PIONEERING WITH PASSION

GREAT² - Radiation Assessment on DC and RF operated AlGaN/GaN-HEMTs

M. Rostewitz, K. Hirche J. Lätti

2013 ESTEC Radiation Workshop

Outline

- Project Objectives
- Device Overview
- GaN Radiation Test Structure (RTS)
  - Gamma Irradiation
  - Proton Irradiation
  - Heavy Ion Irradiation
- Packaged UMS GH50 L-band RF power cell
  - SEB voltage determination
  - RF driven heavy ion testing
- Packaged UMS GH25 X-band MMIC
  - RF driven heavy ion testing
  - DC operated SEE test
- Summary

ESTEC contract. no. 21.499/08/NL/PA

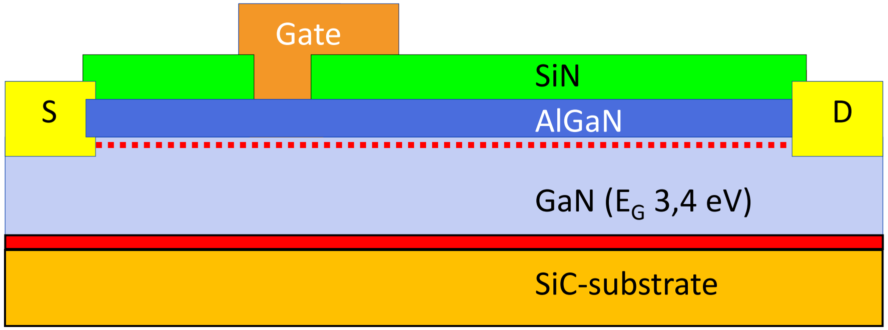
ESA – GREAT^2

GaN Reliability Enhancement And Technology Transfer

University of Rome Tor Vergata

- Establishment of space compatible GaN HEMT and GaN MMIC foundry processes
  - UMS GH50, GaN HEMT process
    - useable up to 6 GHz (L-, S- and C-band)
  - UMS GH25, GaN MMIC process
    - useable up to 20 GHz (X- and Ku-band)
- Duration: 06/2008 – 07/2013
- Space evaluation of processes planned as follow on activity

Irradiated GaN Devices

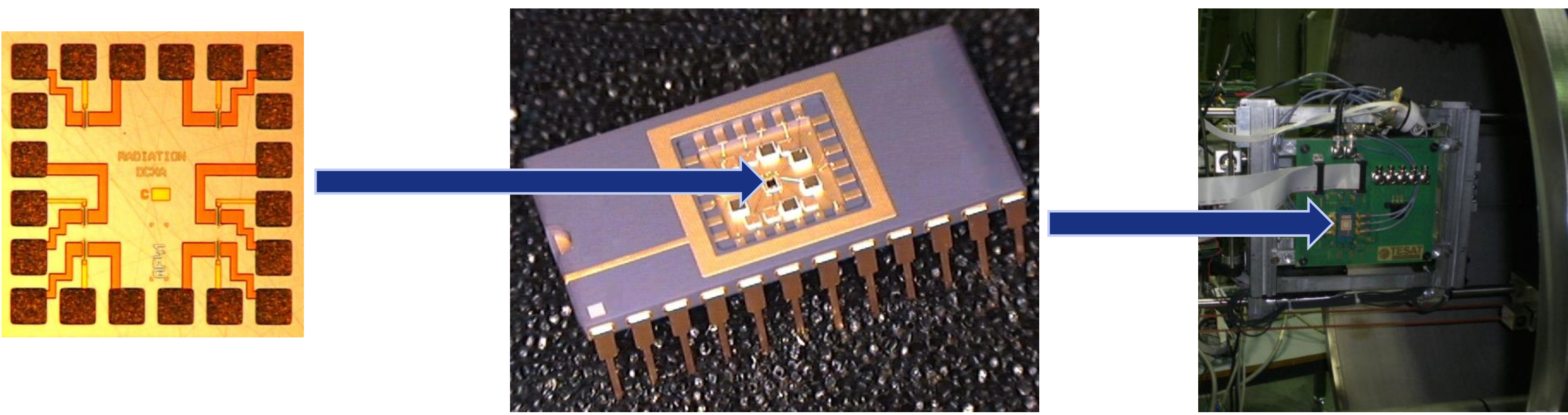


AlGaN/GaN-Field Effect Transistor (GaN-HEMT)

