dotfive
Towards 0.5 TeraHertz Silicon/Germanium Heterojunction Bipolar technology (SiGe HBT)

DOTFIVE newsletter #1

2009

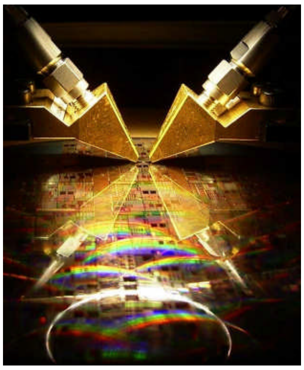
Welcome to the DOTFIVE mid term newsletter

DOTFIVE is an ambitious three-year European project focused on advanced RTD (Research, Technology and Development) activities necessary to move the Silicon-Germanium Heterojunction Bipolar Transistor (HBT) into the operating frequency range of 0.5 TeraHertz (THz) (500 GigaHertz GHz). This high frequency performance is currently only possible with more expensive technology based on III-V semiconductors, making high integration and functionality for large volume consumer applications difficult.

The new transistors developed by DOTFIVE will be used for designing circuits enabling power efficient millimeter-wave applications such as automotive radar (77 GHz) or WLAN communications systems (60 GHz – Wireless Local Area Network). In addition to these already evolving markets, DOTFIVE technology sets out to be a key enabler for silicon based millimetre-wave circuits with applications in the security, medical and scientific areas. A higher operating speed can open up new application areas at very high frequencies, or can be traded in for lower power dissipation, or can help to reduce the impact of process, voltage and temperature

Technology progress: After 18months of execution, the DOTFIVE project has made outstanding progress

In February 2008, the DOTFIVE project has been launched by the coordinator of the project STMICROELETRONICS (Gilles THOMAS) and 14 other European partners. The project with the very ambitious objective to reach the 0.5THz mark will be completed in 2010.



After one year, the 4 technology providers (2 companies and 2 research institutes) made OUTSTANDING PROGRESS towards the main objective. All of these partners have achieved the first year target assigned to the consortium with different process flows.
For this second year, the partners are closing in on their 2nd year goal with a maximum oscillation frequency (Fmax) of 0,4Thz at room temperature and a gate delay of 3ps.

The project is split into five technical work packages where important progress has been made to reach the 0.5THz.

WP1 TCAD and physics based predictive modelling

The influence of additional uniaxial stress on a biaxially strained 100GHz SiGe HBT by physics-based simulation has been investigated. Results show a significant dependence of maximum fT on uniaxial strain, especially in 010 direction (lateral direction of the intrinsic base). Additional tensile stress reduces peak fT while additional compressive stress increases it.
The same structure has been used to calculate impact ionization rates. The results are as expected with the majority of the impact ionization taking place in collector.

WP2 Evolutionary SiGe HBT technology

Starting from the high speed SiGe BiCMOS technology BiCMOS9MW which features a SA selective epitaxial SiGe HBT with 230 GHz / 290 GHz f_T / fmax, two shrinking phases have been performed by STMicroelectronics.

EVENT 2009

BCTM event 2009

http://www.ieee-bctm.org/

EVENT 2010

Second Seminar - 18th January 2010

http://www.dotfive.eu/index.php?id=140/

5 THz dotfive

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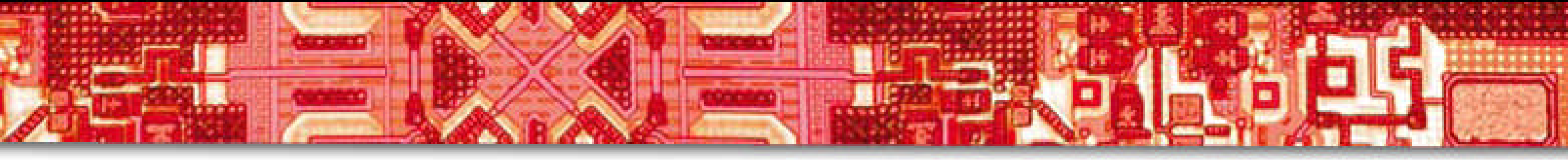
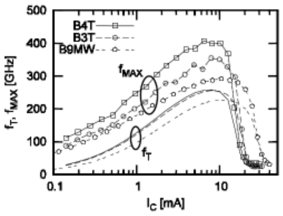
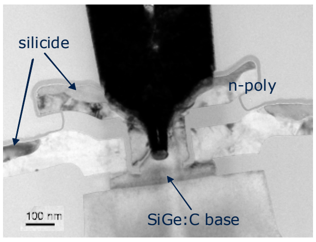
European Project supported within the Seventh Framework Programme for Research and Technological Development





