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Electrical and thermal characterization of single and multi-finger InP DHBTs

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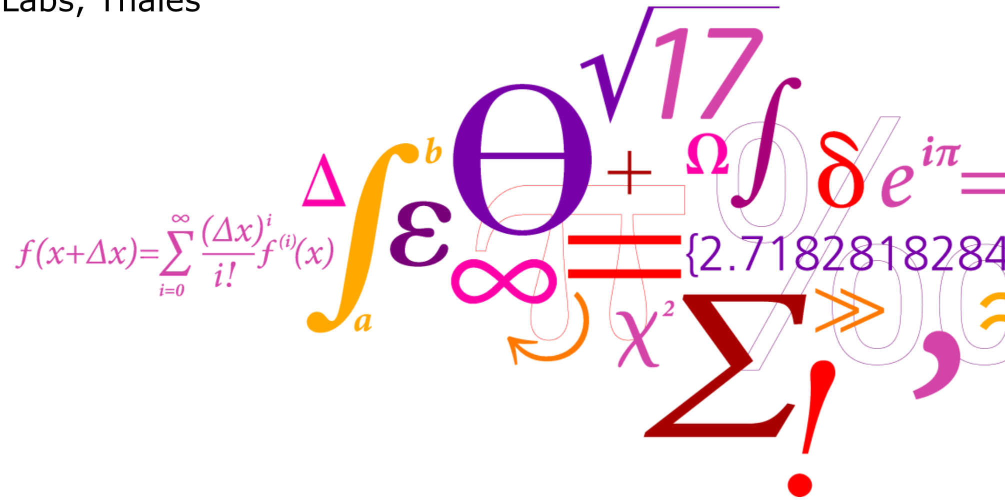
DTU



Outline

- Motivation
- Electrical characterization
- Thermal characterization
- Conclusions

Motivation - 1

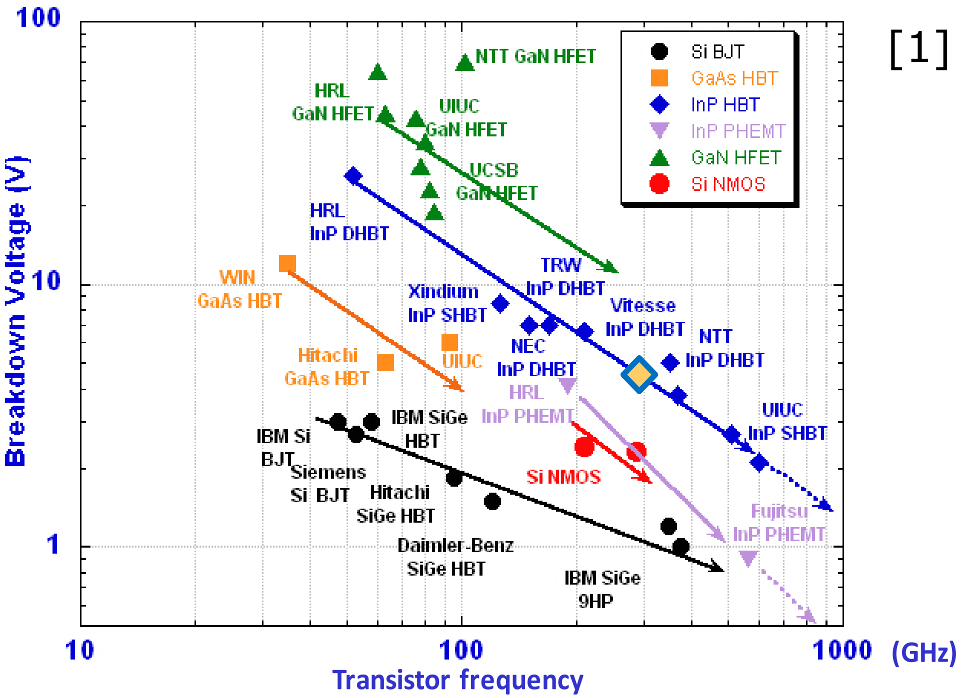
- Mobile data traffic is growing at a very fast pace and the capacity of mobile backhaul network must be increased to face this data explosion. In that respect there is at present an increased interest in exploiting the millimeter-wave (mm-wave) frequency range (30-300 GHz) for wireless backhauling.