- Radiation Test Structures (RTS)
  - Single gate finger, 50 µm gate width
    - GH25, 250 nm gate length
    - GH50, 500 nm gate length
  - Enabling to detect even small current drifts
- Power cell GaN-HEMT and GaN-MMIC in RF package, respectively
  - Multiple gate fingers
    - GH25, 3.4 mm gate width
    - GH50, 2.4 mm gate width
  - Enabling irradiation both under DC and RF operation

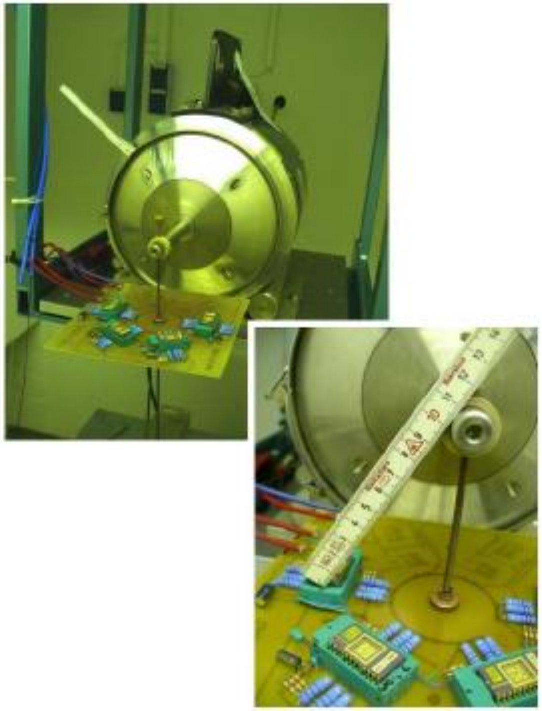
Radiation Test Structure (RTS)

- 6 AlGaN/GaN HEMTs on a chip (UMS GH50 and GH25 process)
  - In total 128 DC packages assembled and tested within GREAT²
- Typical GH50 breakdown voltage: $V_{DS,BD}$ = 195 V (std. dev. 6.9 V)
- Typical GH25 breakdown voltage: $V_{DS,BD}$ = 135 V (std. dev. 5.4 V)



Gamma Irradiation - RTS

- Ionization sensitivity
  - Total Dose: 1000 krad
  - Dose-rate of 36 kRad(Air)/hr
  - $V_{DS} = 50$ V
  - Biased at pinch-off condition
  - Limit: ΔIdss, Δgm,max and ΔV_T < **15** %
  - Result: ΔIdss, Δgm,max and ΔV_T < **9** %

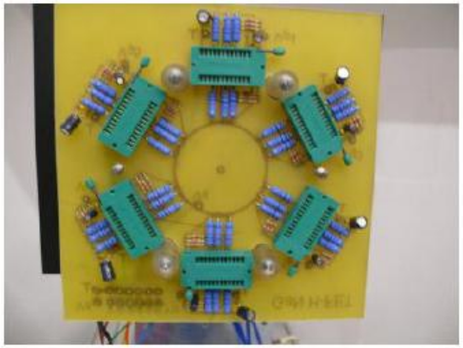


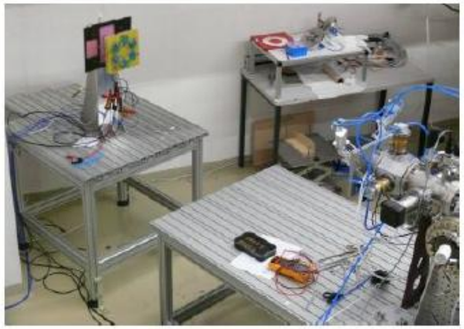
- Ionization irradiation insensitive process
  - GH50-10
  - GH25-10 itn2

