSS}	100 mA/mm	150 mA/mm	150 mA/mm	-
Max. Drain Current I_{DSAT}	500 mA/mm	500 mA/mm	500 mA/mm	600 mA/mm
Gate-Drain Breakd. Voltage V_{BD} (Leakage Curr. 1mA/mm)	10 V	5 V	> 9 V	4 V
Noise Figure NF @ 12 GHz	-	0.6 dB	< 0.8 dB	0.6 dB
Noise Figure NF @ 26 GHz	-	1.5 dB	< 2.0 dB	1.5 dB
Output Power P_{out}	200 mW/mm	150 mW/mm	400 mW/mm	150 mW/mm

* at low noise bias I_D = 83 mA/mm, V_{DS} = 2 V

Table 2: GaAs HEMT Process Characteristics

	HBT 30 (Mobile Comm)
Emitter width	3 μm
Cut-Off Frequencies f_T / f_{max}	30 GHz / 60 GHz*
On-Resistance R_{on}	450 $\Omega/\mu m^2$
Offset Voltage V_{off}	< 0,3 V
Current Gain β	80
Max. DC Current Density j_{DCmax}	0,2 $mA/\mu m^2$
Collector-Emitter Breakd. Voltage V_{CEO}	> 10 V
RF Output Power/Emitter Area P_{out}/A_E	0,3 $mW/\mu m^2$*

* at V_{CE} = 3 V

Table 3: GaAs HBT Process Characteristics