Leibniz Ferdinand Braun Institut

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Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

# THz Electronics with InP

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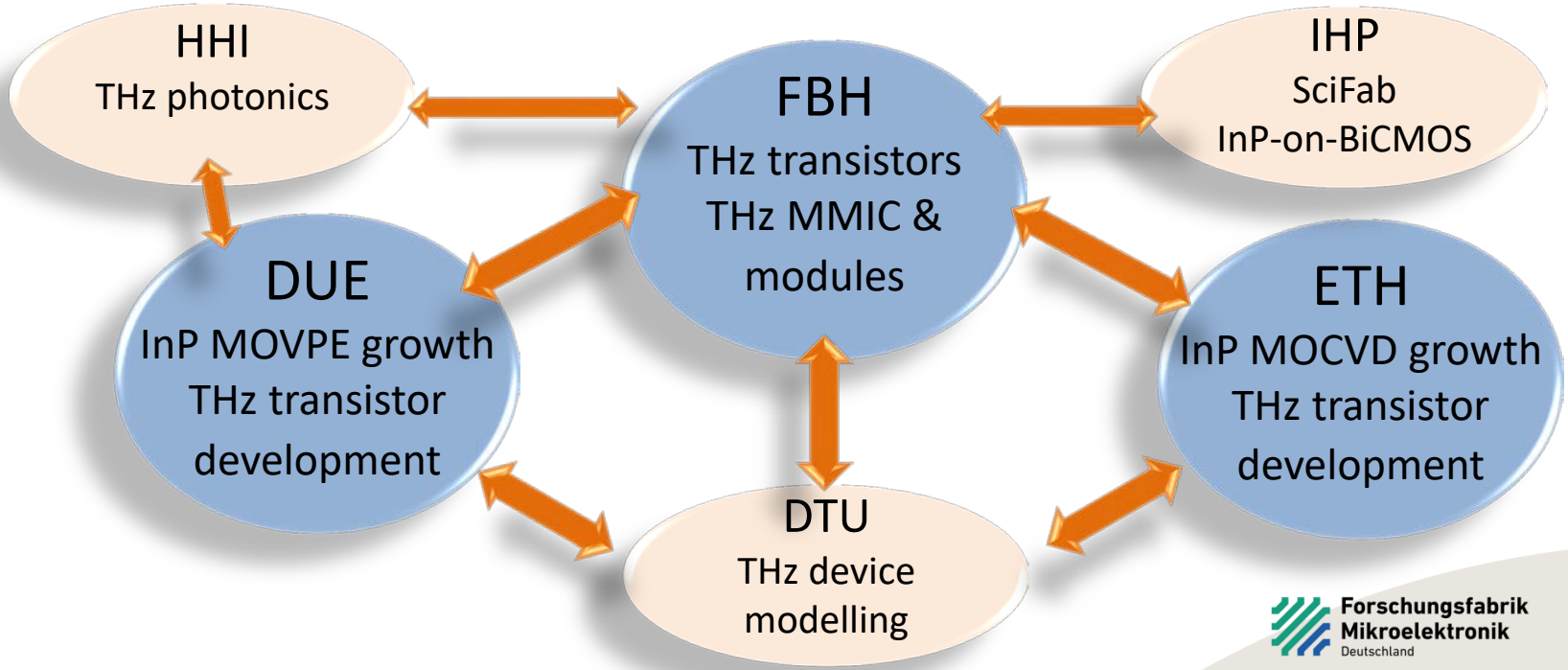
Ferdinand-Braun-InstitutLeibniz-Institut für Höchstfrequenztechnik

# THz Electronics Cooperative Initiative

Aim within Flagship: Establish Center for THz MMIC Electronics

**From material … to MMIC … to application**




Forschungsfabrik Mikroelektronik Deutschland

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# Ferdinand-Braun-Institut – Facts & Figures

- Institute within Forschungsverbund Berlin e.V., Member of Leibniz Association
- **Mission:** Applied research and development on III-V semiconductor devices, circuits and modules for microwave technology and optoelectronics

- Staff: 290 (incl. 140 scientists & PhD candidates) from 17 nationalities
- Budget / Turnover (2017): 33.0 M€ (incl. 18.5 M€ project revenues)
- **Partner in Forschungsfabrik Mikro-elektronik Deutschland (FMD)**
- **Goal:** Realization of an industry compatible process line with focus on THz electronics
- Excellent experience in large-scale project management and project calls