A first shrinking phase, called B3T, led to a 260 / 350 GHz f_T / f_{max} HBT available for circuit prototyping in the first year of the DOTFIVE project. Using still a conventional SA selective epitaxial base HBT, a second shrinking phase resulted in DOTFIVE to the B4T technology providing a maximum oscillation frequency of 400 GHz together with a transit frequency of 265 GHz (wafer averages). These outstanding performance data have been obtained for a collector base breakdown voltage of 6.0 V and a collector emitter breakdown voltage of 1.5 V

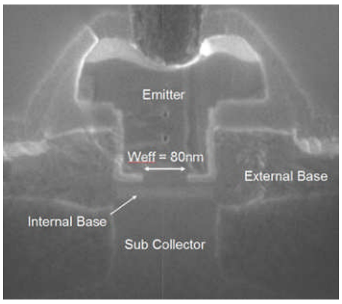
Fig1: f_T and f_{max} of STMicroelectronics's BiCMOS9MW, B3T and B4T technology



In WP2 also various improvements on Infineon's SiGe HBT technology B7HF200 have been performed. The technology features also SA selective epitaxial base transistor and is used for example in automotive radar applications at 77 GHz. The improvements are new transistor layouts with tighter design rules, a reduction of the emitter window width, a shallower collector as well as new SiGe base profiles with 30% Ge content. The new SiGe HBTs have provided a CML ring oscillator gate delay time of 2.8 ps (wafer averages) together with a transit frequency f_T of 235 GHz.

Fig2: TEM Cross section of Infineon's SA selective epitaxial base HBT

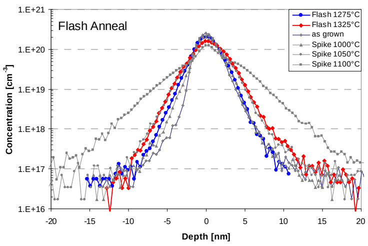
WP3: Advanced SiGe HBT process modules and architecture



An improved fully self-aligned SiGe:C HBT architecture featuring a single-step epitaxial collector-base process has been developed. An f_{MAX} value of 400GHz is reached by structural as well as intrinsic advancements made to the HBT device. A SEM cross-section of the device is shown in Fig. 3. The architecture features very small base active width, due to the self-alignment of the external base to the collector region, and the self-alignment of the emitter to the base.

Fast thermal treatments to remove implantation damage and to activate impurities are usually carried out by spike anneals with ramp rates from 100K/s to 300K/s. Recently, techniques, like flash anneal, were developed which achieve ramp rates up to 10^5K/s.

*Fig 3: **SEM cross-section of novel device***



Also, a study of the capability of the flash anneal for SiGe HBT fabrication is presented. Before starting integration lots, model experiments on blanket wafers are completed to study the effects of flash annealing on HBT-typical doping profiles and to find an appropriate temperature range for transistor functionality (Fig.4).

Fig 4: SIMS measurements of B profiles annealed at different temperatures with a conventional spike anneal (gray lines) or flash anneal (blue and red line)

Static and dynamic transistor characteristics demonstrate the potential of this technique for improving the high-speed performance. However, the question, whether one can take an extra advantage by this method compared to a standard spike anneal or not, has to be explored further. For this purpose device architectures and processes are needed that take into account the strongly decreased diffusion lengths, in particular of the extrinsic base doping, due to the reduced thermal budget.

WP4: Device and compact modelling, device characterization

The development of the high-performance 0.5THz HBT's pursued within the DOTFIVE project requires a continuous device miniaturization. This results in physical effects, which did not play a significant role so far and, hence, are not captured in existing compact models. In DOTFIVE these physical effects and other compact modelling related issues that have been observed so far from experimental data and device simulation of advanced doping profiles and device structures are identified. Based on their physical understanding improved compact model formulations have already been developed for the existing fabricated transistors.

