Current Tendencies in SiGe BiCMOS Technology Developments

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Agenda

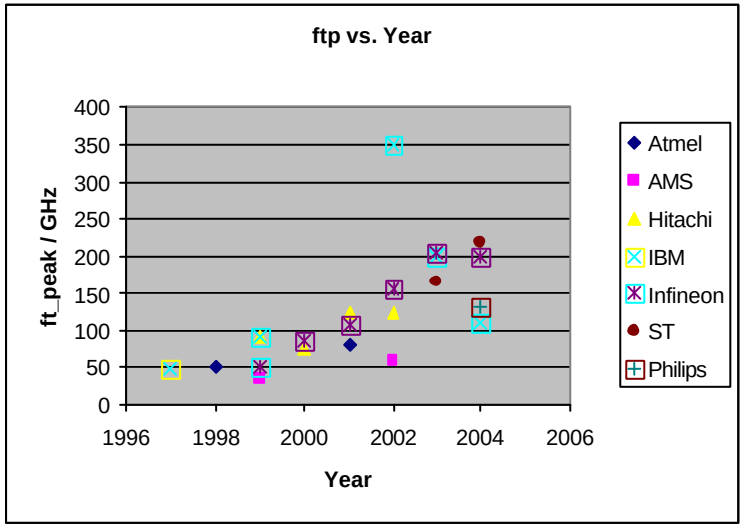
- **This presentation is intended to give an overview about the main tendencies in SiGe – BiCMOS – Technology since 1997 . We will consider two topics:**

1. **The evolution of important FoMs like**
   - ft_peak, BVce0, ftp * BVce0,
   - we,
   - fmax, ft_peak / fmax_peak and
   - Rb*Cbc

2. **The status of BiCMOS – Technologies, as it was presented by different at the BCTM 2004, Montreal**

Peak ft vs. years

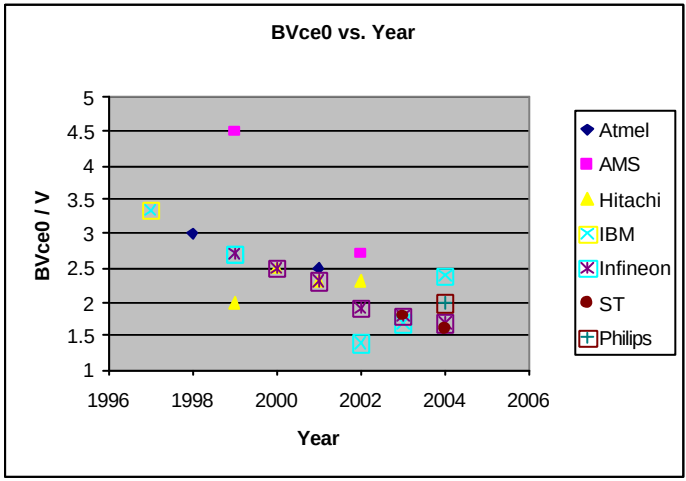
- ftp increases continuously as has crossed the 200GHz line
- IBM set the record with 350 GHz in 2002
- However, more important is the ftp / BVce0 trade off



ftp	Atmel	AMS	Hitachi	IBM	Infineon	ST	Philips
1997				47			
1998	50						
1999		35	90	90	52		
2000			76		85		
2001	80		124		106		
2002		60	122	350	155		
2003				200	206	166	
2004				110	200	220	131

BVce0 vs. years

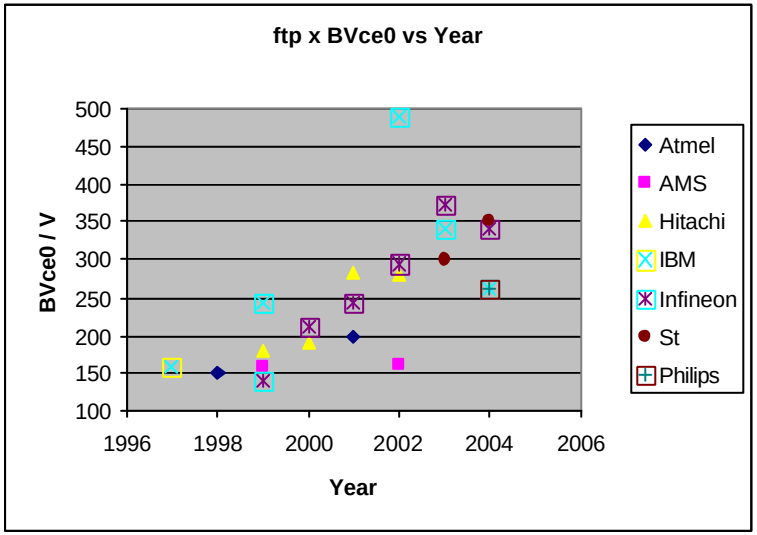
- Vertical scaling results in decreasing BVce0, down to <2V
- IBM's record ftp-value of 350 GHz is reached by the price of very low BVce0 = 1.4V
- Seems, that BVce0 ~ 1.8V is a lower limit for analog application
- Because of these low BVce0, for certain applications BVcb0 must be considered as FoM



