SiC-based microwave devices and circuits

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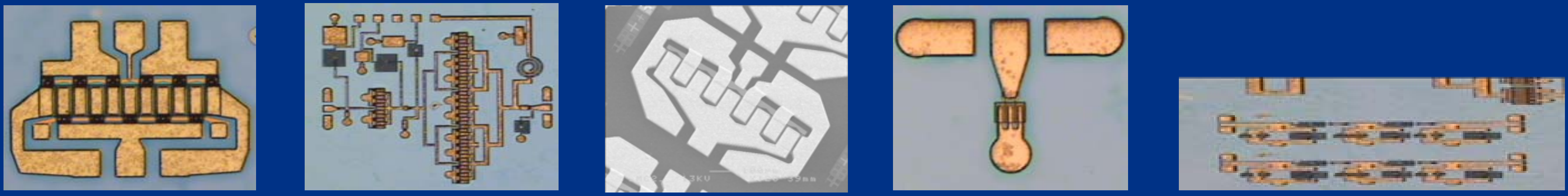


Outline

- SiC MESFET
- SiC MMIC
- AlGaN/GaN HEMT
- AlGaN/GaN MMIC
- Summary

Why SiC AlGaN-GaN

The WBG high frequency electronics is *emerging* i e due to the extreme properties of the material, components with extreme properties can be realized which can have an enormeous impact on systems regarding

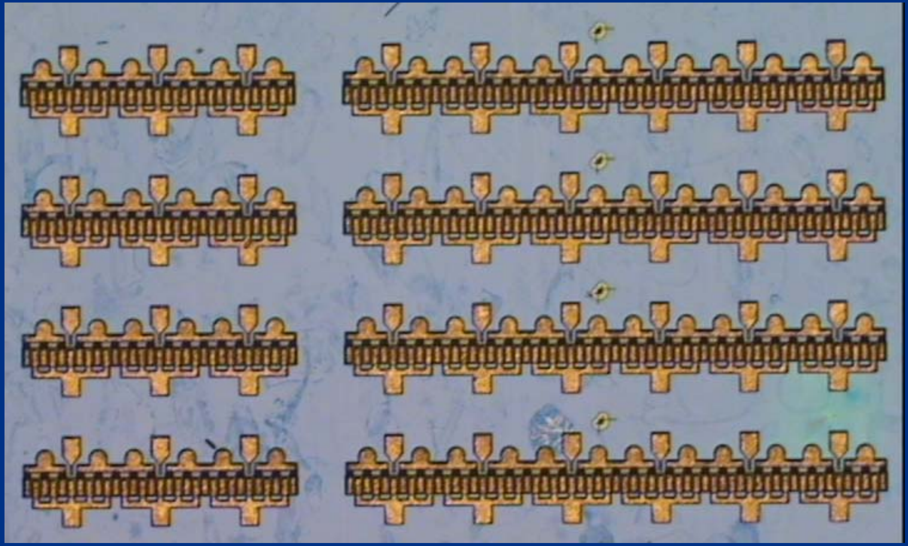
-Linearity	wireless communication
-Ruggedness	radar/space applications (high lifetime)
-Output power	radar systems
-Bandwidth	radar systems and communication

SiC material system more mature than AlGaN/GaN

MESFETs

New generation MESFET double recess, field plate

- 7.8 W/mm @ 3 GHz
- V_{BR} = 200 V
- I_{DSS} > 500 mA/mm
- 70% drain efficiency in class AB operation @ 3 GHz



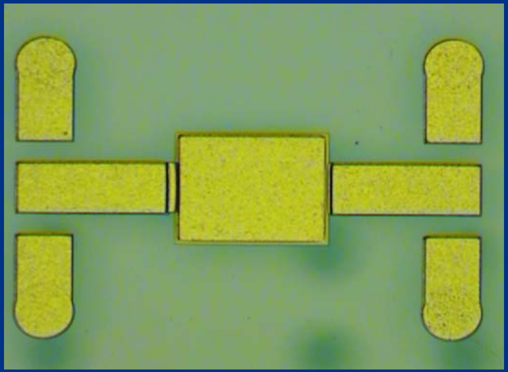
Via-hole grounded 3mm and 6mm SiC MESFETs

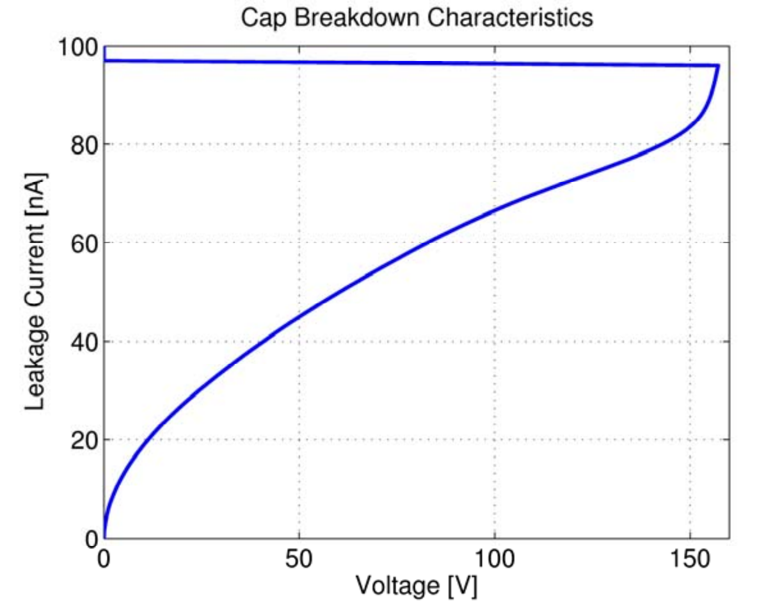
μ-strip MMIC Process Modules

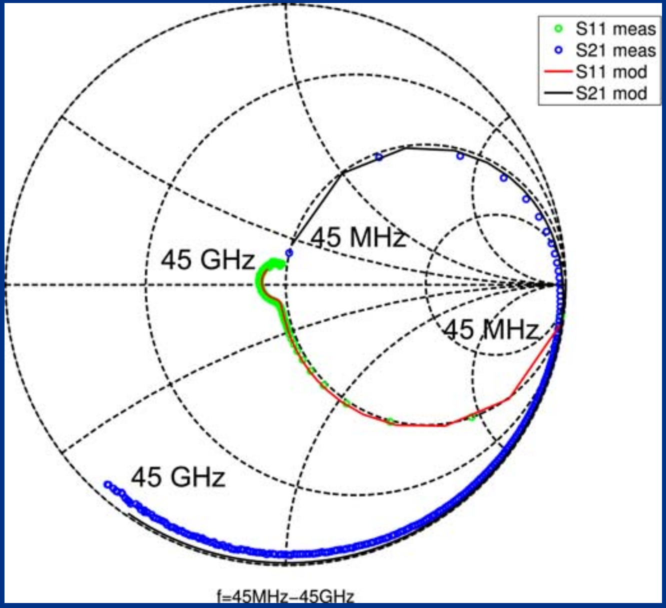
- MESFETs
- MIM Capacitors
- Spiral Inductors
- Thin Film Resistors (TFRs)
- Via-holes

