

Flash lamp anneal process implementation proving potential of a THz SiGe-BiCMOS technology

Leibniz-Institute for High Performance Microelectronics

Andreas Mai, *et al.*

Department Head „Technology for Smart Systems“
UAS Wildau Professor „Micro & Nanoelectronic“

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BlitzLab – Symposium „Ultrakurzzeitprozessierung funktioneller Halbleiterschichten“

Forschungsfabrik Mikroelektronik Deutschland

Leibniz Association

IHP – Innovations for High Performance Microelectronics

Continuously growing passion for microelectronics

Institute of the Leibniz Association

- >360 employees from ~**30 countries**

- ➢ R&D 8“ pilot line since 2000 → 24/7 industry like operation
  - ➢ Heterointegration „NanoLab“ in 2015,
  - ➢ SiGe-BiCMOS & Exploratory CRextension in 2021
- industrial cooperation (Infineon, XFAB) for advanced Si-RF technologies
- Member of the **„Research Fab Microelectronics Germany“** (FMD)

Agenda

1	**Motivation**
2	SiGe-HBT performance factors
3	SiGe-HBT & BiCMOS technology improvements by FLA
4	Summary

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Motivation

- **Our world is not digital!**
- Novel and upcoming applications (communication, sensing,..) require diverse functionality which could not eb afforded by advanced cmos technologies
- High-speed SiGe HBTs used today & future applications
  - Automotive radar @ 24 GHz, 77 GHz and 120 GHz for transportation
  - High data rate **optical and wireless links** …
    - Back-haul for 5G mobile comm. (optical or wireless)
    - Short-range wireless links for high data rates
  - mm and sub-mm wave imaging and sensing in medicine, industry, and science
  - High-resolution sensors for robotics

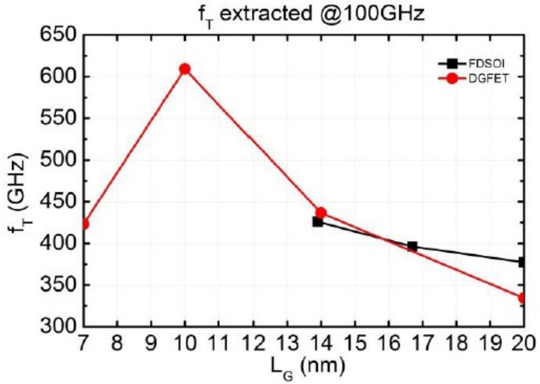
Advantages:

- SiGe BiCMOS targets frequencies and data rates which are out of reach for state-of-the-art CMOS
- Cut-off frequencies (f_T, f_{max}) typically 3-10x larger than operating frequency

Perspective of SiGe HBTs for Future Electronic Systems

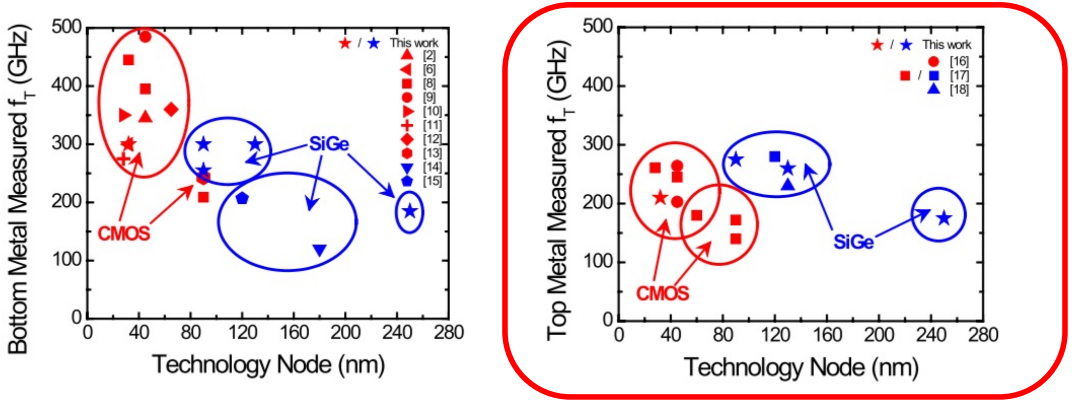
- Main device technology discussion currently ongoing in is on advanced node CMOS
- What is the role of SiGe BiCMOS in future electronic systems?
  - Due to their RF and mm-wave performance SiGe BiCMOS is a key technology for next generation mm-wave, sub-THz Systems and THz systems
- Transit frequency comparison of advanced node CMOS vs. SiGe HBT