BVce0	Atmel	AMS	Hitachi	IBM	Infineon	ST	Philips
1997				3.35			
1998	3						
1999		4.5	2	2.7	2.7		
2000			2.5		2.5		
2001	2.5		2.3		2.3		
2002		2.7	2.3	1.4	1.9		
2003				1.7	1.8	1.8	
2004				2.4	1.7	1.6	2

BVce0*ftp vs. years

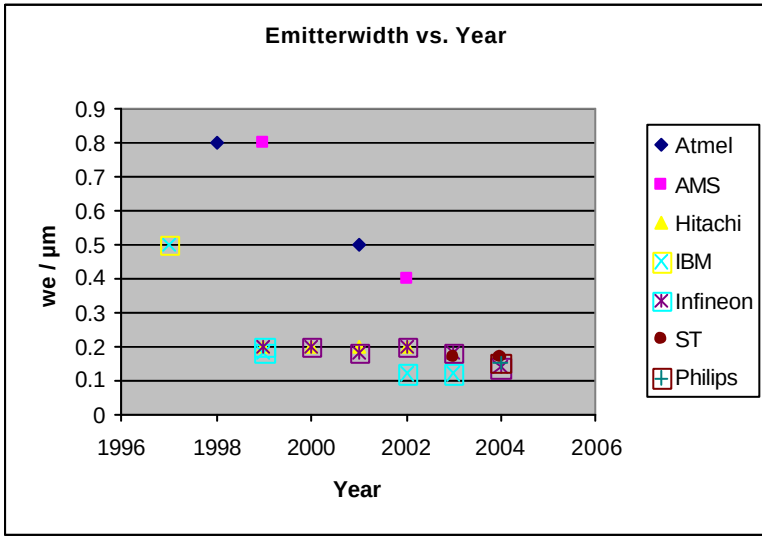
- BVce0 * ftp was remarkable increased since 1997
- the Johnson limit, often roughly given a 200 GHz*V was crossed around 2000
- interestingly IBM has shown an opposite trend last three years



BVce0*ftp	Atmel	AMS	Hitachi	IBM	Infineon	St	Philips
1997				157.45			
1998	150						
1999		157.5	180	243	140.4		
2000			190		212.5		
2001	200		285.2		243.8		
2002		162	280.6	490	294.5		
2003				340	370.8	298.8	
2004				264	340	352	262

Minimum emitter width vs. years

- BiCMOS technologies benefit from lateral scaling, driven by the CMOS technologies
- lowest real emitter width is realized by IBM with 0.12 µm
- lateral scaling reduces Rb and increases fmax