MIM Capacitors

- SiO_2/Si_3N_4 stack
- CPUA = 200 pF/mm^2
- V_{BR} = 150 V

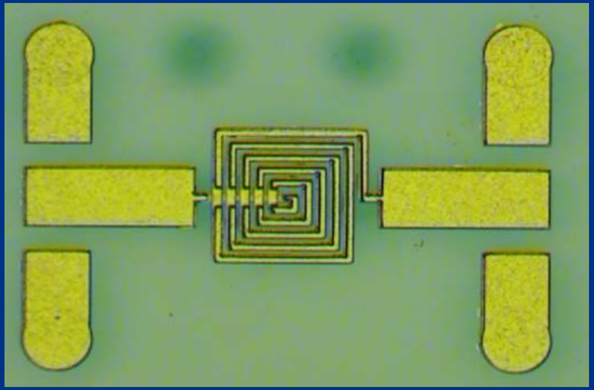


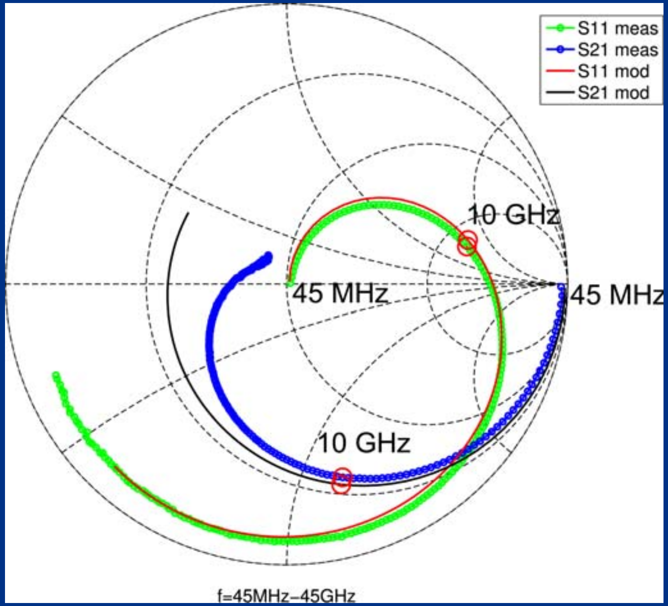




Spiral Inductors

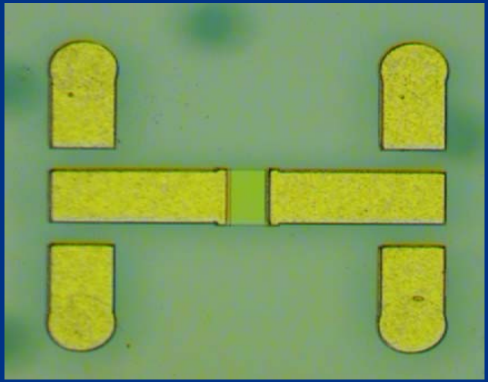
- Air-bridged spiral inductors
- 0.4-3.6 nH
- $I_{MAX} > 1$ A

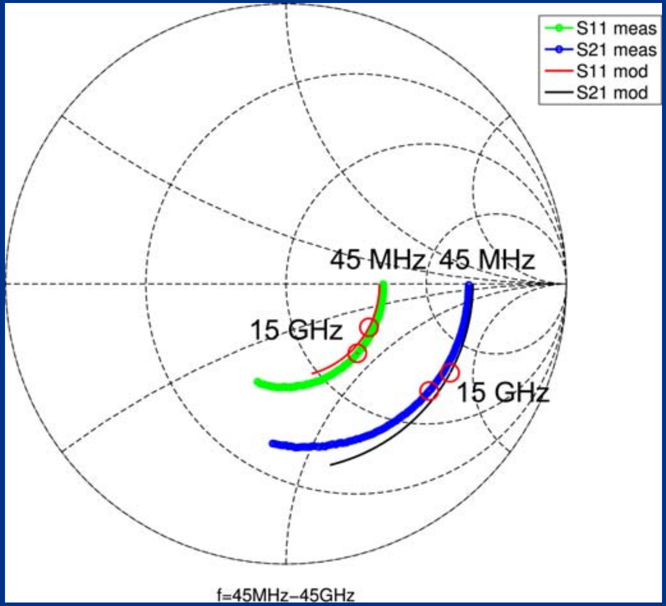




Thin Film Resistors (TFRs)

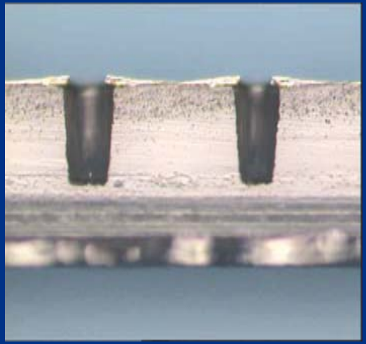
- Reactively sputtered TaN
- Sheet resistivity 45Ω/□



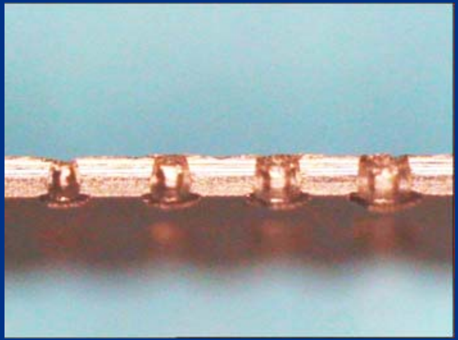


Via-holes

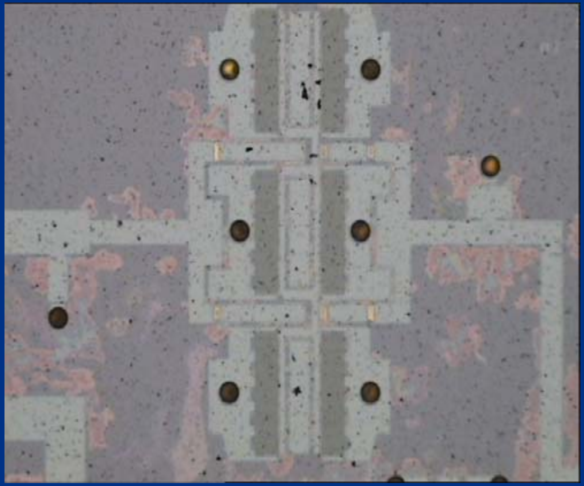
- Lapping
- Flourine based (NF_3) ICP etching
- Excellent geometrical properties
- Front side compatible