Proton Irradiation - RTS

- Displacement damage sensitivity
  - Proton energy 35 MeV
  - Flux: ~2 x 10^9 p cm^{-2} s^{-1}
  - Fluence up to 1.5 x 10^{12} p cm^{-2}
  - V_{DS} = 50 V
  - Biased at pinch-off condition

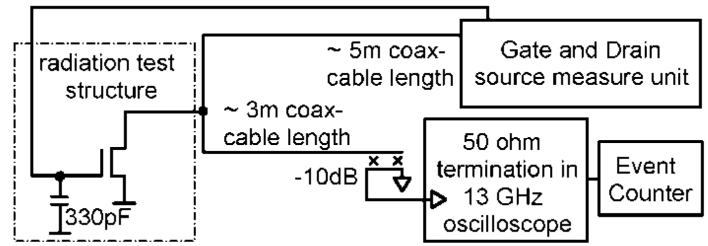
  - Limit: ΔIdss, Δgm,max and ΔV_T < **15 %**
  - Result: ΔIdss, Δgm,max and ΔV_T < **7 %**



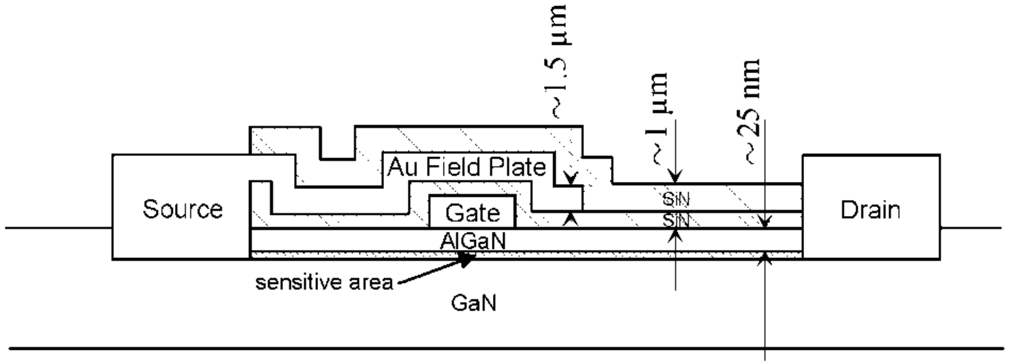


- Displacement damage insensitive process
  - GH50-10
  - GH25-10 itn2

Heavy Ion Irradiation - RTS

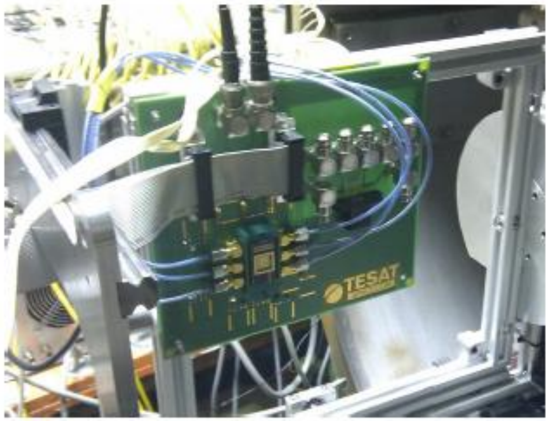


- SEB voltage determination
  - LET(Xe-ion in GaN) = 52 MeV mg^{-1} cm^{-2}
  - Fluence: 5 x 10^6 ions cm^{-2}
  - Flux: 15,000 ions s^{-1} cm^{-2}
  - Range ~ 20 µm
  - Biased at pinch-off condition