<u>It's also about cost!</u>



Peak f_t (extracted) vs. Physical Gate Length for FDSOI and Double-gate (FinFeFET) MOSFETs

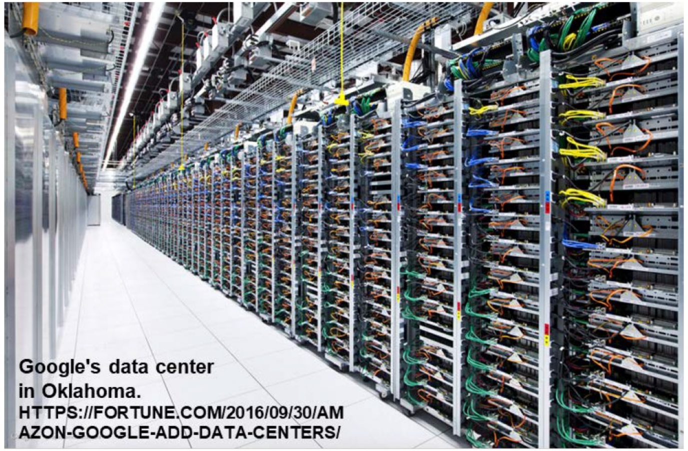
Source: IRDS Outside System Connectivity 2021



Measured ft at bottom metal (left) and top metal layer for different technology nodes in SiGe and CMOS technologies

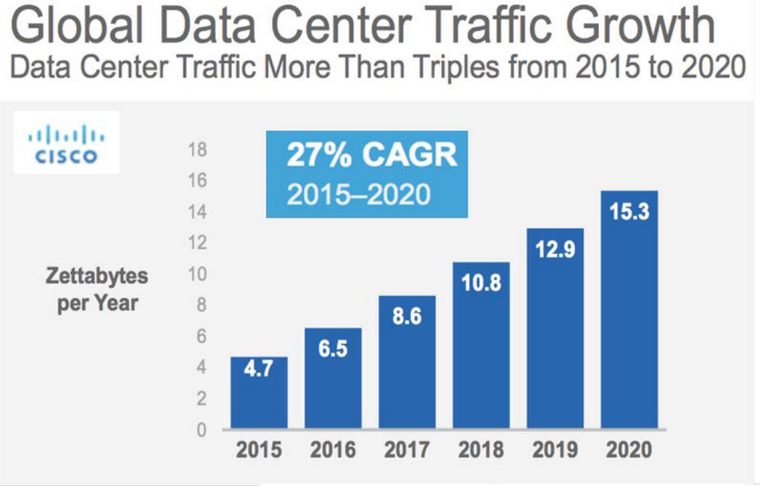
Source: R. Schmidt et al. – A Comparison of the Degradation in RF Performance Due to Device Interconnects in Advanced SiGe HBT and CMOS Technologies, *IEEE Transactions on Electron Devices, Volume 62, Issue 6, June 2015*

Example: Silicon photonic for high speed transceivers



"Without optical fibers there would be no internet nor broadband" *

….https://www.nobelprize.org/nobel_prizes/physics/laureates/2009/illpres.html



Source: Cisco Global Cloud Index, 2015–2020

Si Photonics technology has been an important enabler for datacenter interconnect

➔ Devices with opto-electrical bandwidth >> 50 GHz and corresponding rf- devices (cut-off frequency >> 300GHz) required to allow generation and detection > 100 Gbaud

➔ **SiGe-BiCMOS plus advanced PIC as key enabling technology** ➔ **require advanced process techniques to suppress device interaction**