Measurements of DC characteristics and RF characteristics for cold and hot states as well as temperature dependent measurements have been performed on the most recent DOTFIVE technologies using 50GHz and 110GHz measurement systems, respectively. Experimental characterization on high-speed transistors and related de-embedding structures as well as DC test structures has been performed. Finally, a common set of test structures for characterization, process de-embedding, and compact modelling has been implemented by the fabrication partners and is continuously being refined.

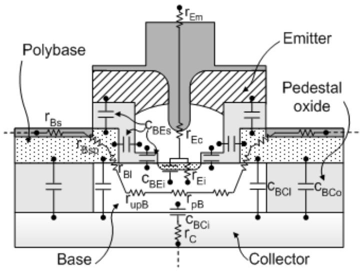
BCTM event 2009 - IEEE BIPOLAR / BiCMOS CIRCUITS AND TECHNOLOGY MEETING (OCTOBER 13/14, 2009)

This year marks the return of BCTM to Europe; for this opportunity, the partners of the DOTFIVE project (Univ. of Napoli, Infineon, STMicroelectronics, XMOD, Univ. of Bordeaux, Univ. of Bundeswehr, Technical Univ. Dresden) have participated in the BCTM event 2009 in Capri and have presented their results.

Bipolar/ BiCMOS Circuits and Technology Meeting BCTM 2009

The IEEE sponsored BCTM is the main event in the BIPOLAR / BiCMOS circuits and technology area in 2009 and regroups the major players of the domain. With this event the DOTFIVE consortium aims at disseminating their work to an international audience

The European project DOTFIVE addresses evolutionary scaling of self-aligned SiGe:C HBTs, investigates novel HBT architectures and develops novel process modules to push SiGe BiCMOS technology towards 500 GHz f_{MAX} and 2.5 ps gate delay. In this way, the DOTFIVE partners presented during the BCTM, the following papers:



SiGe HBTs process technology:

- ***Advanced Process Modules and Architectures for Half-Terahertz SiGe:C HBTs*** (IMEC, Infineon, STMicroelectronics, Technical Univ. Dresden, IHP)
- ***A Conventional Double-Polysilicon FSA-SEG Si/SiGe:C HBT Reaching 400 GHz f_{MAX}*.** This paper summarizes the work carried out to improve performances of a conventional double-polysilicon FSA-SEG SiGe:C HBT towards 400 GHz f_{MAX}. (STMicroelectronics)
- ***A 400 GHz f_{MAX} Fully Self-Aligned SiGe:C HBT Architecture***. An improved fully self-aligned SiGe:C HBT architecture featuring a single-step epitaxial collector-base process is described. (IMEC).

Performance and Operating Constraints of SiGe HBTs:

- ***Theoretical Analysis and Modeling of Bipolar Transistor Operation Under Base Current Reversal*** (A two-dimensional theoretical analysis of bipolar transistor operation under reversal base current conditions has been presented. (Univ. Napoli)

Device Physics: Simulation and Structures:

- ***Electron Transport in Extremely Scaled SiGe HBTs .Transport and noise in a THz-SiGe HBT are investigated using classical TCAD tools and full solutions of the more physics-based Boltzmann equation.*** The transport is quasi-ballistic and the classical models fail to yield accurate results. (Univ. of Bundeswehr)

State-of-the-art Measurements and Parameter Extraction:

- ***Investigation of High Frequency Coupling between Probe Tips and Wafer Surface.*** This paper presents an investigation of the coupling between probes tips and the wafer surface through EM-simulation, and compares the simulation results to measurements. (IMS)

mmW BiCMOS Circuits:

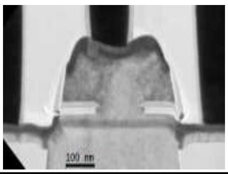
- ***168 GHz Dynamic Frequency Divider in SiGe:C Bipolar Technology***. This paper presents a SiGe bipolar dynamic frequency divider operating up to a maximum frequency of 168 GHz. (Infineon)