A 140 µm deep via-hole



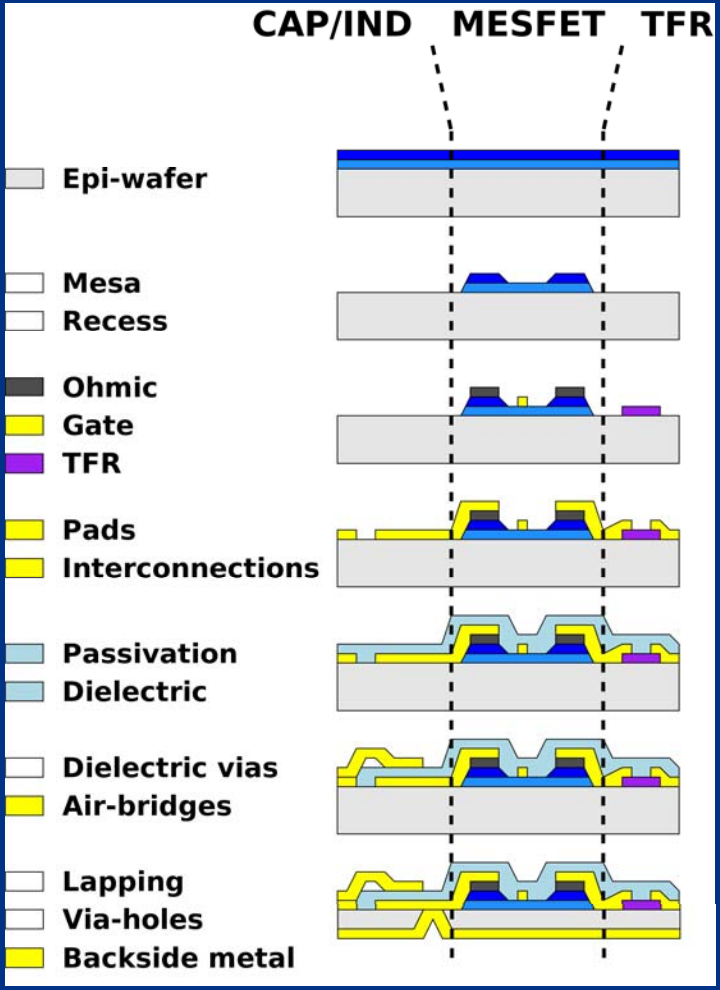
Through wafer via-holes



80 µm diameter through wafer via-holes on an MMIC chip

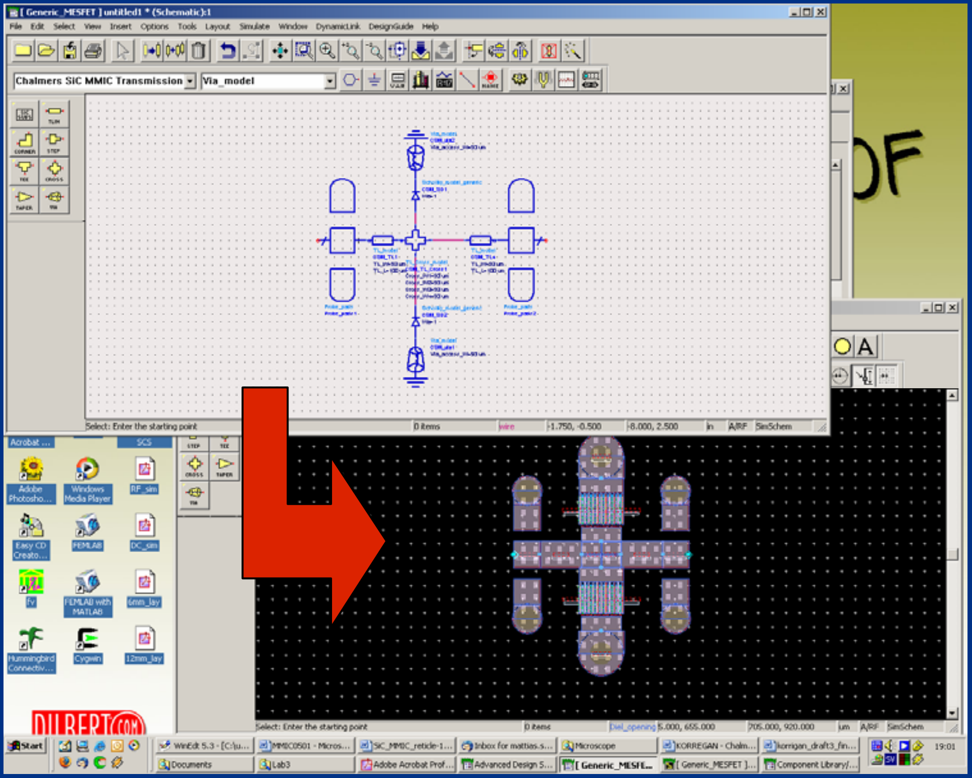
Process Sequence

- 13 mask steps
- Epi-wafer based
  - – no implantation or CVD regrowth
- 3 weeks turnaround time