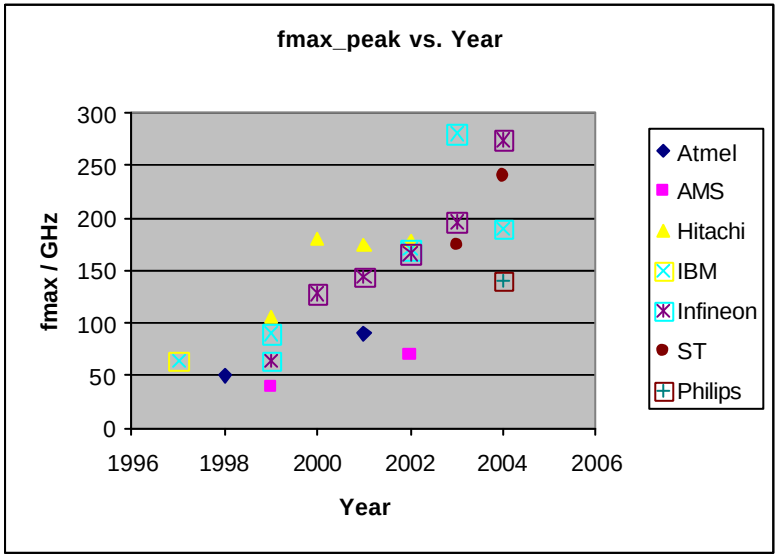


we	Atmel	AMS	Hitachi	IBM	Infineon	ST	Philips
1997				0.5			
1998	0.8						
1999		0.8	0.2	0.18	0.2		
2000			0.2		0.2		
2001	0.5		0.2		0.18		
2002		0.4	0.2	0.12	0.2		
2003				0.12	0.18	0.17	
2004					0.14	0.17	0.15

Source for this and following pages: Palankovski / Quay, Analysis and Simulation of Heterostructure Devices, Springer 2004 and Proc. BCTM 2003-2004

fmax_peak vs. years

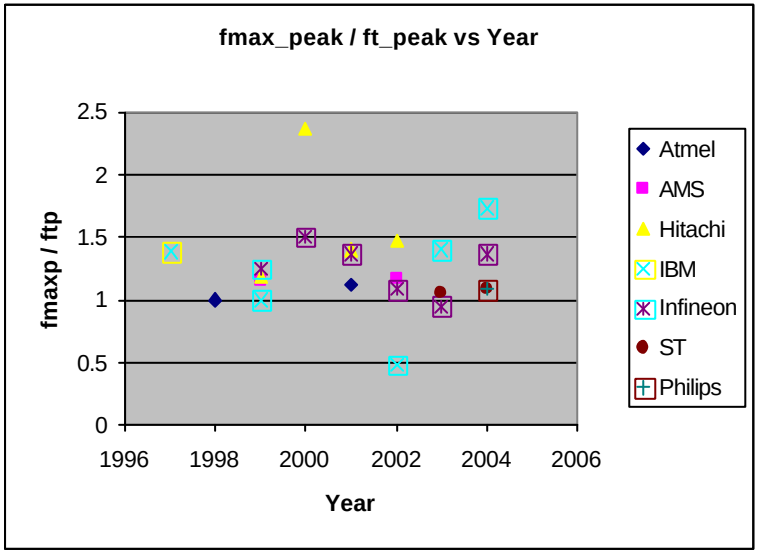
- fmax increases nearly in same way as ftp
- maximum value was reached by IBM in 2003
- obviously in most cases a balanced compromise between ftp and fmaxp was the goal



fmax_peak	Atmel	AMS	Hitachi	IBM	Infineon	ST	Philips
1997				65			
1998	50						
1999		40	107	90	65		
2000			180		128		
2001	90		174		145		
2002		70	178	170	167		
2003				280	197	175	
2004				190	275	240	141

Ratio fmaxp by ftp vs. years

- the right trade of between fmaxp and ftp is a basic technology problem
- for most technologies we observe a ratio of 1...1.5
- this seems to be the best compromise

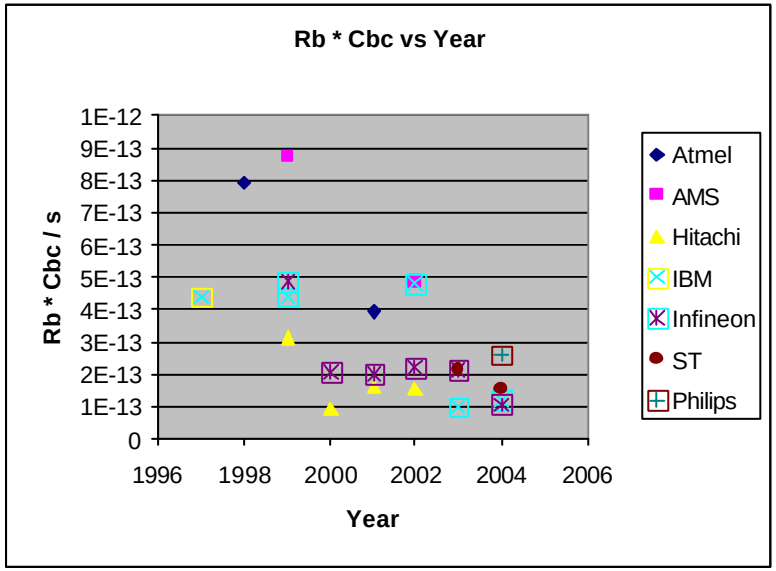


fmaxp_ftp	Atmel	AMS	Hitachi	IBM	Infineon	ST	Philips
1997				1.38			
1998	1.00						
1999		1.14	1.19	1.00	1.25		
2000			2.37		1.51		
2001	1.13		1.40		1.37		
2002		1.17	1.46	0.49	1.08		
2003				1.40	0.96	1.05	
2004				1.73	1.38	1.09	1.08