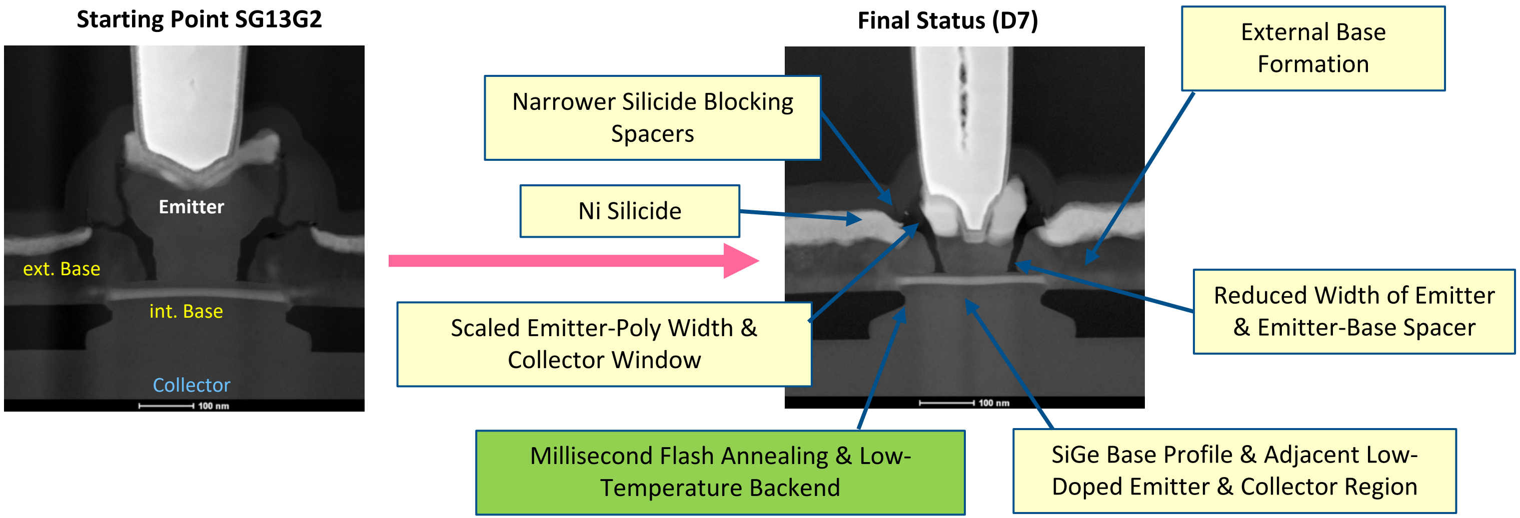
Agenda

SiGe-HBT Optimization @ IHP & Process Modifications

Starting point: IHP's 130nm BiCMOS "**SG13G2**"

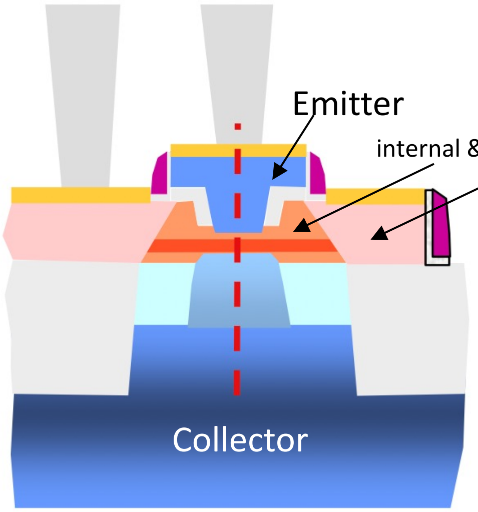
- Highly-doped collector isolated by STI
- Elevated extrinsic base

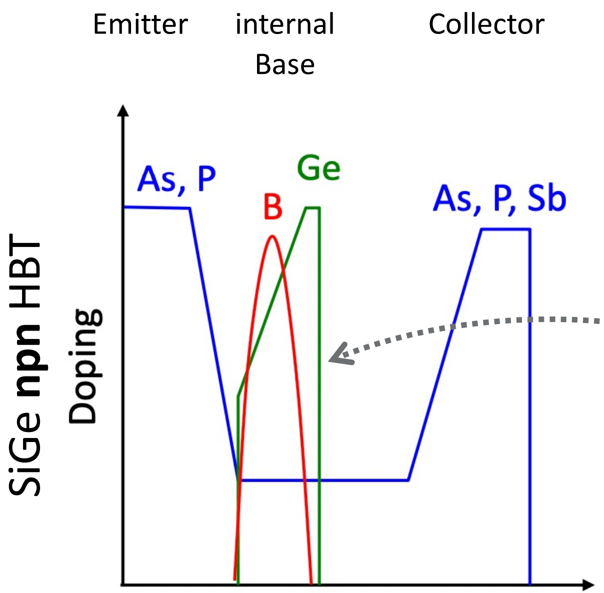
Exploration of HBT performance limits irrespective of CMOS process constraints