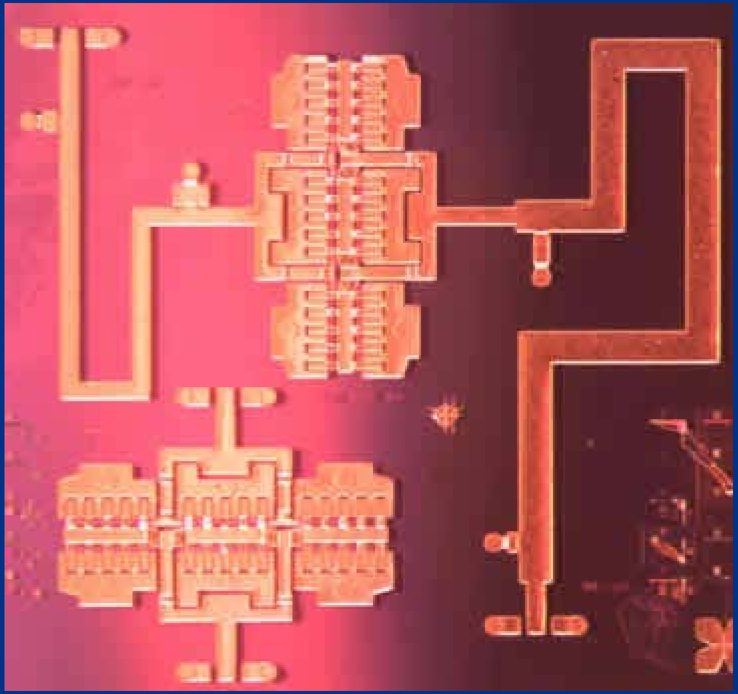
Modeling and Integration

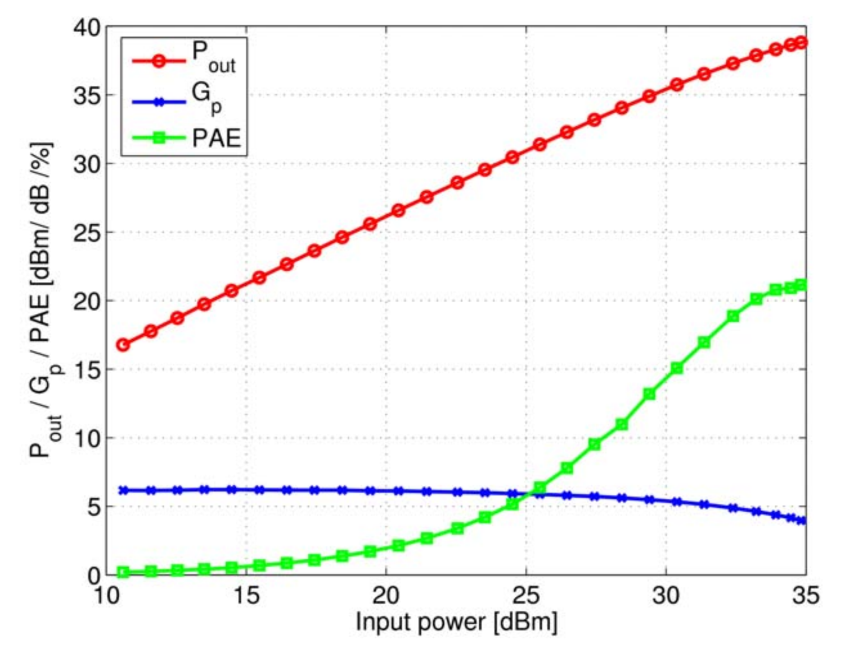
- Built in scaleable models in ADS
- Design kit implemented
- Auto layout
- DRC
- Scalable MESFET model under development



First circuit demonstrators 1/(3)
(using previous generation of MESFET)

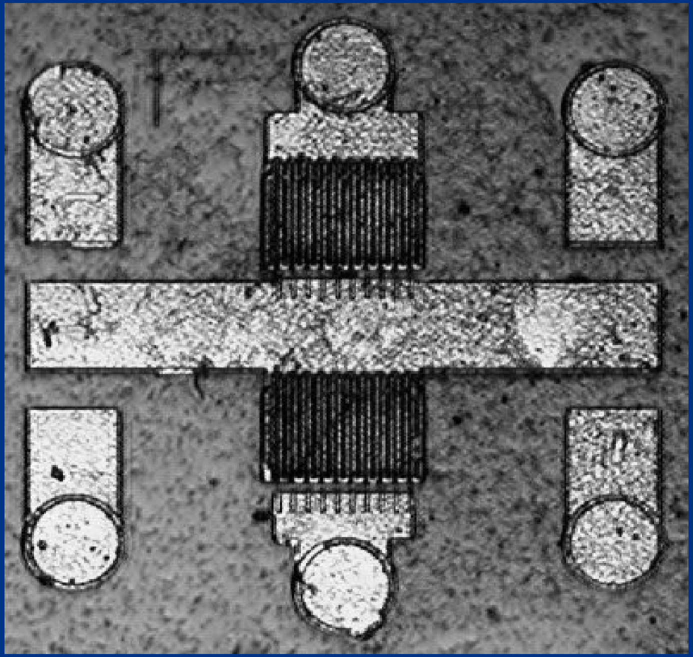
- Simple narrowband S-band power amplifier
  - 8 W (pulsed) @ 3 GHz

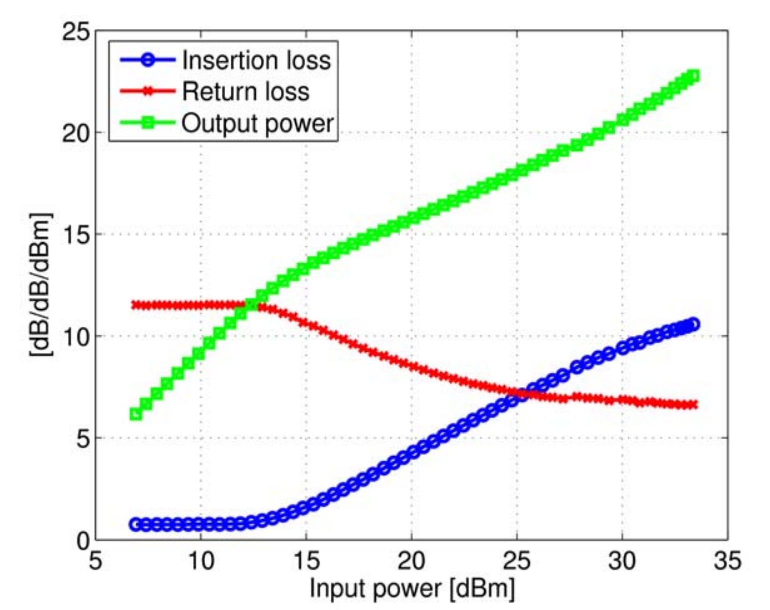




Circuit Demonstrators 2/(3)

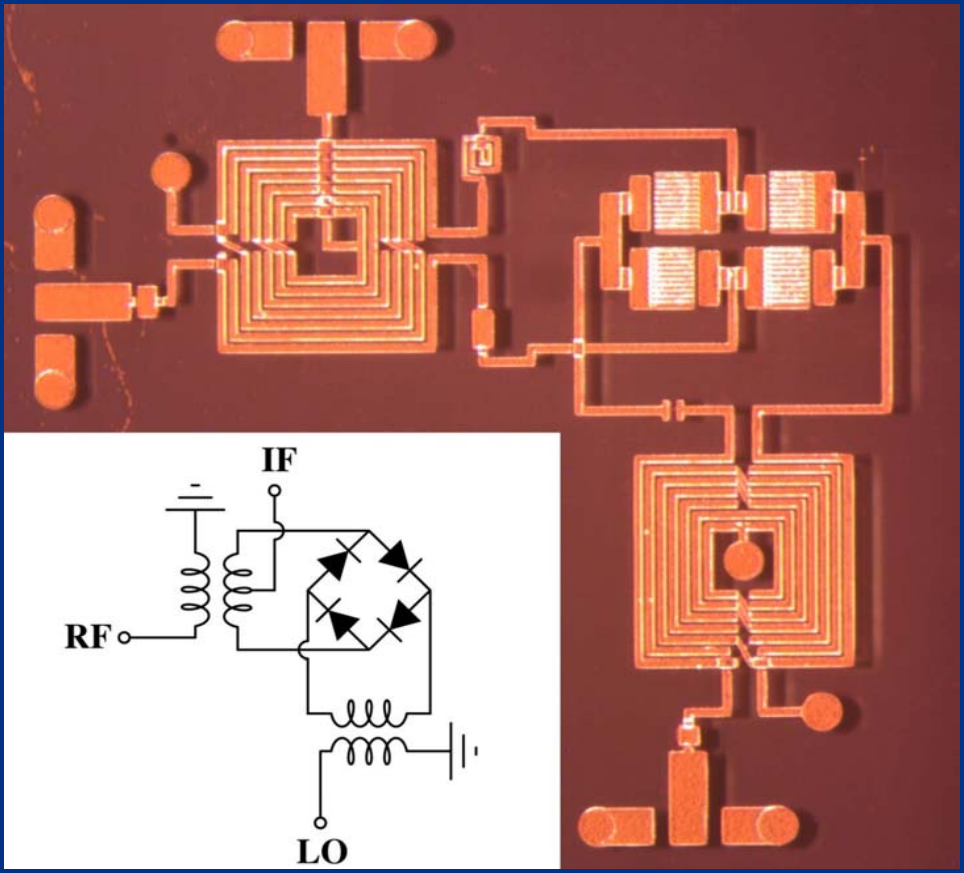
- BtB Schottky diode power limiter for radar receiver protection
  - insertion loss <1 dB @ 3-4 GHz