- EU FP7 project **InP DHBT MMIC Technology for Millimeter-Wave Power Applications (IN-POWER)**

- **Partners:** DTU and III-V Lab

- **Objective:** development of an optimized technology for **mm-Wave MMIC power amplifiers**
  - higher frequency of operation
  - higher output power
  - reduced thermal effects

Motivation - 2

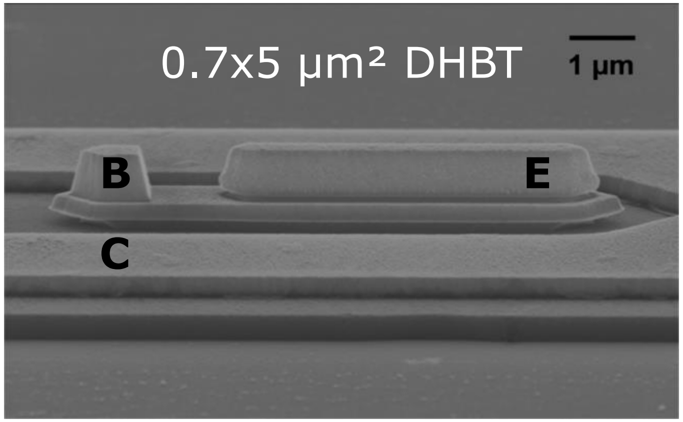


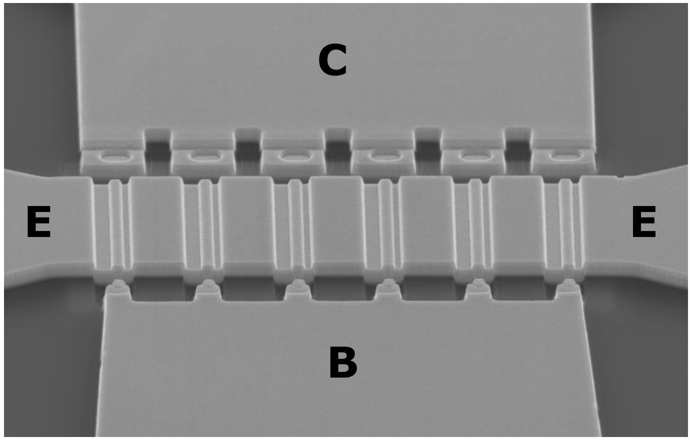
[1]

InP HBT technology is of great interest for mm-wave applications since it fills the gap between high power GaN devices limited to lower frequencies and other technologies like SiGe HBT with very high cut-off frequencies but lower breakdown voltage.

Device presentation

- **Gas Source-MBE**
  - InP/InGaAs DHBT
  - ~ 30 nm C-doped and graded base
  - 190 nm collector
- **Process**
  - Wet-etched triple mesa technology
  - Self-aligned base-emitter metallization
  - E-beam and stepper lithography
- **Emitter dimensions**
  - W_E: 0.5, 0.7, 1, 1.5 µm
  - L_E: 5, 7, 10 µm
- **Number of fingers**: 2,3,4,8

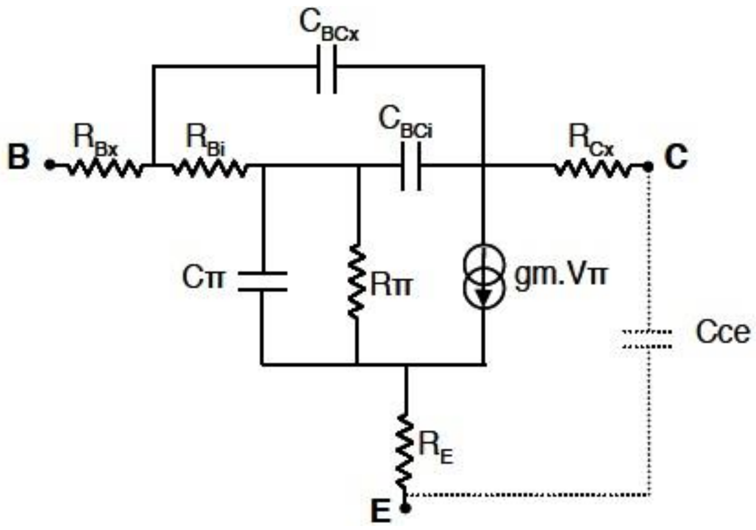

0.7x5 µm² DHBT



Characterization

- Electrical and thermal properties of single and multifinger devices
- DC measurements and S-parameters up to 110 GHz