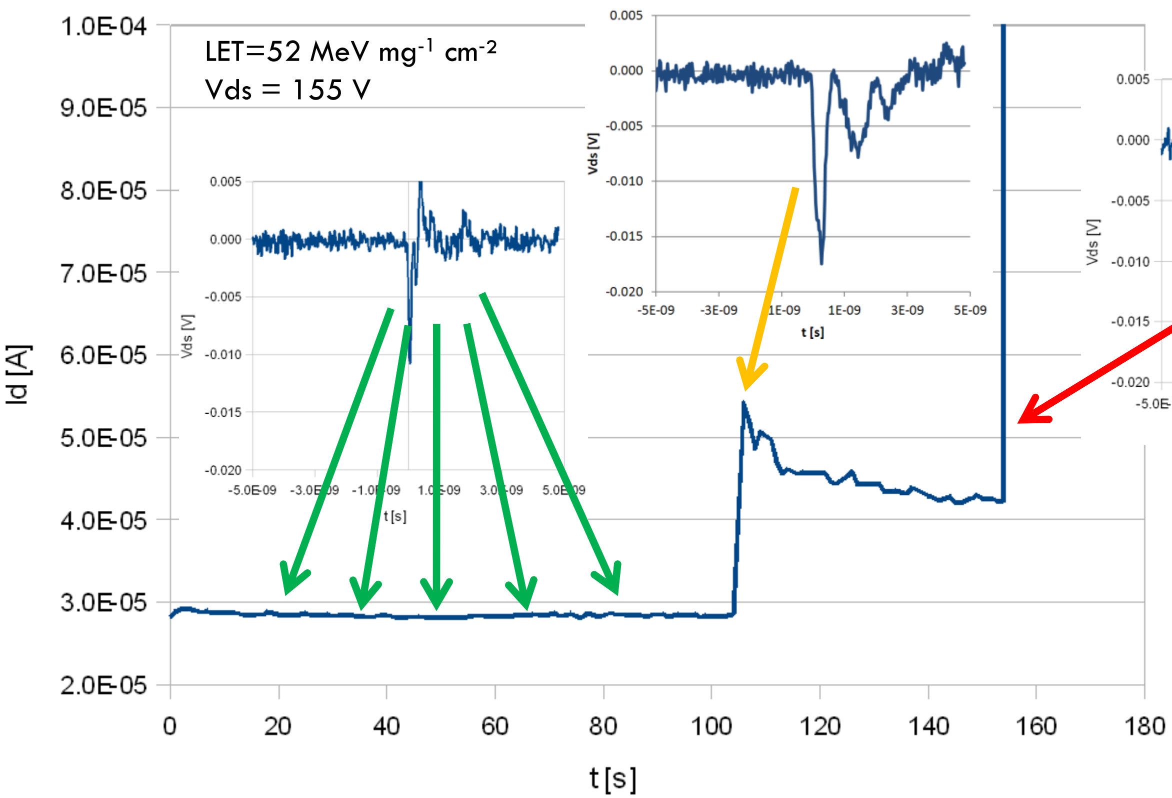


- L-band GH50-10 RTS
  - Devices withstood a drain voltage level of 150 V
  - SEB voltage at 155 V and higher ($V_{DS,BD}$ = 195 V)

- X-band GH25-10 itn2 RTS
  - Devices withstood a drain voltage level of 110 V
  - SEB voltage at 115 V and higher ($V_{DS,BD}$ = 135 V)