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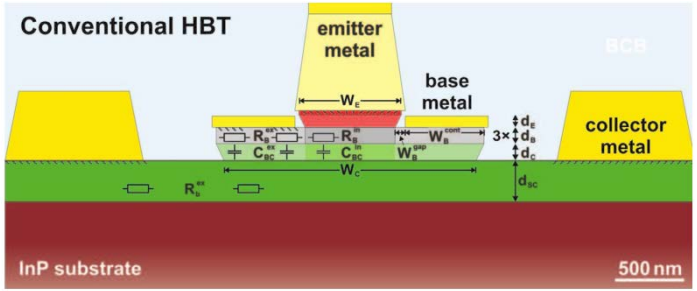
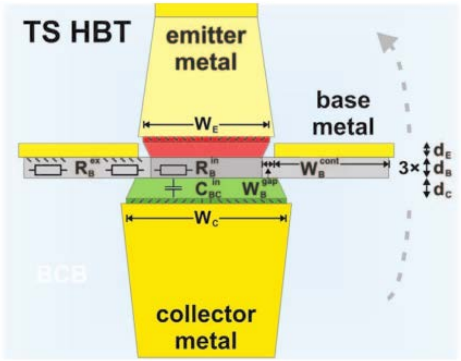
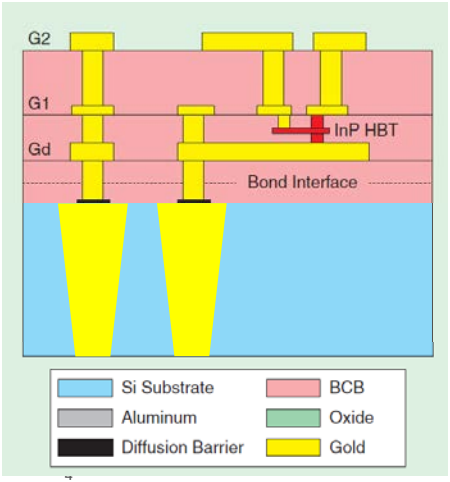
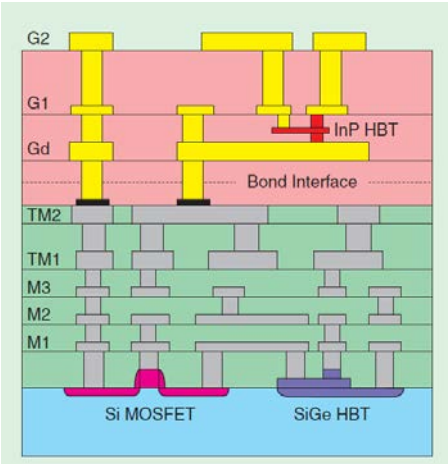
# Transfer substrate process




Advantages

- Reduced parasitics → higher cut-off frequencies

$$f^2_{max} = f\tau / 2\pi R_{bb} C_{cb}$$

- Flexible Substrate → e.g. heterointegration with BiCMOS

Disadvantages

- Higher process complexity
- Poor thermal management → (output power)

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# THz electronics @ FBH

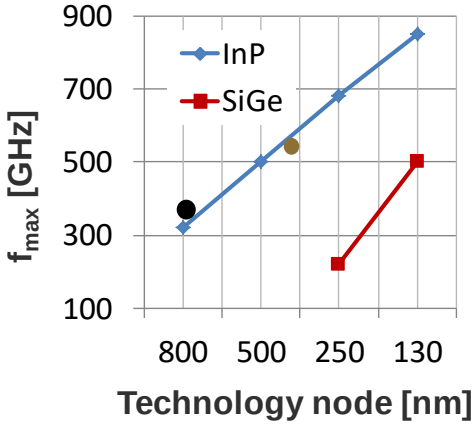
Goal: THz Electronics operating beyond 1 THz

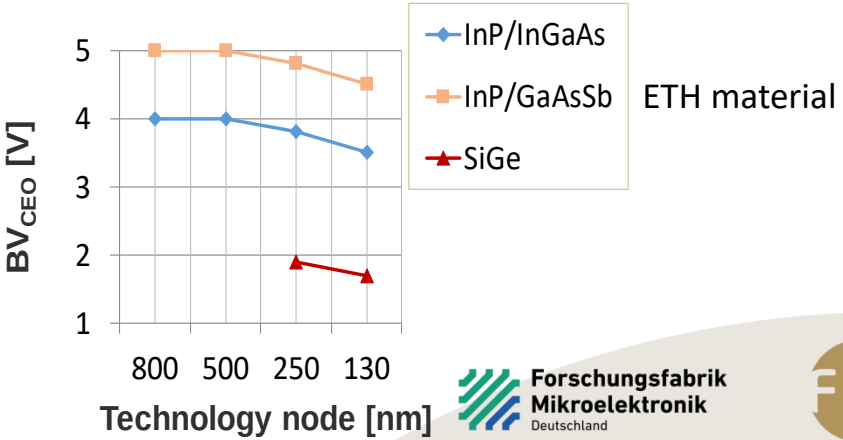
FBH InP & GaN technologies contribute to the success of THz applications in industry & society