π small-signal model



- Safe Operating Area
- f_T and f_{max}
- Thermal resistance

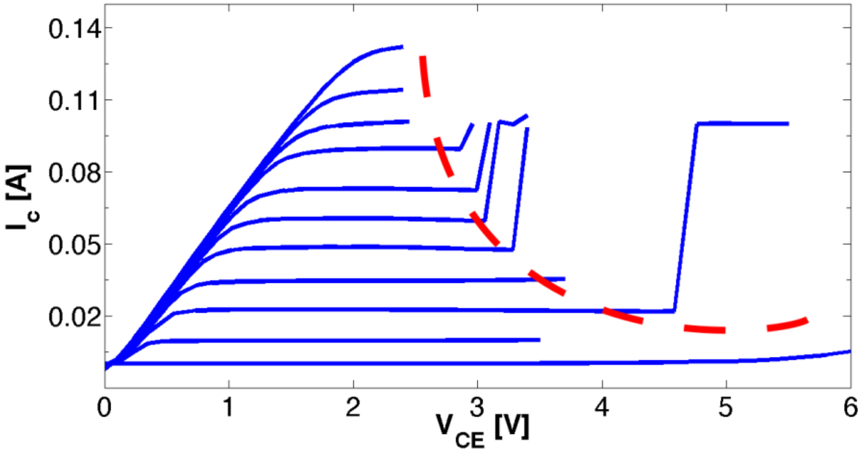
This work focuses on the impact of **geometrical dimensions** and **number of fingers** on device performances

Safe Operating Area

Breakdown voltage > 6 V

- Low I_c, High V_{CE}: breakdown probably due to impact ionization
- High I_c, Low V_{CE}: breakdown due to high junction temperature

0.2 mA < I_B < 2 mA



SOA: 4 fingers DHBT

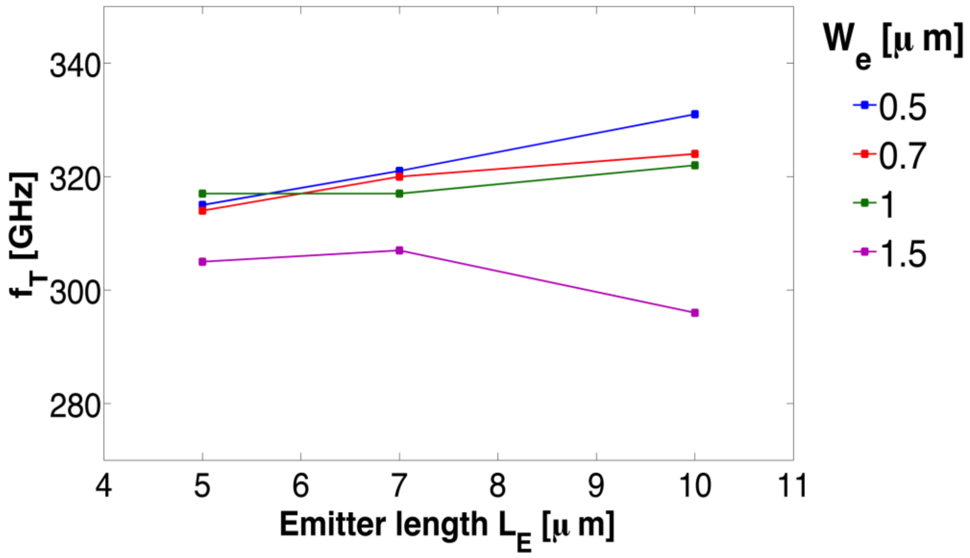
Electrical characterization – f_T

Single finger: Cutoff frequency f_T vs. emitter length

$$\frac{1}{2pf_t} = t_b + t_c + r_E\left(C_{je} + C_{bc}\right) + \left(R_E + R_C\right)C_{bc}$$

$J_C \approx 5$ mA/µm²

- Peak value: 320 GHz
- f_T is almost constant for increasing emitter length and is independent on geometrical dimensions for small number of fingers



