THz Electronics with InP

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Aim within Flagship: Establish Center for THz MMIC Electronics

From material ... to MMIC ... to application

- **HHI**
  - THz photonics

- **DUE**
  - InP MOVPE growth
  - THz transistor development

- **FBH**
  - THz transistors
  - THz MMIC & modules

- **IHP**
  - SciFab
  - InP-on-BiCMOS

- **ETH**
  - InP MOCVD growth
  - THz transistor development

- **DTU**
  - THz device modelling
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 Mikroelektronik 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
Transfer substrate process

Advantages
- Reduced parasitics $\rightarrow$ higher cut-off frequencies
  $f_{\text{max}}^2 = \frac{f_t}{2\pi R_{bb} C_{cb}}$
- Flexible Substrate $\rightarrow$ e.g. heterointegration with BiCMOS

Disadvantages
- Higher process complexity
- Poor thermal management $\rightarrow$ (output power)
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
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

Schwarzschild Optics

Excellent NEP ~ 26 pW/Hz^{0.5} [1]
Excellent pulse performance [2]


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, 
  \( f_t/f_{\text{max}} = 350/550 \text{ GHz}, \) 
  \( I_{C,\text{max}} = 40 \text{ mA} \)
- MIM capacitor & thin film resistor

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

Vias:

- InP G2 \(\rightarrow\) Gd
- InP G1 \(\rightarrow\) Gd
- BiCMOS TM2 \(\rightarrow\) M1
- BiCMOS TM1 \(\rightarrow\) M1

Low-loss vertical RF transitions between InP and BiCMOS layer stacks (< 0.5 dB @ 320 GHz)
Optimized with 3D EM

InP Double Heterojunction Bipolar Transistors (DHBTs)

- 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 $f_{\text{MAX}}$ DHBT Demonstrated in Europe so far...
  - $f_{T} \times BV > 2.4 \text{ THz-V}$ (Highest of any Bipolar Technology)
  - $f_{\text{MAX}} \times BV > 3.8 \text{ THz-V}$
- Record Performance MMICs Demonstrated in FBH Process Based on ETH Epi

Contact:
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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
Thank you.