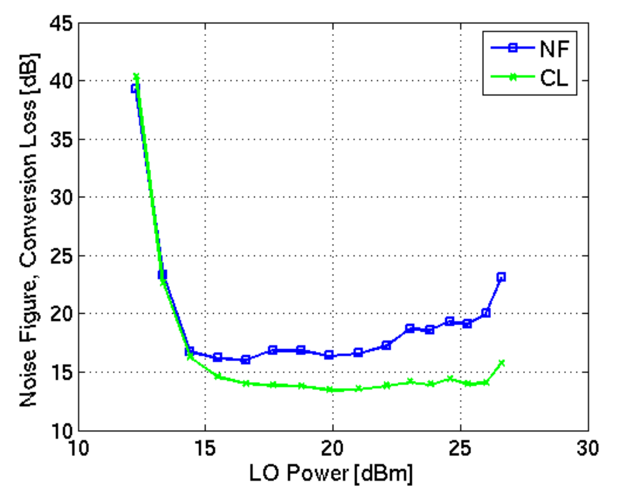


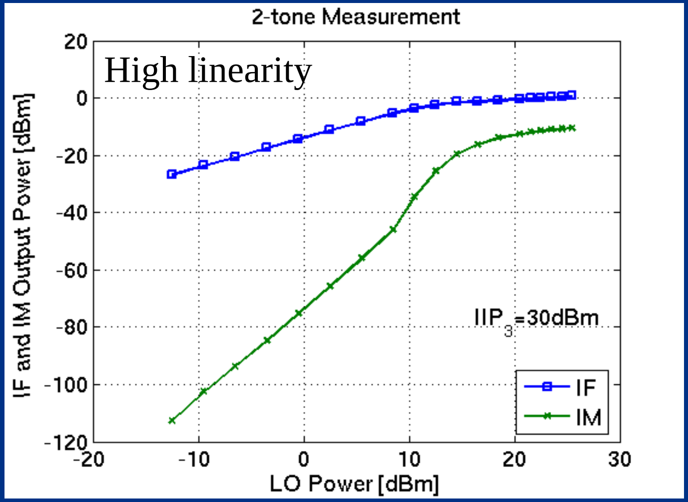


Circuit Demonstrators 3/(3)

Double balanced S-band Schottky mixer







f_{LO}=3GHz, f_{RF}=3,3GHz, f_{IF}=300MHz

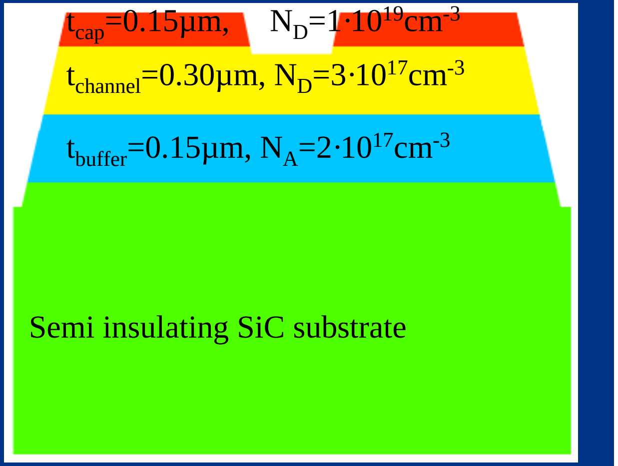
CL_{min}=13dB, NF_{min}=16dB

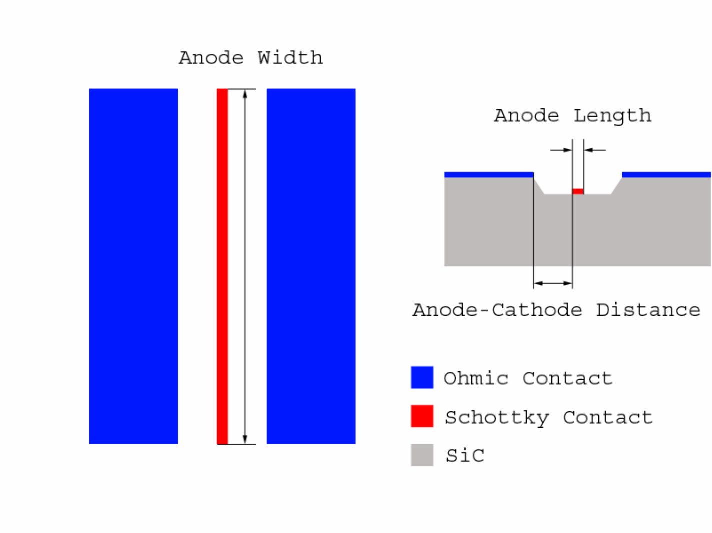
SiC planar Schottky

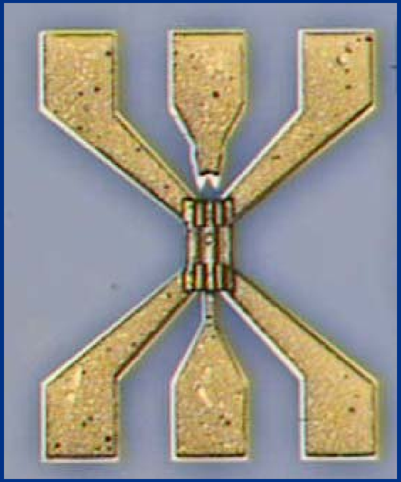
Goal: High f_c at high power.

Compatible with MMIC process.