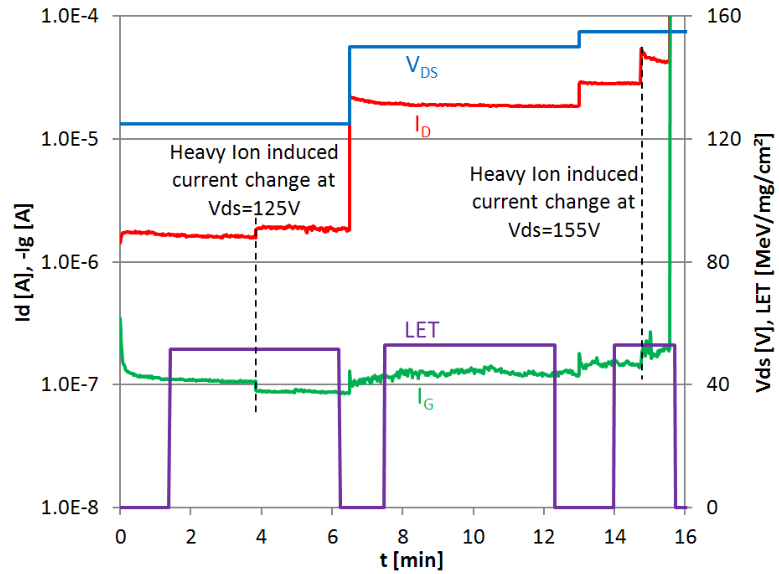


Observations during RTS SEE campaign



- Drain current increase and SEB caused by enhanced Single Event Transients (SETs) at Vds = 155 V
  - decay time >> 150 ps

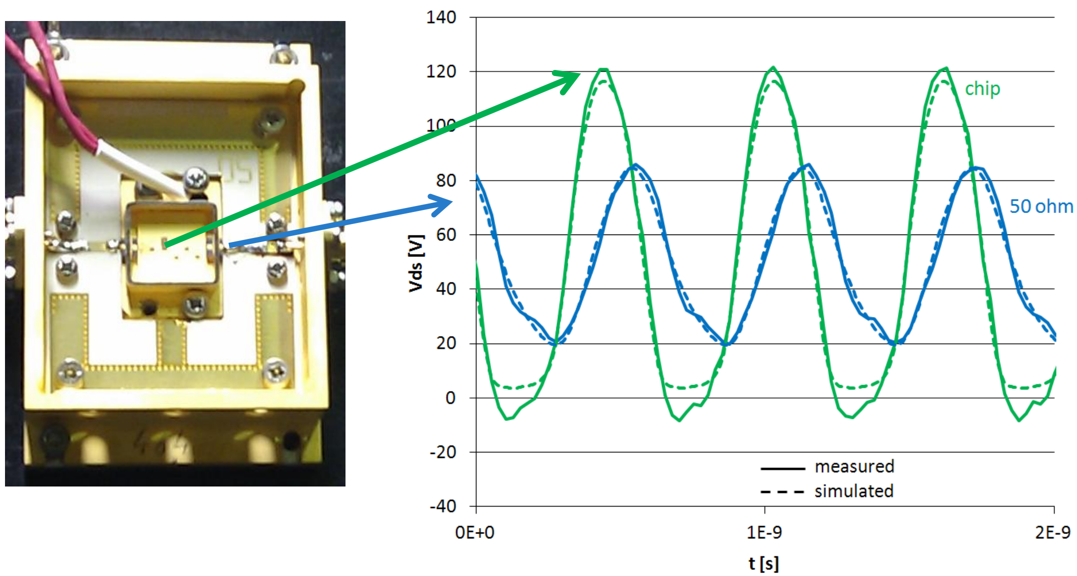
Observations during RTS SEE campaign



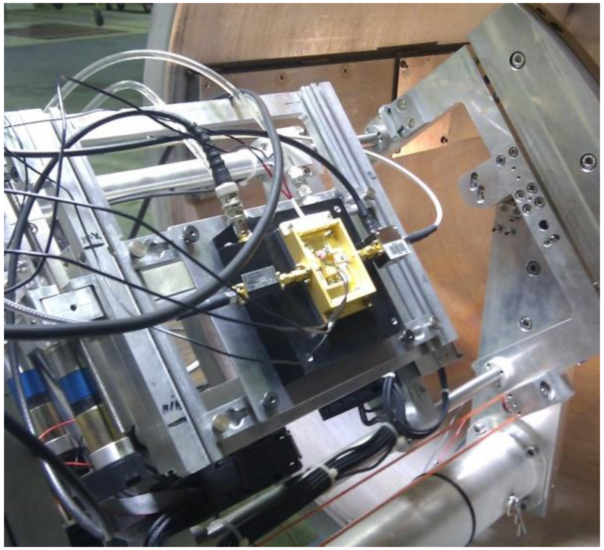
- Voltage levels below Vds= 140 V
  - Id increase, Ig decrease => channel or buffer region leakage path
- Voltage levels above Vds= 140 V
  - Id increase, Ig increase => gate-drain diode leakage path