[Heinemann, IEDM 2016]

SiGe HBT - architecture and key parameters



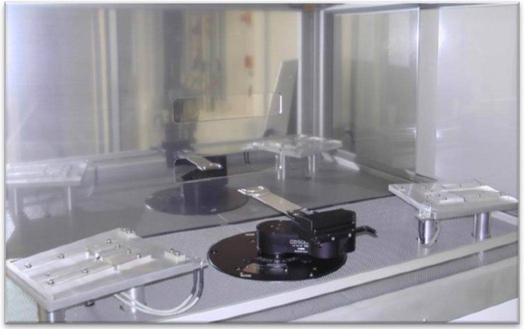


SiGe HBT as vertical current controlled device

- Performance dependence of “parasitic” parameters as R and C of junctions and ports
- Nano scale requirements for doping ➔ **width < 30nm** steep profile **accuracy of <10nm**
- In-situ doping of inner transistor; Carbon incorporation ➔ but activation of external ports (ion-doped) required

Optimization of vertical base profile by Flash-anneal

- FHR FLA200B @ HZR @ Dot7 project!
- Parameters:
  - 8” wafer size
  - 16 Xe-flash lamps (up to 35 J/cm2 (0.9-20ms)
  - Gases: Ar, N2, O2
  - 12 x 2.5 kW halogen re-heat lamps



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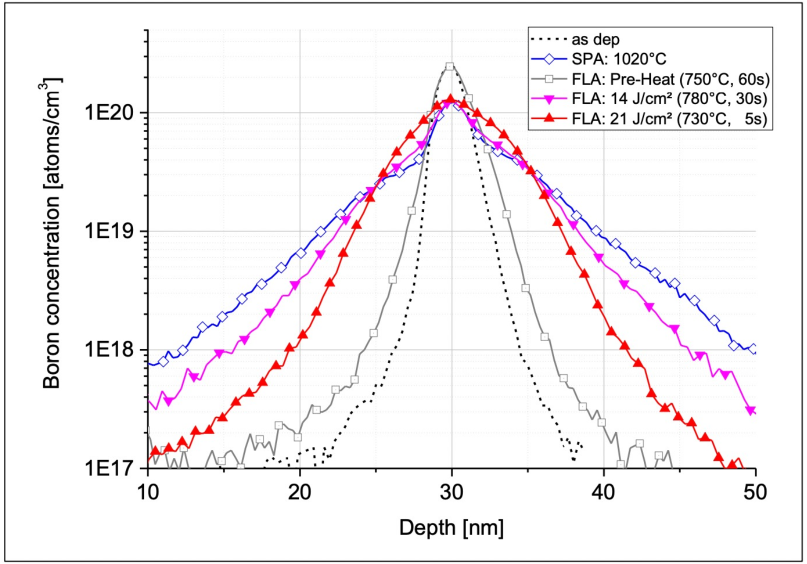
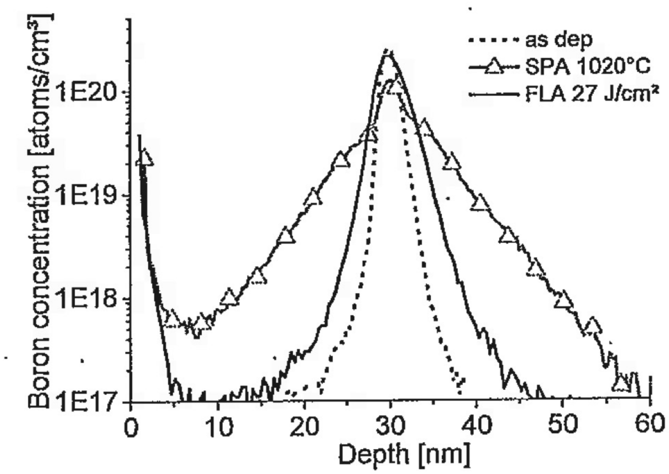
Boron doped SiGe profile evaluation

- Test runs for FLA200B evaluation
  - FLA with 27 J/cm^2 close to as-implanted boron profile





Millisecond Flash Lamp Annealing and Application for SiGe-HBT
A. Scheit, et. Al
Proc. 12th International Conference Ion Implantation And Other Applications Of Ions And Electrons (ION 2018), abstr. book 32 (2018)