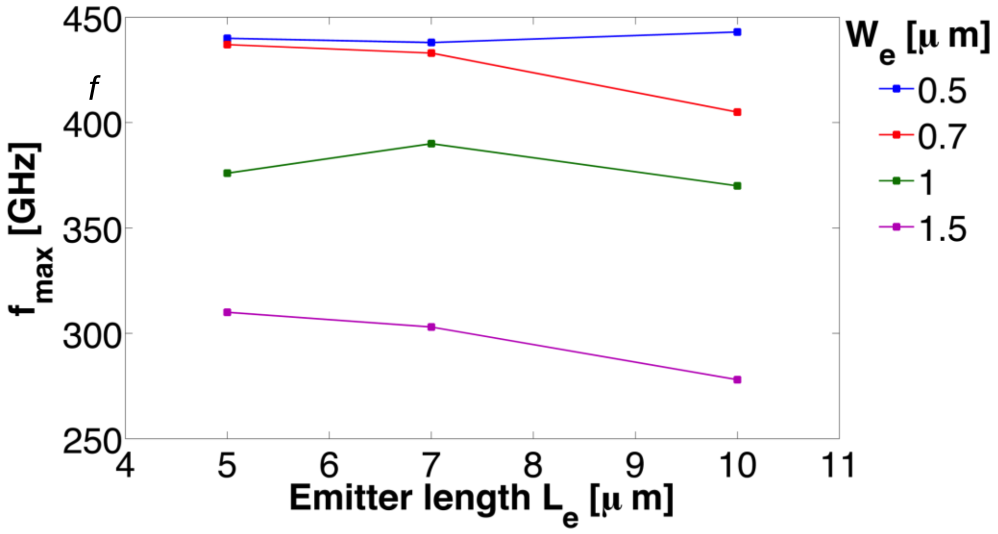
Electrical characterization – f_{max}

Single finger: Maximum oscillation frequency f_{max} vs. emitter length

$$f_{max} \approx \sqrt{\frac{f_t}{8\pi\left(R_{bx}\left(C_{bcx}+C_{bci}\right)+R_{bi}C_{bci}\right)}}$$

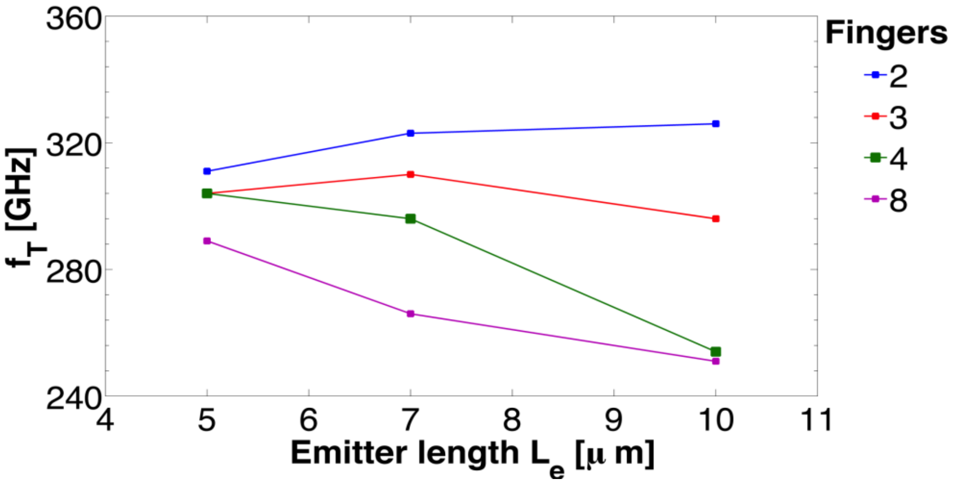
- Peak value: 450 GHz
- f_{max} generally decreases with emitter length due to a reduction of effective conduction area of the base contact
- f_{max} decreases 30% with W_e because of the increase in $C_{bci}R_{bx}$ product