Packaged L-band GH50 RF Power Cell

- Breakdown voltage: $V_{DS,BD}$ = 170 V and higher
- V_{DS} = 50 V: Pout ~ 40.3 dBm @ 1.7 GHz
  - Results in a measured and simulated peak voltage of 120 V



SEB voltage determination – L-band RF power cell



- Biased at pinch-off condition
- Fluence: 5×10^6 ions cm^{-2}
- Flux: 5,000 ions s^{-1} cm^{-2}
- LET(Xe-ion in GaN) = 53 MeV mg^{-1} cm^{-2}
  - SEB voltage of 125 V in 1st GH50 test campaign for one device; three devices passed V_{DS} = 125 V
  - SEB voltage in latest test campaign reduced to ~ 120 V
    - 125, 125, 120 and 110 V

GH50 RF power cell and RTS SET Cross Section

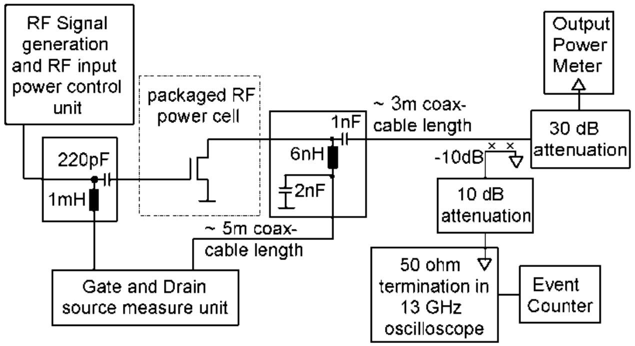
- Extracted SET cross section is larger than expected SET cross section
  - not restricted to area between gate and drain
- Observation: Current changes and SEB´s are caused by enhanced transients
- 15 % of the extracted cross section can be assigned to a critical area
  - assumption: related close to gate (gate-drain diode?)

15 %

	Cross section		
Test device	geometrical	extracted	enhanced
RTS	3.0E-6 cm^2	7.8 E-6 cm^2	1.2 E-6 cm^2
RF power cell	1.4E-4 cm^2	2.2 E-4 cm^2	3.4 E-5 cm^2

15 %

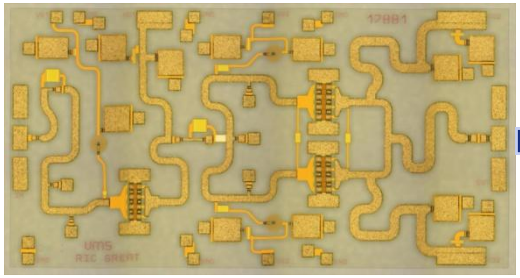
SEE Test on RF driven GH50 L-band RF power cells



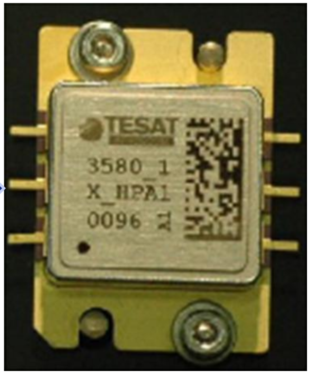
- Fluence: 5 x 10^5 ions cm^{-2}
- Flux: 5,000 ions s^{-1} cm^{-2}
- No device failure in 1st test campaign
  - LET(Xe-ion in GaN) = 53 MeV mg^{-1} cm^{-2}
    - 3 devices tested at Vds = 50 V, > 40. 3 dBm CW RF output power, > 7 dB compression
    - 3 devices tested at Vds = 60 V, > 41. 5 dBm CW RF output power, > 7.4 dB compression
  - LET(Xe-ion in GaN) = 69 MeV mg^{-1} cm^{-2}
    - 1 device tested at Vds = 50 V, > 40. 3 dBm RF output power, > 7 dB compression
      - CW
      - QPSK modulated