- Non-destructive testing
- Wireless communications
- Imaging, Space & Security

Push the power & frequency limits

*… with a little help from our friends*

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# THz Electronics: InP-HBT MMICs

## Circuits

InP-on-BiCMOS sources (VCO & multiplier)

- 164 GHz: 7 dBm
- 328 GHz: -12 dBm

InP oscillators

- 270 GHz, 290 GHz, 480 GHz

InP frequency doublers

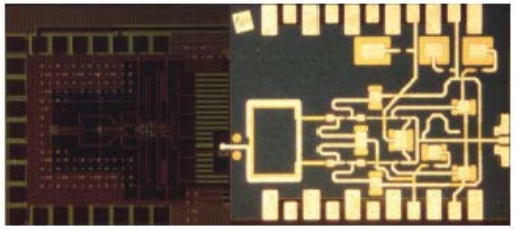
- G-band : 140 … 220 GHz, 8 dBm @ 180 GHz

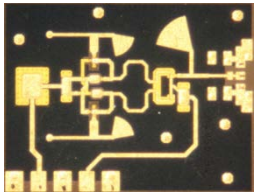
W-band and 140 GHz PA for wireless communications

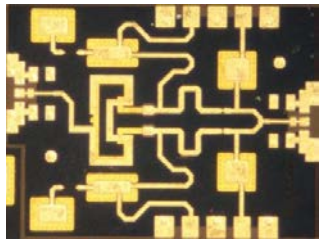
- Pout > 19 dBm @ 90 GHz, PAE > 14 %

Wideband Amplifiers

- Bandwidth > 100 GHz up to 220 GHz with > 10 dBm output power & 8 dB noise figure







# THz Detection with Single Pixel THz Camera at 500 GHz

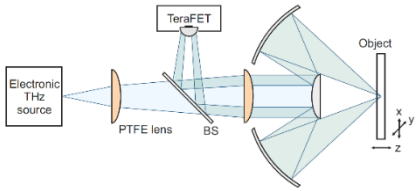
SNR = 40 dB

Raster scan => long acquisition time

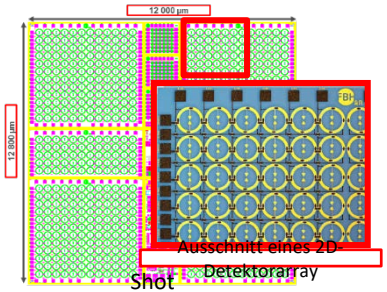
Excellent NEP ~ 26 pW/Hz$^{0.5}$ [1]

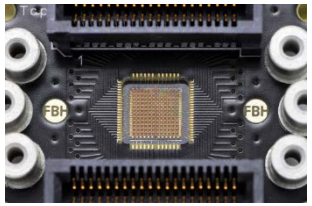
Excellent pulse performance [2]

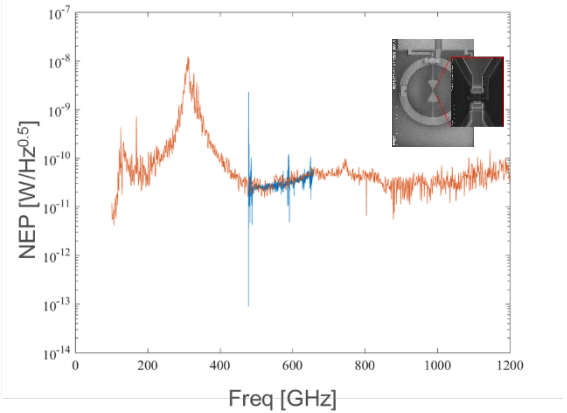
Schwarzschild Optics









[1] Maris Bauer et al, „Optimization of the Design of Terahertz Detectors Based on Si CMOS and AlGaN/GaN Field-Effect Transistors", Intern. J. High Speed Electronics and Systems Vol. 25, Nos. 3 & 4 (2016) 1640013