- Higher activation by 50% approved for boron & Ge doped layers

Flash lamp anneal for advanced SiGe-HBT and BiCMOS

- Test runs for FLA200B implementation in
  - Qualified SiGe BiCMOS technologies (G2*)
  - Novel single SiGe-HBT device architectures (D7*)

➔ resistance decrease by steeper profile at similar/better activation

- Additional technology improvements necessary to keep the performance increase

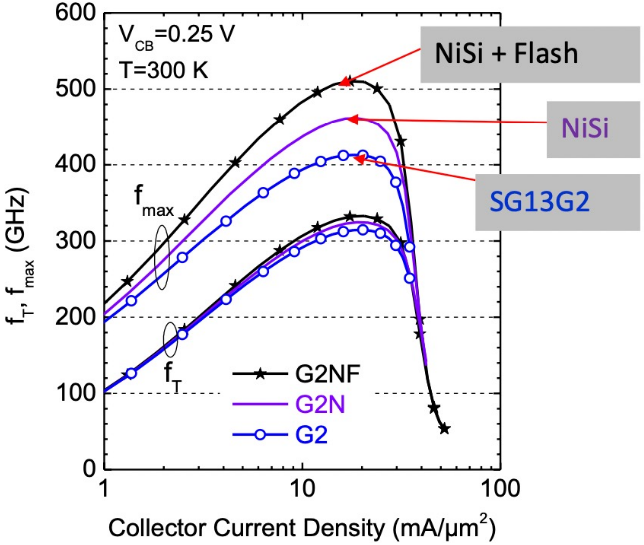
Process Changes compared to G2	Affecting	G2N	G2NF	D7a	D7b	D7bs
Emitter-Base Spacer & reduced emitter width	R_B, C_{BE}			x	x	x
External Base Region	R_B			x	x	x
Emitter Deposition	R_E			x	x	x
Hard-mask for selectively implanted collector	C_{BC}, R_C			x	x	x
Thicker Co silicide	R_B			x		
Narrower silicide blocking spacers	R_B			x	x	x
Lower final RTA temperature	base transit time, g_m			x	x	x
SiGe base profile & adjacent low-doped emitter & collector region	total transit time, g_m, C_{BC}, C_{BE}				x	x
Millisecond flash annealing	R_B, R_E		x		x	x
Low-temperature backend including Ni silicide	R_B, R_E	x	x		x	x
Scaled collector window & emitter-poly width	C_{BC}, R_B					x

SiGe HBT with f_T/f_{max} of 505 GHz/720 GHz
B. Heinemann et. al
Proc. IEEE International Electron Devices Meeting (IEDM 2016), 16-51 (2016)

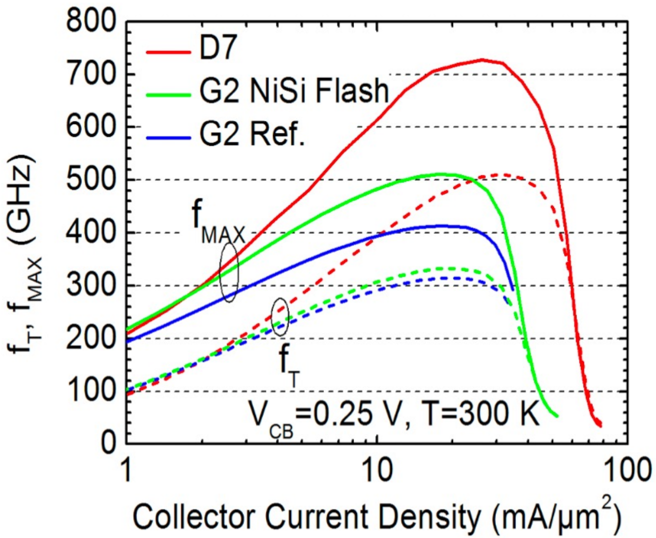
SiGe-HBT device performance results (I)

- Beside additional process flow optimizations (NiSi, low-T BEOL) the flash-lamp anneal push frequency performance to $f_{max}/f_T > 0.7/0.5$ THz