Packaged RF X-band GH25 MMIC

- Breakdown voltage: $V_{DS,BD}$ = 75 V and higher
- V_{DS} = 30 V
- P_{out} ~ 39.5 dBm @ 8.5 GHz

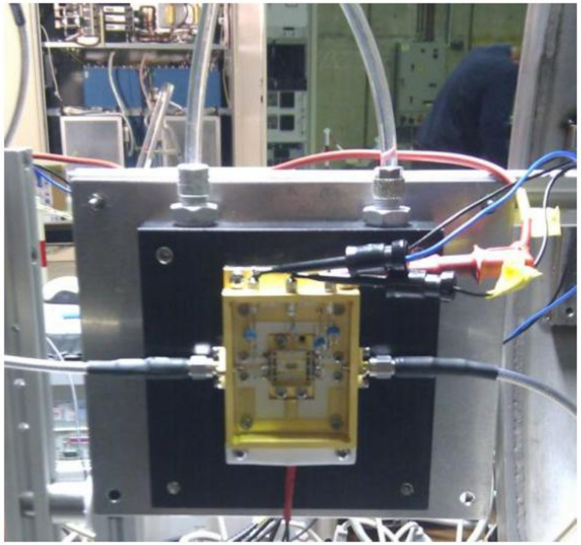


UMS GH25 8 W GaN X-Band MMIC, 4.1 x 2.2 mm²

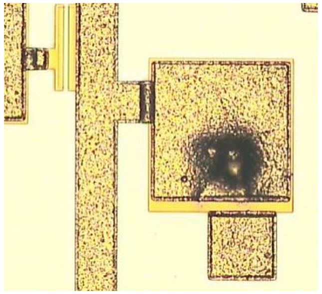


SEE Test on RF driven X-band GH25 RIC´s

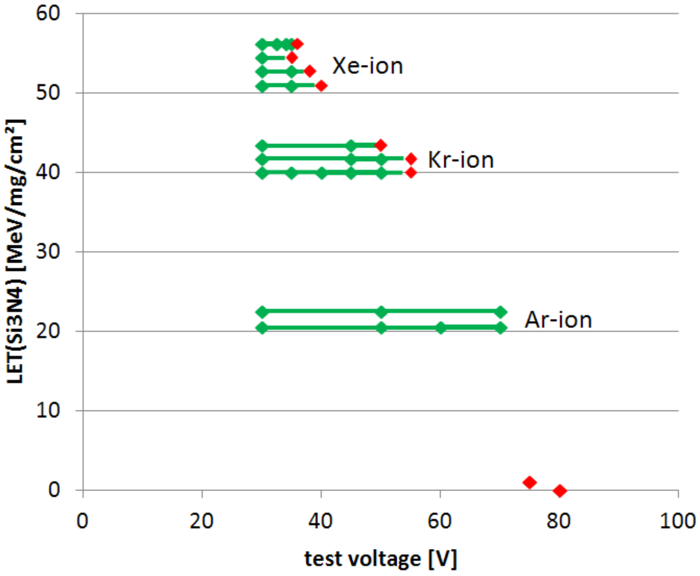
- Fluence: 5×10^{5} ions cm^{-2}
- Flux: 5,000 ions s^{-1} cm^{-2}
- **No device failure occurred**
  - LET(Xe-ion in GaN) = 53 MeV mg^{-1} cm^{-2}
    - 4 devices tested at Vds = 30 V, > 39 dBm CW RF output power, > 5 dB compression
      - CW
      - QPSK modulated