Time constant Rb*Cbc vs. years

- time constant Rb*Cbc was reduced by nearly one order
- the contributions are

1. Rb reduction by lateral scaling
2. Cbc reduction by reduction of SIC implant and lateral SIC dimensions



RB*Cbc	Atmel	AMS	Hitachi	IBM	Infineon	ST	Philips
1997				4.4E-13			
1998	8E-13						
1999		8.7E-13	3.1E-13	4.4E-13	4.9E-13		
2000			9.3E-14		2.1E-13		
2001	3.9E-13		1.6E-13		2E-13		
2002		4.9E-13	1.5E-13	4.8E-13	2.2E-13		
2003				1E-13	2.1E-13	2E-13	
2004				1.2E-13	1.1E-13	2E-13	2.6E-13

Evolution of important FoMs
Summary

ft_peak	↑
BVce0	↓
ftp * BVce0	↑

we	↓
fmax_peak	↑
ftp / fmaxp	~const.

Rb*Cbc ↓

Agenda

1. The evolution of important FoMs like
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   - we,
   - fmax, ft_peak / fmax_peak and
   - Rb*Cbc

2. The status of BiCMOS – Technologies, as it was presented by different at the BCTM 2004, Montreal

   - Infineon
   - ST
   - TSMC
   - Philips
   - IBM
   - IHP

Infineon
SiGe Bipolar – Technology for Automotive Radar

- Application: 77 GHz automotive radar
- Balanced compromise for most important transistor parameters
- Carbon is used, Mono-crystalline emitter lowers RE, ftp vs. BVce0 varied by SIC

Parameter	npn1	npn2	npn3	Unit	Remarks
we	0.14	0.14	0.14	µm	
le	2.6	2.6	2.6	µm	
ft_peak	200	135	80	GHz	Vbc=0
fmax	275	285	225	GHz	Vbc=1
Beta	250				
Jc	8.2			mA/um2	at peak ft
BVce0	1.7	2	3.1	V	
BVcb	5.8	8.3	10.5	V	
ftp * BVce0	340	270	248	V	
Rpinch	2.8			kOhm/sq	
Re*Ae	1.3			Ohm um2	
Cbe	6.3			fF	
Cbc	5.5	4.6	3.6	fF	
Ccs	3.7			fF	

Source: Proc. BCTM 2004, paper 4.2, p.84

STMicroelectronics
220/240 GHz SiGeC HBT for 90nm BiCMOS - Technology

- ST presented at BCTM2003 the BiCMOS9 process with 0.13µm ft=166/fmax=175 GHz
- This 220 GHz HBT is the consequent further development for 77 GHz radar application, Carbon is used, only HP npn devices where presented
- Note the high beta and the high Jc(ft_peak) = 15 mA / um2

Parameter	HP1	HP2	HP3	Unit	Remarks
we	0.17	0.17	0.17	µm	
le	1.6	3.6	5.6	µm	
ft_peak	220	220	220	GHz	
fmax	240	230	220	GHz	
beta	1700				
Jc	15.00	15.00	15	mA/um2	at peak ft
BVce0	1.6			V	Vbe=0.7
BVce0	2.2			V	Vbe=0.92
BVcb	5.6			V	
ftp * BVce0	352			V	
Rpinch	2			kOhm/sq	
Re*Ae				Ohm um2	
Cbe				fF	
Cbc				fF	
Ccs				fF	

Source: Proc. BCTM 2004, paper 12.1, p.225

TSMC
SiGe HBTs for Optical and Wireless Applications

- Process is based on 0.18 µm CMOS
- High speed npn (2 SIC masks), standard npn (1 SIC mask) and high voltage npn (no SIC) are available
- Application: wired and wireless telecommunication (probably WLAN)