Full SiGe-BiCMOS process



Single SiGe-HBT (D7) performance

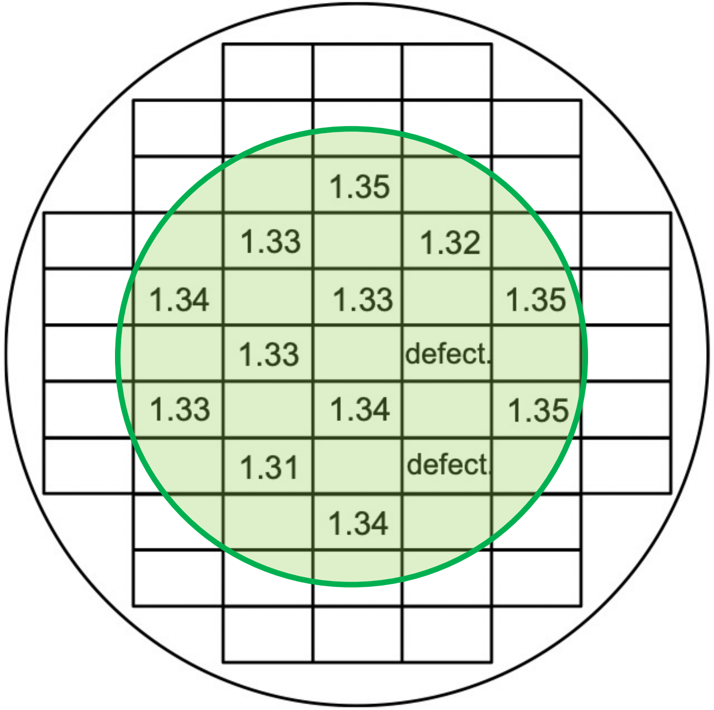


Millisecond Flash Lamp Annealing and Application for SiGe-HBT
A. Scheit et. Al; GMM-Nutzergruppentreffen Heißprozesse und RTP & Nutzergruppentreffen der GMM-Fachgruppe Ionenimplantation, Erlangen, April 03 - 04, 2019, Germany

SiGe-HBT device performance results (II)

- Wafer map of gate delays in picoseconds for CML ring oscillators
- Peripheral regions are omitted taking into account the non-uniformly distributed power density of the flash anneal
- Only ≈50% wafer area show sufficient device performance

➔ but: wafer production tools already available – challenges for process stability, lifetime, etc. – for medium wafer volumes a critical tradeoff



SiGe HBT with f_T/f_{max} of 505 GHz/720 GHz
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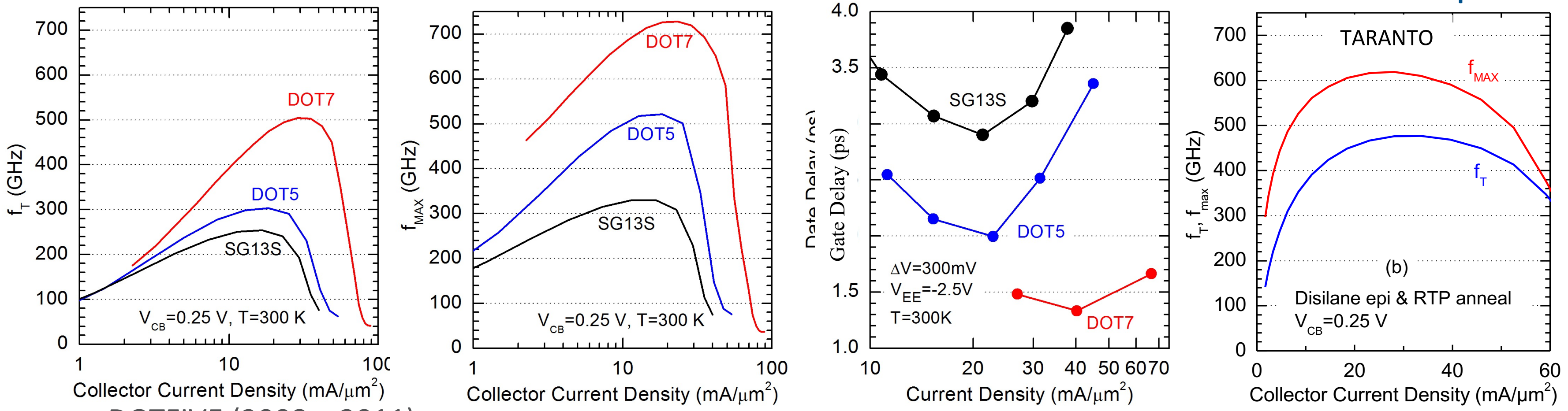
Evolution of High Performance BiCMOS Technologies