[2] K. Ikamas *et al.*, "Efficient detection of short-pulse THz radiation with field effect transistors," *2017 International Conference on Noise and Fluctuations (ICNF)*, Vilnius, 2017, pp. 1-4.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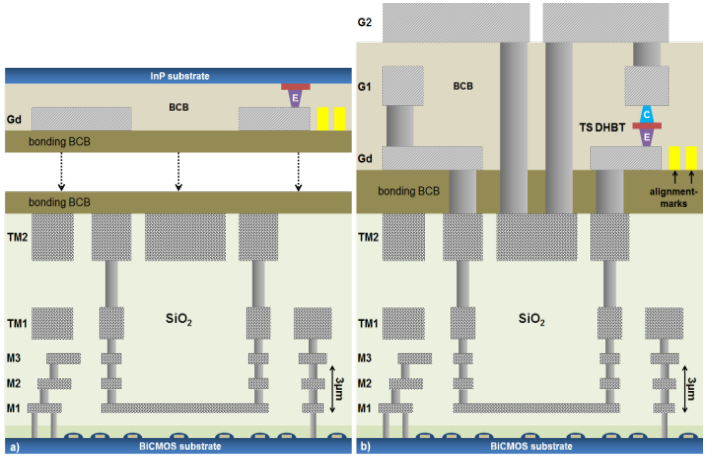
# SciFab - Vertical Layer Stackup and Interconnects

## InP HBT module

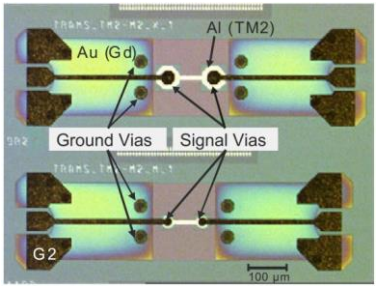
- 3 Au 2µm/4µm metal layers on BCB
- 800/500 nm InP DHBT single- and double finger,
  $f_T/f_{max}$= 350/550 GHz,
  $I_{C,max}$ = 40 mA
- MIM capacitor & thin film resistor




## Full BiCMOS process IHP SG250 (optionally with TSV instead of BiCMOS stack)

Vias:

- InP G2 → Gd
  InP G1 → Gd
  BiCMOS TM2 → M1
  BiCMOS TM1 → M1




**Low-loss vertical RF transitions between InP and BiCMOS layer stacks (< 0.5 dB @ 320 GHz)**

**Optimized with 3D EM**

I. Ostermay, et al, "Three-dimensional InP-DHBT on SiGe-BiCMOS integration by means of Benzocyclobutene based wafer bonding for MM-wave circuits," Microelectronic Engineering, vol. 125, pp. 38–44, Aug. 2014.



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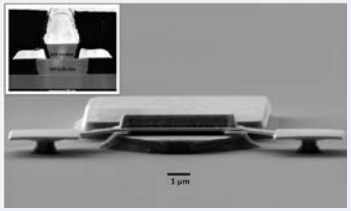
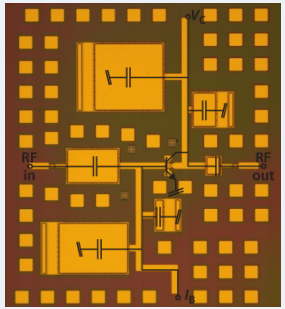
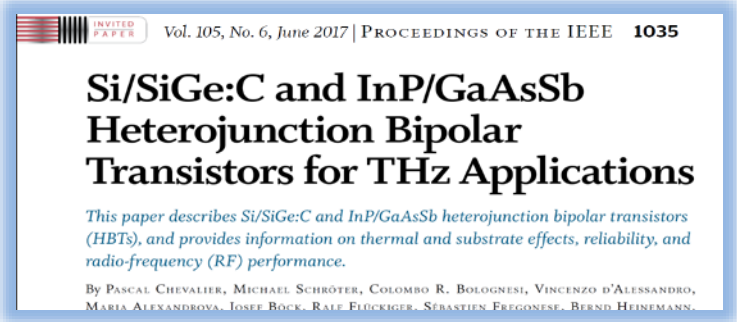
# InP Double Heterojunction Bipolar Transistors (DHBTs)

*Contact:*
*Prof. Dr. Colombo Bolognesi*
*Millimeter-Wave Electronics Group (MWE)*
*http://www.mwe.ee.ethz.ch/*





- 4G Phones Rely on Multiple Technologies
- Pioneering Expertise in InP/GaAsSb DHBT Materials
  - High-Speed T&M Equipment Manufacturers Use InP DHBTs in Key Blocks (@ SSI-MSI Levels)
  - Adopted by *Agilent/Keysight* (in production since 2004)
  - *Teledyne-Lecroy* also Adopted InP DHBTs for 100 Gbit/s
  - 600 GHz also Demo`ed by *NTT* Japan
  - Heterogenous Integration Becoming Widespread
- Full In-House Fabrication (MOCVD to MMICs)
  - The only THz $f_{MAX}$ DHBT Demonstrated in Europe so far…
- $f_T$ x *BV* > 2.4 THz-V (Highest of any Bipolar Technology)
  - $f_{MAX}$ x *BV* > 3.8 THz-V
- Record Performance MMICs Demonstrated in FBH Process Based on ETH Epi