Planar design:

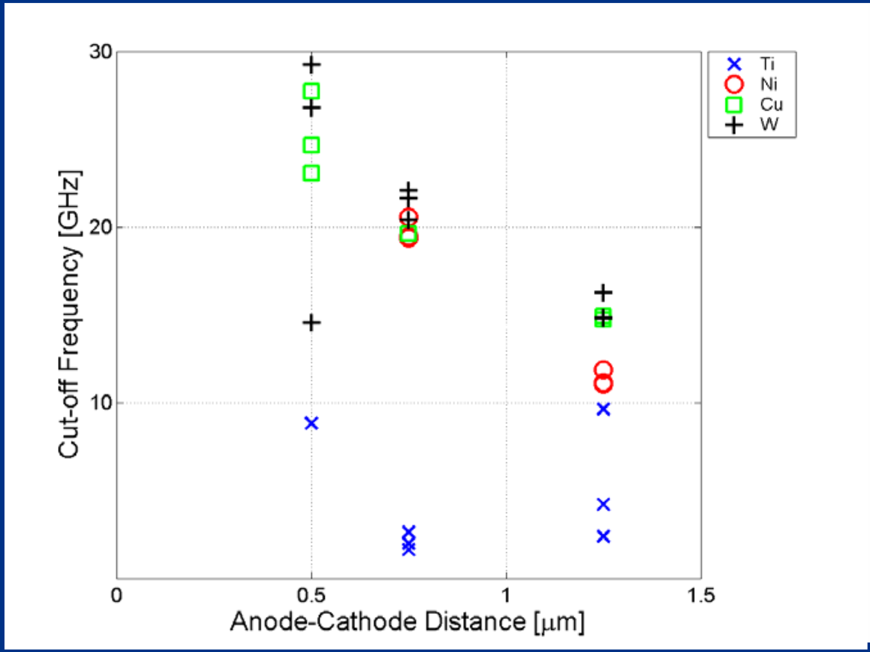


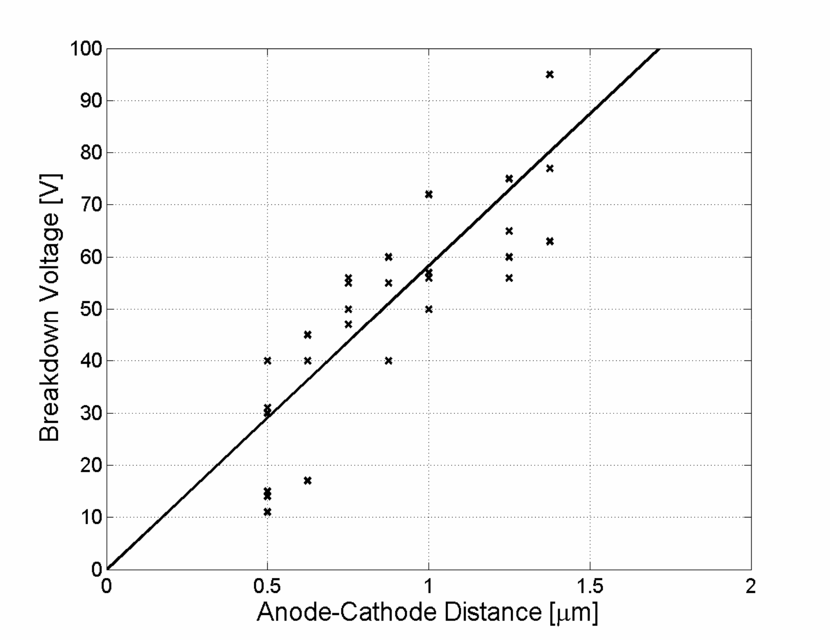




Device Results

Schottky Metal	Ti	Ni	Cu	W
Max Cut-off Frequency, $f_{c,max}$ [GHz]	9,6	20,6	27,7	30,8
Barrier height , φ_B [eV]	1,0	1,4	1,5	1,3
Ideality Factor, η	1,9	1,2	1,7	1,5





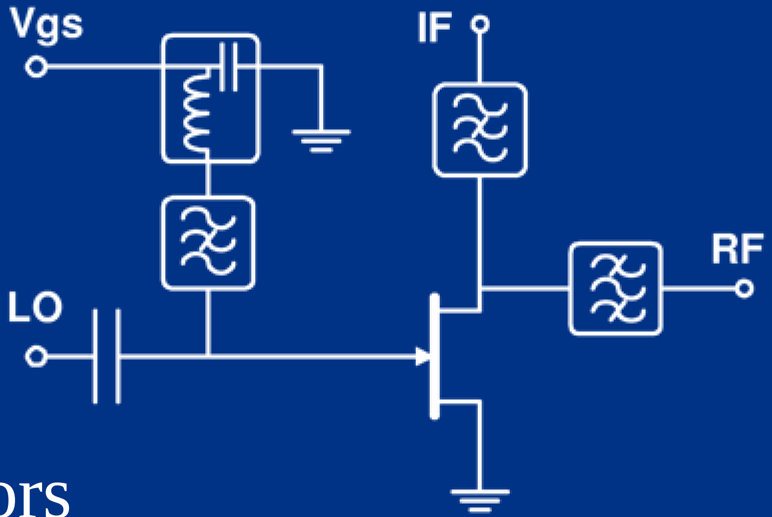
Summary and Conclusions

- Complete SiC MMIC process module library
- High voltage and power compliant passives
- Design kit implemented
- Circuit demonstrators successfully realized

Next:
New generation MESFET, including NL model extraction

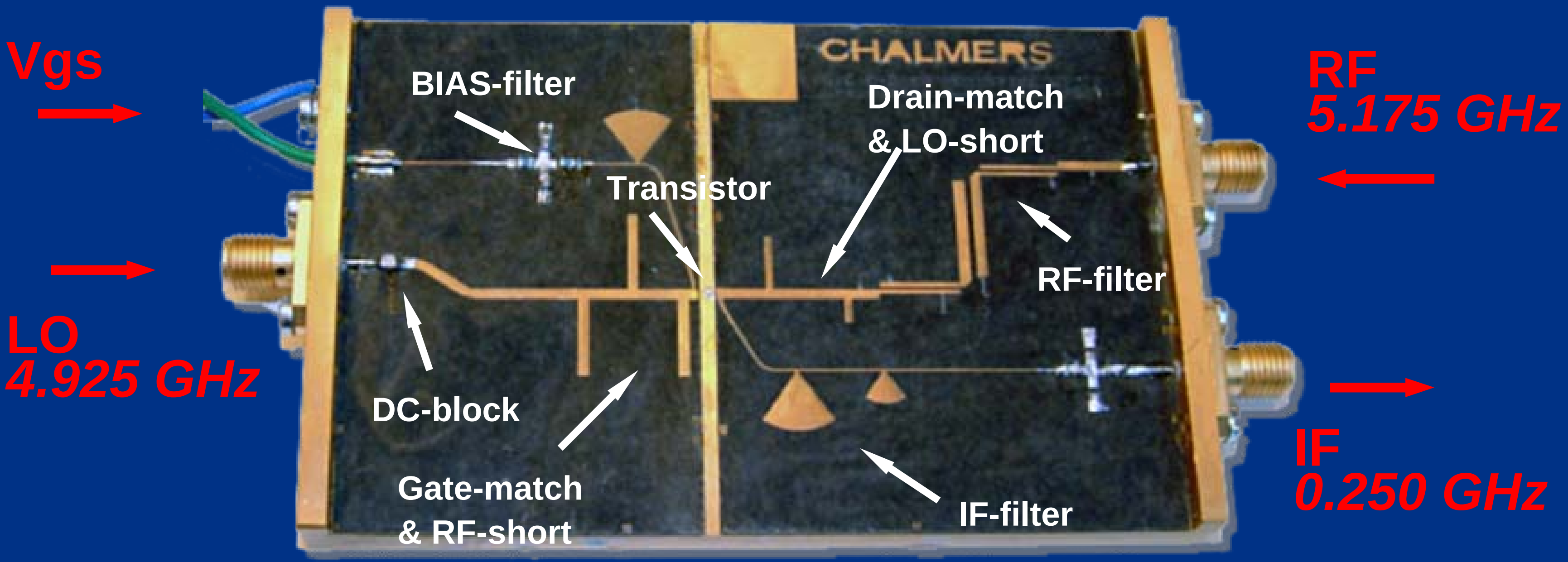
Other circuits : resistive mixer results

Why WBG mixer ?