- Improvement of SiGe HBTs RF performance

Full SiGe-BiCMOS process



- DOTFIVE (2008 – 2011)
  - Demonstration of HBTs with 500 GHz f_{max}
- DOTSEVEN (2012 – 2016)
  - Demonstration of HBTs with 700 GHz f_{max}
- TARANTO (2017 – 2020)
  - Industrial BiCMOS platforms with 600 GHz f_{max} at ST (55 nm) and Infineon (90 nm)
  - IHP addresses integration of DOT7 HBT in 130 nm

Source: H. Rücker at al. – Device Architectures for High-Speed SiGe HBTs, *BCICTS 2019, Nashville, TN*

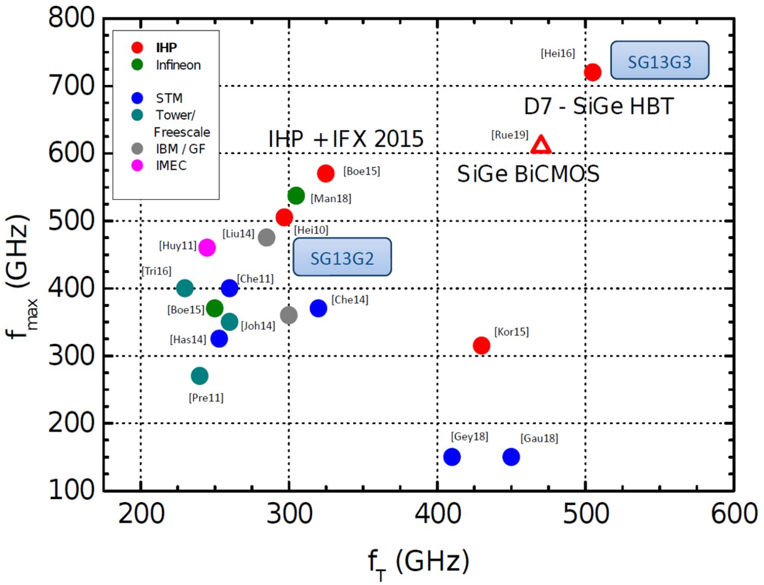
Evolution of High Performance BiCMOS Technologies

- Comparison of IHP BiCMOS Technologies

	SG13S	SG13G2	SG13G3*
HBT f_t / f_{max}	250 / 340 GHz	350 / 500 GHz	500 / 700 GHz
$W_{Emitter}$	170 nm	130 nm	110 nm
HBT BV_{CE0}	1.7 V	1.6V	1.5V
CMOS node	130 nm		
Active devices	Schottky diodes, Antenna diodes, PN diodes, ESD		
Varactors	NMOS Varactor		
Resistors	Poly-Si, Thin Film		Poly-Si
MIM Caps	1.5 fF / µm² (Al) 2.1 fF / µm² (Cu)	1.5 fF / µm² (Al) 2.1 fF / µm² (Cu)	2.1 fF / µm²
Metallization	7 Layers AL incl. 2 & 3 µm layers or Cu: 4 + 2 (3µm) Al: 2 (3µm)	7 Layers AL incl. 2 & 3 µm layers or Cu: 4 + 2 (3µm) Al: 2 (3µm	Cu: 4 + 2 (3µm) Al: 2 (3µm

*Target Values

- Keep performance advantage for SiGe-HBT



Summary

- Advanced SiGe BiCMOS and EPIC technologies are key enabler for future applications as 6G communication & sensing

- Continuous improvement of device performance and exploring of new process implementations (as FLA) are required and have to be demonstrated

- possibilities needs to be evaluated for industrial use cases

- Flash-lamp anneal proved their potential to push the rf-performance of Sige-HBT

Acknowledgment

- Thanks to my colleagues at IHP in particular:
  - Holger Rücker, Bernd Heinemann,
  - Alexander Scheit, Thomas Lenke

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Thank you for your attention!

Prof. Andreas Mai

IHP – Innovations for High Performance Microelectronics
Im Technologiepark 25
15236 Frankfurt (Oder)
Germany
Phone: +49 (0) 335 5625 733
Fax: +49 (0) 335 5625 321
Email: mai@ihp-microelectronics.com

www.ihp-microelectronics.com

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