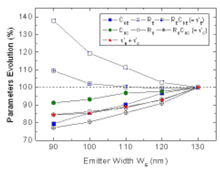
Also, the following paper was presented in September 2009 at SISPAD in San Diego, USA:

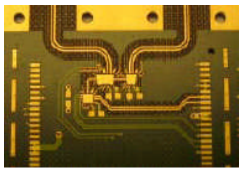
On the feasibility of 500GHz Silicon-Germanium HBTs:

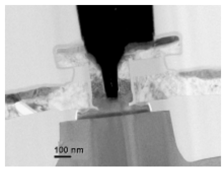
- A procedure for rapid TCAD-based evaluation of realistic device performance
- Generation of compact model libraries with realistic 500GHz transistor structures for exploratory circuit design. (Technical Univ. Dresden, Univ. of Bundeswehr)

More information for this event: http://www.ieee-bctm.org/

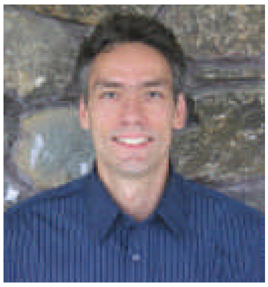








Interview – Ullrich Pfeiffer – University of Wuppertal – Work package 5 leader



Ullrich Pfeiffer, is a physics graduate who specialized in high-frequency circuits and system. He did his Ph.D. in experimental particle physics at the University of Heidelberg from 1996 to 1999 with the focus on highly integrated real-time trigger electronics now being installed at the European Centre for Nuclear Research (CERN). From 2001 to 2006 he was with the IBM T.J. Watson Research Centre where his research involved RF circuit design for millimeter-wave communication systems. In 2007 he received a European Young Investigator Award. Since 2008 he holds the High-frequency and Communication Technology chair at the University of Wuppertal, Germany. He was the co-recipient of the 2004 and 2006 Lewis Winner Award for Outstanding Paper at the IEEE International Solid-State Circuit Conference, the co-recipient of the 2006 IBM Pat Goldberg Memorial Best Paper Award, and the 2008 EuMIC Best Paper Award.

Why have you chosen this specialisation in your work?

I always found it fascinating that the physical principle of electromagnetic radiation holds true over a very large frequency range. The electromagnetic spectrum extends from below radio transmission through to the size of an atom. The fact that one will soon be able to integrate millions of transistors operating at terahertz frequencies is quite intriguing, and I'm sure, this will inspire many new high-frequency applications which make a difference in our daily life.

Why working in EC project and why especially in DOTFIVE?

What makes a European funded project unique are the people within it. The spirit of large scale international collaborations is always something I have enjoyed. One gets to know many bright people and is working in an environment that helps to generate new ideas. In DOTFIVE we improve our knowledge and capabilities across all relevant scientific areas. This includes understanding the device physics and its modelling. We are trying to push transistor operation and their process technologies to the limits while we develop new circuits and applications, which can make a difference.

What kind of exiting applications the result of the DOTFIVE project could bring?

DOTFIVE results will impact applications in two ways. On one hand, DOTFIVE will improve already existing applications, such as automotive radar applications for instance, by improving their performance and lowering their power dissipation. On the other hand, it enables completely new applications at very high frequencies. We are targeting novel radar, communication, and terahertz imaging/sensing applications at 160, 220 and even up to 650 GHz. Unlike x-rays, terahertz radiation is non-ionizing so that health risks are minimal and imaging systems are capable of detecting concealed weapons through clothing or baggage. I see high-speed and highly integrated terahertz cameras, which can operate in real-time, being used in future medical and security applications.

What are your prognostics of evolution for the high frequency circuit in the future?

I'm very confident that there will be an increased need for high-frequency circuits in the future. Many of today's digital and analog circuits will be pushed further to ever higher speed and data-rates. On top of this, the terahertz region of the electromagnetic spectrum (100 GHz to 10 THz) is of growing scientific and commercial interest. There are, however, technical challenges to be faced in exploiting this band with integrated circuit technologies, mostly because this band spans the transition between electronic and photonic technologies. At this transition I see circuit innovation having a major impact in the near future.

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