- High linearity /LO-power
- Highly rugged
- ‘Proof of concept’ demonstrators made at CTH
- PhD student Kristoffer Andersson

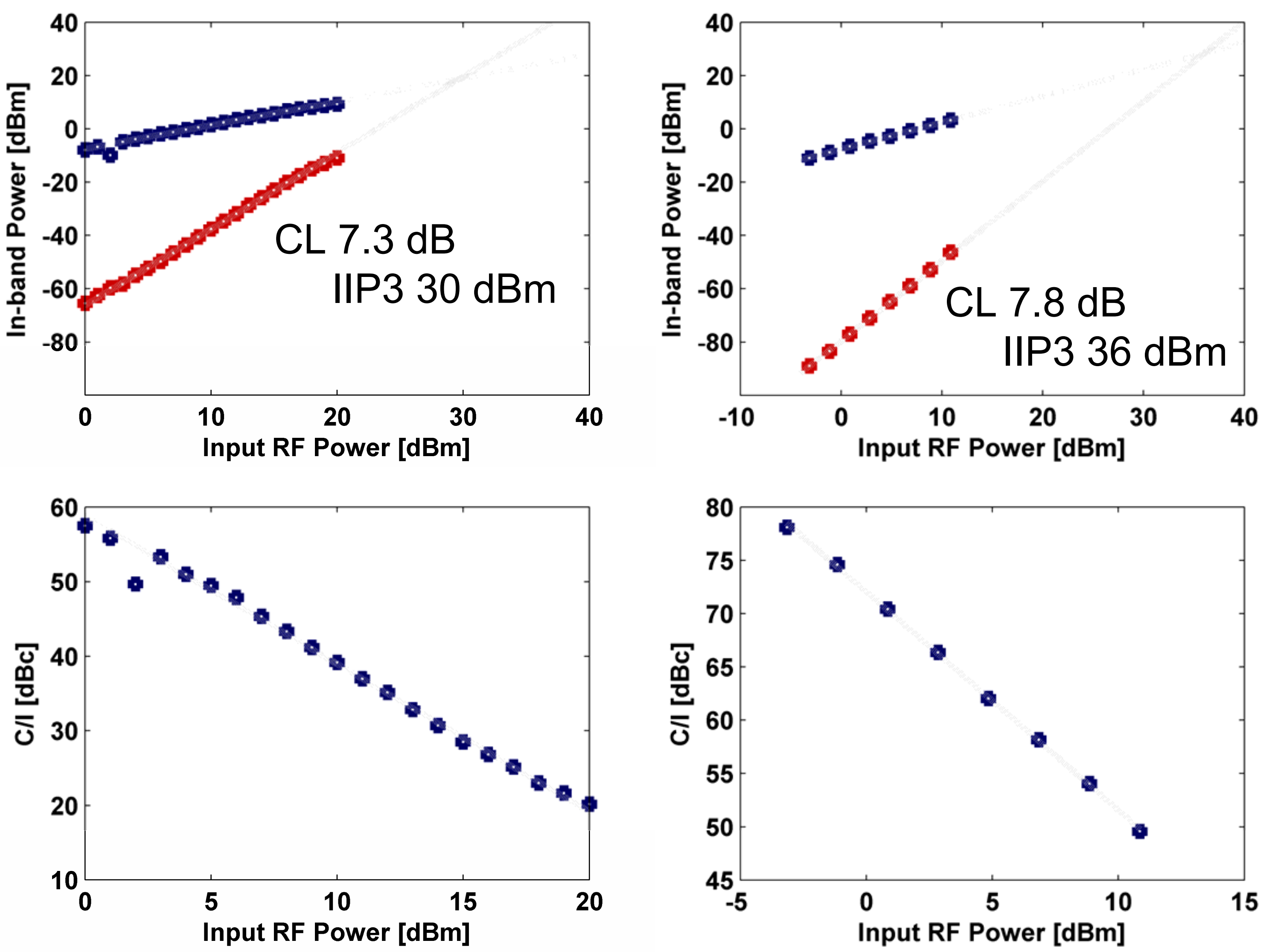
C-Band Resistive Mixer:



- Single-Ended
- Hybrid/Microstrip
- Narrowband

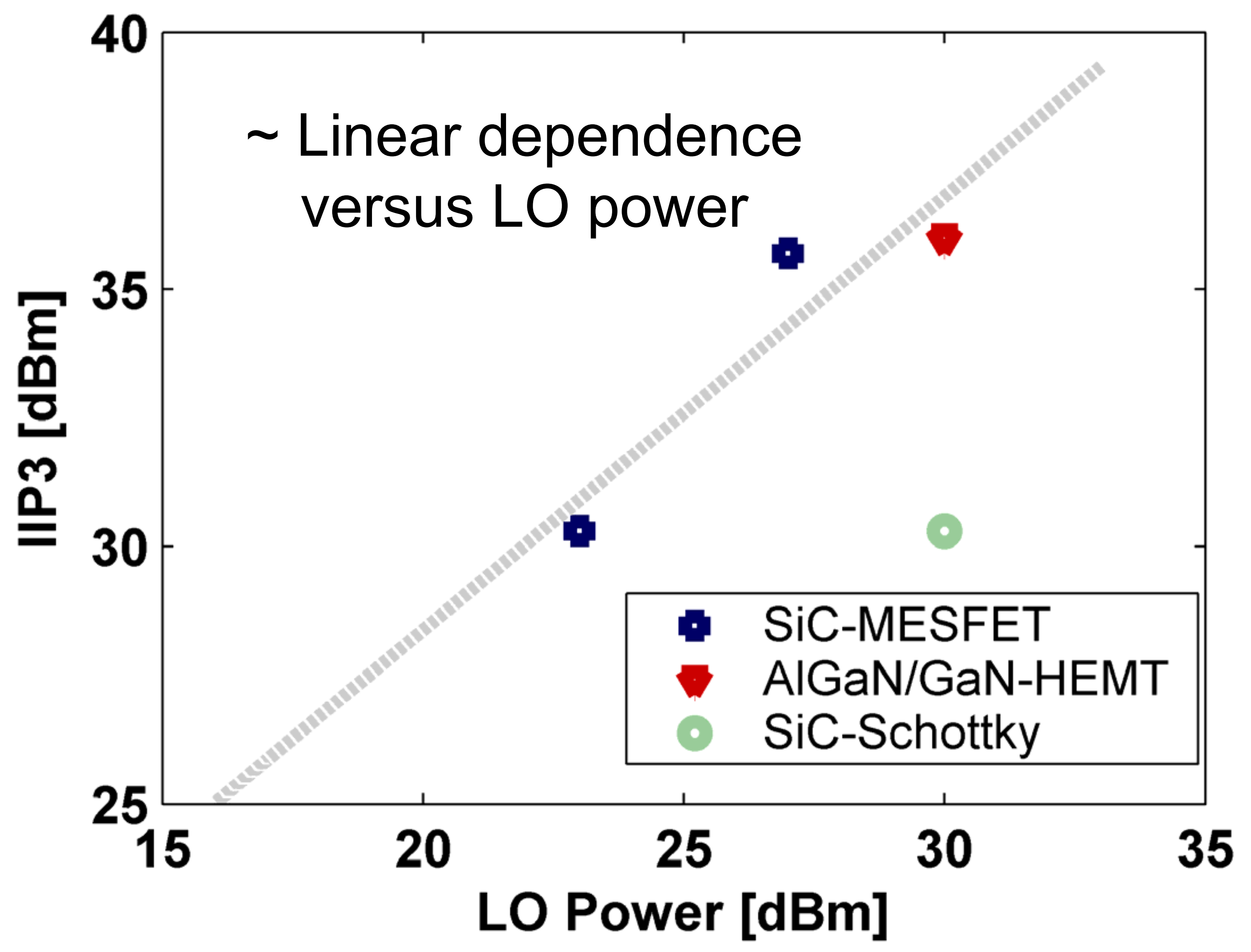
SiC-MESFET @23 dBm LO

AlGaN/GaN-HEMT @ 30 dBm LO



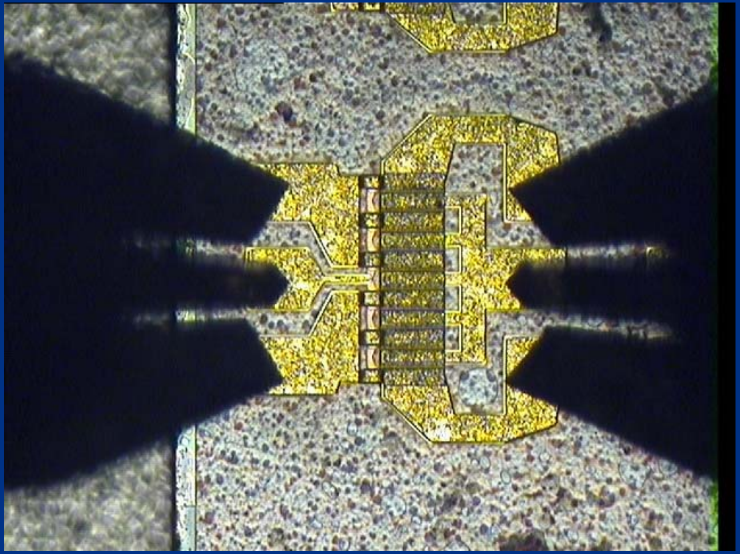
* RF input limited due to instrumentation failure

Chalmers WBG mixers so far:



HEMTs

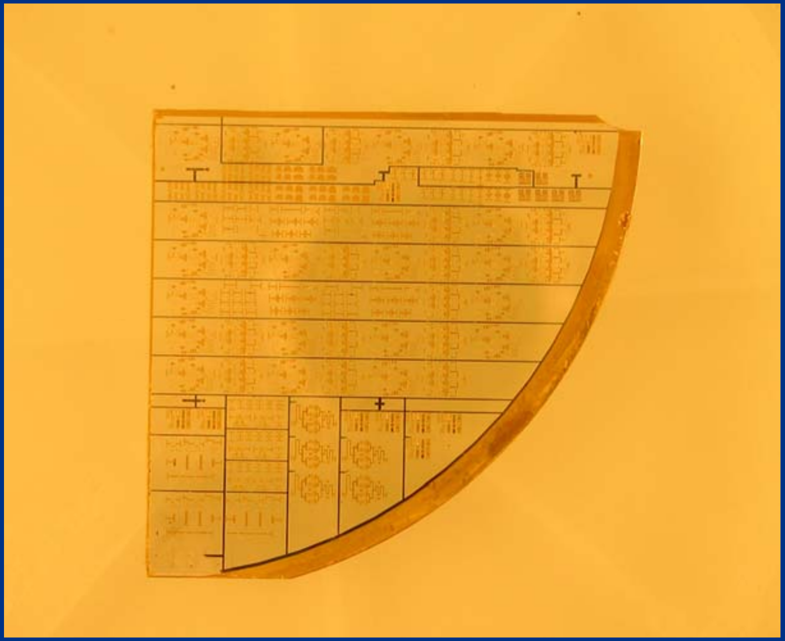
HEMTs w/o field plate



- 9.7 W/mm @ 3 GHz
- I_{DSS} = 1.2 A/mm
- 75% drain efficiency in class C operation @ 3 GHz

AlGaN/GaN MMIC

- Fall 2006
  - KORRIGAN
- Preliminary process run
  - Passive modeling
  - Experimental circuits



Summary

- SiC MESFETS with power densities of 7.8 W/mm @ 3 GHz
- SiC MESFET microstrip MMIC process demonstrated 2005 including three circuit demonstrators
- New circuits based on our high η/P_{dens} MESFET process is under development
- AlGaN-GaN HEMT on SiC process with 9.4 W/mm (without fieldplate) demonstrated
- AlGaN/GaN MMIC demonstrators to come during fall 2006

People

- Kristoffer Andersson, Ph.D. Student
  - Models, Characterization, and Demonstrator Circuits
- Fredrik Allerstam, Ph.D. Student
  - SiC MOSFET processing
  - SiC oxide growth
- Guðjón Guðjónsson, Ph.D. Student
  - SiC MOSFET processing
- Martin Fagerlind, Student
  - GaN MMIC processing
- Mattias Südow, Ph.D. Student
  - SiC and GaN MMIC
  - SiC Schottky Diodes
- Hans Hjelmgren, Ph.D.
  - Simulations
- Per-Åke Nilsson, Ph.D.
  - Process line responsible
  - processing of SiC MESFET, MOSFET
- Niklas Rorsman, Ph.D.
  - Project leader (SiC MESFET/GaN HEMT), processing and characterization
- Einar Ö. Sveinbjörnsson , Ph.D
  - Project leader SiC MOSFET
- Herbert Zirath, Professor
  - Group leader

Pulsed Load-pull device evaluation

- Load and source tuners, 0.8 – 18 GHz, 8-50, V and W band
- Pulsed VNA, 0.5-20 GHz
- Pulsed power meter
- Pulsed IV, 100 V 4 A
- 400 W bias supply
- P_{IN} = 30 dBm, 2-8 GHz