Parameter	HS	STD	HV	Unit	Remarks
we	0.18	0.18	0.18	µm	
le	10.16	10.16	10.16	µm	
ft_peak	130	80	60	GHz	Vbc=1
fmax	90	100	95	GHz	
Beta	300	300	300		
Jc	10.94	2.73	1.37	mA/um2	at peak ft
BVce0	2.3	3.4	4.8	V	
BVcb				V	
ftp * BVce0	299	272	288	V	
Rpinch				kOhm/sq	
Re*Ae				Ohm um2	
Cbe				fF	
Cbc	17	9.9	7.7	fF	
Ccs				fF	

Source: Proc. BCTM 2004, paper 4.3, p.88

Philips
QUBiC4X: An 130 / 140GHz SiGeC-Technology

- This process addresses a wide appl. range: PA, analog, high speed
- Three device types presented: standard , high voltage and special devices for PA with BVce0 =4.8V, BVcb0=16.5V
- Epi mono-emitter was used for low RE
- For the PA devices obviously a special process version was used

Parameter	STD_HBT	HV_HBT	PA_HBT	Unit	Remarks
we	0.15	0.15	0.15	µm	
le	20.1	20.1	20.1	µm	
ft	131	71	51	GHz	Vcb=0.5
fmax	141	136	115	GHz	
Beta	400	400	160		
Jc	4.40	1.10	0.8	mA/um2	at peak ft
BVce0	2	3.1	4.8	V	
BVcb	9	13	16.5	V	
ftp * BVce0	262	220	245	V	
Rpinch	2.8	2.8	3.2	kOhm/sq	
Re*Ae	2.5	2.5	20	Ohm um2	
Cbe					
Ccb/Ae	7	3.2	3	fF/um2	
Ccs/Pcoll	0.22	0.22	0.22	fF/um	

Source: Proc. BCTM 2004, paper 12.3, p.233

IBM 8WL
A low complexity 0.13um SiGeC BiCMOS Technology

- IBM comes back to reality and presents a technology for realizing circuits instead of ft-records, **focus: low process complexity & low cost**
- Application: wireless, mixed signal, system on a chip 3G
- **Carbon** is used, three devices presented, including a **HV with BVce0=4.7 V**

Parameter	HP	MP	HB	Unit	Remarks
we	0.12	0.12	0.12	µm	
le	3	3	3	µm	
ft	110	71	51	GHz	
fmax	190	166	133	GHz	
hfe	200				
Jc	5.50	2.2	0.83	mA/um2	at peak ft
BVce0	2.4	3.3	4.7	V	
BVcb	8	13	16	V	at 10 µA
ftp * BVce0	264	234	239.7	V	
Rpinch				kOhm/sq	
Re*Ae				Ohm um2	
Cbe				fF	
Cbc				fF	
Ccs				fF	

Source: Proc. BCTM 2004, paper 12.4, p.237

IHP Frankfurt(Oder)
A modular, low cost SiGeC BiCMOS Process

- This process is dedicated as a low cost SiGeC BiCMOS process
- Four different HBTs with graded ft/fmax and BVce0 capabilities
- CMOS steps used for HBT, e.g. external, base and collector
- Different ftp / BVce0 realized by use of different collector implants

Parameter	HBT1	HBT2	HBT3	HBT4	Unit	Remarks
we	0.4	0.4	0.4	0.4	µm	we_min=0.24
le	0.82	0.82	0.82	0.82	µm	
ft	30	50	90	130	GHz	Vce=2V
fmax	70	100	90	138	GHz	Vce=2V
hfe	300	300	300	300		at Vbe=0.7V
Jc	0.46			6.10	mA/um2	at peak ft
BVce0	7	4	2.1	2.1	V	0.5mA
BVcb	20	17	7.7	6.8	V	at 0.1µA
ftp * BVce0	210	200	189	273	V	
Rpinch					kOhm/sq	
Re*Ae					Ohm um2	
Cbe					fF	
Cbc					fF	
Ccs					fF	

Source: Proc. BCTM 2004, paper 12.5, p.241

Status of BiCMOS technologies BCTM 2004
Summary

- First tendency: the use of Carbon for SiGe – BiCMOS - Technologies is not only state of the art, it's mandatory now

- Second tendency: development of BiCMOS technologies with low complexity and low cost (low mask number) including all necessary devices for RF and PA applications. This necessary to be competitive with CMOS technologies

- Third tendency: a set of npn devices with graded key features as ft_peak, fmax_peak and BVce0, BVcb0 is delivered Additional, special devices have been presented, dedicated e.g. for PA applications (Philips, TSMC and IBM)