$J_C \approx 5$ mA/µm²

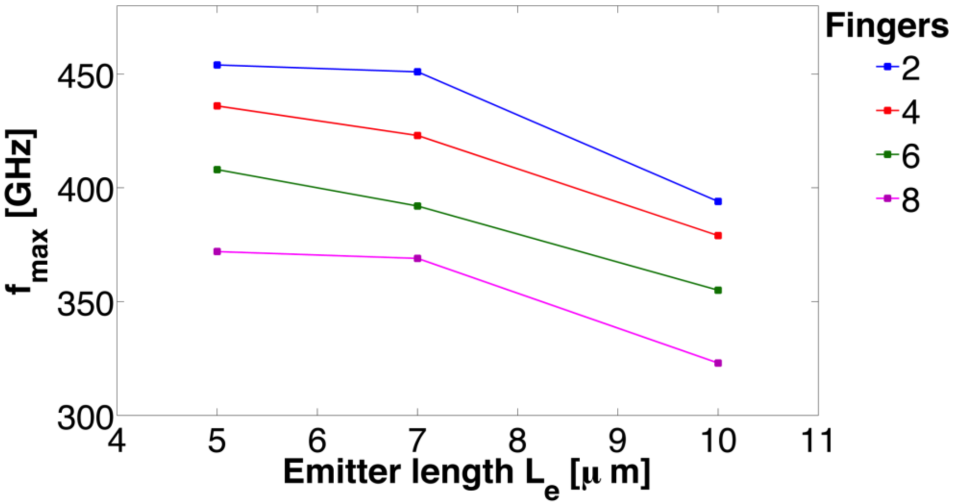


Electrical characterization Multi-finger devices

- The decrease of f_T for higher number of fingers might be explained with an increase in junction-temperature that reduces average carrier velocity



- f_{max} decreases with the number of finger because of increased junction temperature and additional parasitics

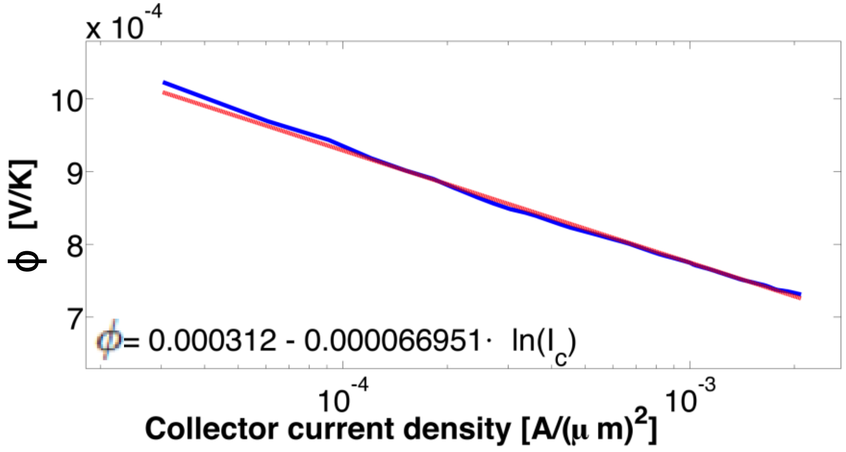


Thermal electric feedback

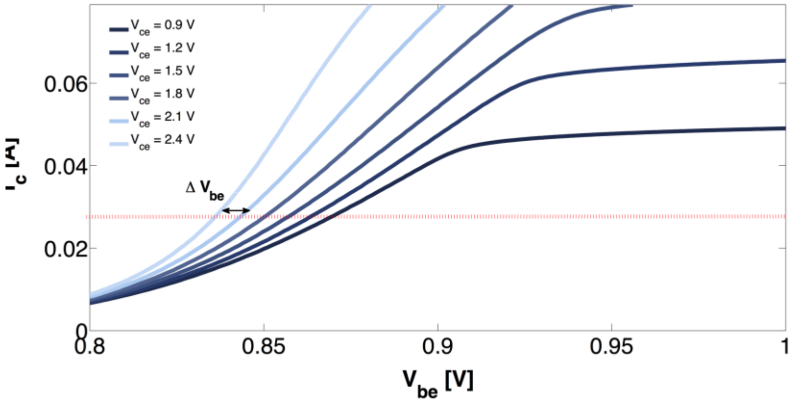
- Extraction of thermal properties from electrical measurements using thermal electric feedback coefficient method [2]

$$\phi = -\frac{\partial V_{be}}{\partial T} = \frac{\beta^*}{q} - \frac{\eta k}{q} \ln \frac{I_C}{I_{s0}}$$

- Method based on the variation of the V_{BE} required for a given current, varying temperature and dissipated power