INVITED PAPER
Vol. 105, No. 6, June 2017 | Proceedings of the IEEE 1035

Si/SiGe:C and InP/GaAsSb Heterojunction Bipolar Transistors for THz Applications

This paper describes Si/SiGe:C and InP/GaAsSb heterojunction bipolar transistors (HBTs), and provides information on thermal and substrate effects, reliability, and radio-frequency (RF) performance.

By Pascal Chevalier, Michael Schröter, Colombo R. Bolognesi, Vincenzo d'Alessandro, Maria Alexandrova, Josef Bock, Ralf Flückiger, Sébastien Fregonese, Bernd Heinemann,

# THz Electronics Research @ University of Duisburg: Materials, Devices and Integration

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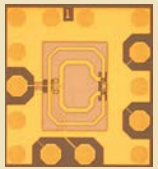
## Complete research value chain: from materials to validation

- expertise in **THz HBT, RTD** and THz IR diode development, THz MMIC and module integration
- **Indium Phosphide** epitaxial growth
  - **MBE** for Resonant Tunneling Diodes
  - **MOVPE** for submicron and nanowire InP HBTs
- **500 m² cleanroom** specialized for III/V components
- high frequency **test equipment**, e.g.
  - S-parameter measurements up to 500 GHz, funding for extension to 1.5 THz approved

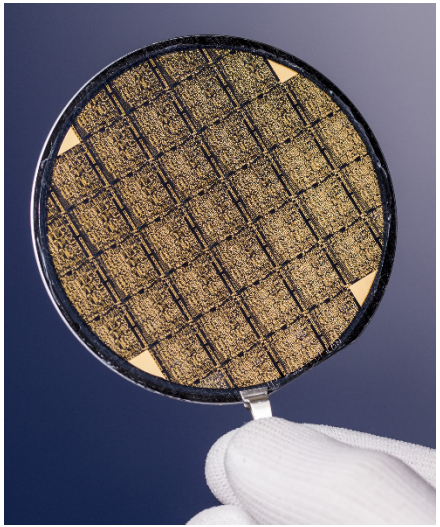

THz-InP-HBT-VCO

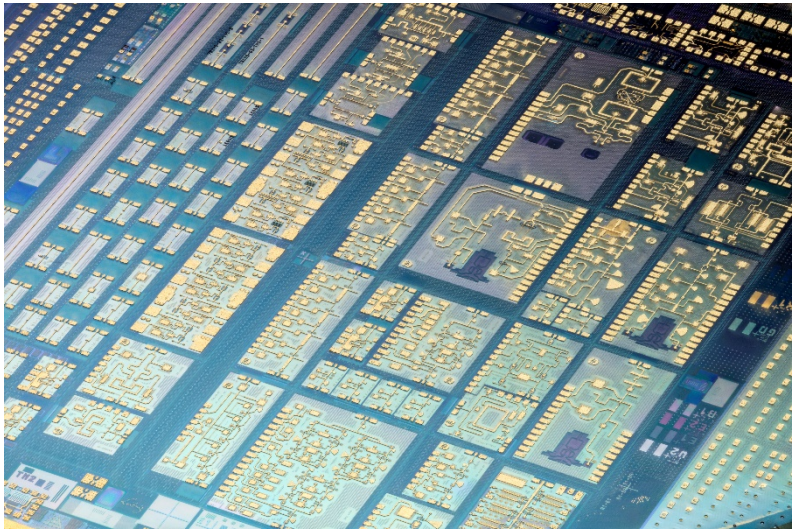

THz-InP-RTD


InP MOVPE


**Duisburg Center for Semiconductor Technology and Optoelectronics (ZHO)**

- *participant in major **DFG THz** collaborative research center **SFB/TRR MARIE***
- *part of **BMBF ForLab** micro- and nanoelectronic university research initiative*
- *strong collaboration with **BMBF FMD consortium**, in particular with **FBH** (THz HBT) and **HHI** (THz OE)*
- *interaction with EU microelectronic and optoelectronic industry*
- *member of **EU TeraApps ITN,** etc.*
- *extensive joint research with **ETHZ** and **DTU***





# Thank you.

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