SEE Test on DC operated X-band GH25 MMIC´s



- LET(GaN) = 12 to 53 MeV mg^{-1} cm^{-2}
- Fluence: 5 x 10^5 ions cm^{-2}
- Flux: 5,000 ions s^{-1} cm^{-2}
- Breakdown on several MIM capacitors observed
  - LET(Ar in Si_3N_4) = 21 MeV mg^{-1} cm^{-2}
    - no failure
  - LET(Kr in Si_3N_4) = 42 MeV mg^{-1} cm^{-2}
    - MIM capacitor breakdown at ~ **50 V**
  - LET(Xe in Si_3N_4) = 53 MeV mg^{-1} cm^{-2}
    - MIM capacitor breakdown at ~ **35 V**
- **Nominal operation at V_{DS} = 30 V**



Summary

- Total dose and displacement damage irradiation insensitivity confirmed
- Heavy ion irradiation insensitivity confirmed
  - DC operation and RF driven RIC´s and power cells
  - Peak voltage of RF driven power cell is slightly higher than the DC test voltage where the first SEB occurred

...but...

- Strongly reduced MIM capacitor breakdown voltage under heavy ion irradiation observed => analysis ongoing, improvement necessary to fully exploit GaN potential

Acknowledgement

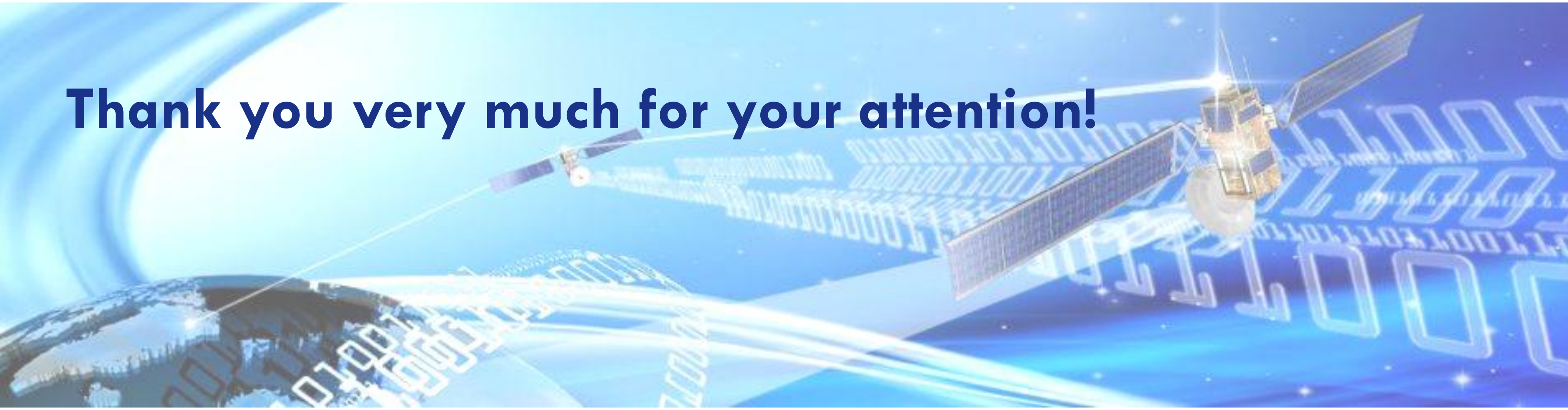
GREAT^2:

ESA/ESTEC Contract No. 21.499/08/NL/PA

Financial support from TRP and

GSTP by DLR and BELSPO is greatly acknowledged

Thank you very much for your attention!



For further information please contact:

Mirko Rostewitz

Tesat-Spacecom GmbH Co. KG
Gerberstraße 49
71522 Backnang

mirko.rostewitz@tesat.de

Rostewitz, M. ; Hirche, K. ; Lätti, J. ; Jutzi, E., „Single Event Effect Analysis on DC and RF Operated AlGaN/GaN HEMTs“, IEEE Trans. Nucl. Sci, DOI:10.1109/TNS.2013.2247774