Coefficient ϕ vs. I_c

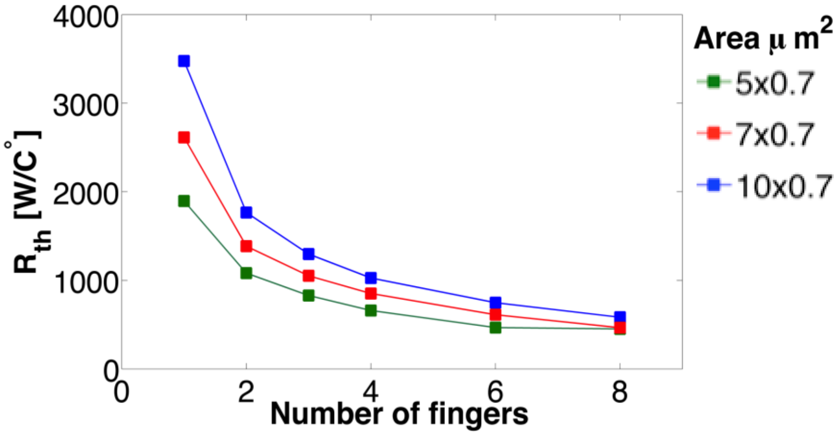


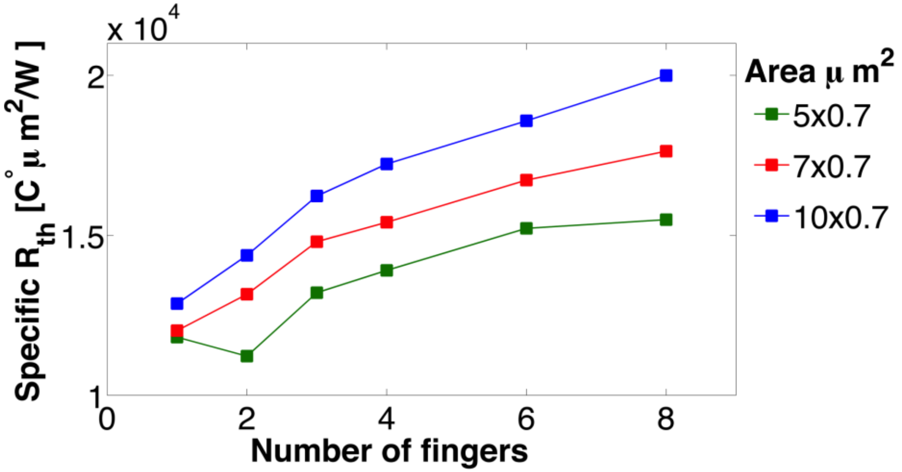
ΔV_{BE} for a given I_c and different dissipated power levels

Thermal resistance

$$R_{th} = \frac{\Delta V_{be}}{\Delta P \phi} = \frac{\Delta V_{be}}{\Delta V_{ce} I_c \phi}$$

- Thermal resistance in the range 3500 – 1900 C° /W (single finger)
- Thermal resistance is lower for larger devices but **specific thermal resistance is higher** due to mutual coupling effects
- Specific thermal resistance increases with emitter length and this might be due to a different temperature distribution across the finger for a given dissipated power





Conclusion

- Electrical and thermal characterization results of InP DHBTs were presented for single and multi-finger devices up to 8 fingers
- Breakdown voltage and SOA were investigated for high I_c and high V_{CE}
- For single finger devices, f_T does not depend strongly on geometrical dimensions. f_{max} decreases with emitter length due to device parasitics
- f_T and f_{max} generally decrease with increasing number of fingers
- Devices with higher emitter area exhibit higher specific thermal resistance than smaller devices because of additional coupling between fingers
- Devices with longer emitter have higher specific thermal resistance because of different temperature distribution along the finger

References

- [1] M. Feng et al., *f_t vs breakdown voltage plot for current viable semiconductor transistor technologies* ,Proc. IEEE, Feb., 2004)
- [2] Liu et al., *Thermal Properties and Thermal Instabilities of InP-based Heterojunction Bipolar Transistors*, IEEE Transaction on Electron Devices (1996)
- [3] B.Ling et al.,*2D Numerical Simulation for InGaP/GaAs HBT Safe Operating Area*, Proceedings of the 9th European Microwave Integrated Circuits Conference

Acknowledgements

III-V lab

IN-POWER

SEVENTH FRAMEWORK PROGRAMME

InP DHBT MMIC Technology for Millimeter-Wave Power Applications

Thanks for your attention!

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