SEE testing on GaAs test vehicles. Methodology, Results and Derating Lessons Learned

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ABSTRACT

- Radiation sensitivity of GaAs components is not so well known as compared to other technologies (Si, SiGe).
- Traditional radiation harness policy consisted in a good dating in DC bias conditions to ensure operation inside a known or expected DC safe operating area (SOA).
- However destructive single event effects (SEE) have been seen on some MESFET devices under nominal DC bias and RF signal and conditions which were compliant with standard dating requirements. Results indicate that radiation susceptibility depends on DC biasing conditions but increases with the level of RF applied to the device
- However analysis of the different manufacturer data sheets and design rule manuals shows that only DC absolute maximum rating are provided. Also all derating rules are given on DC ratings only (ECSS-Q-ST-30-11; JPL D-8545; MIL-HDBK-1547A etc.)

- **Are radiation tests under DC sufficient ? and if RF, what RF signals?,**
- **Do we need to test other technologies than power MESFET like HEMT, pHEMT?,**
- **Do we need to test per device, per lot, per function, per technology process ?**
- **What Test vehicle (TCV, DEC, MMIC) ?**
- **Have we to modify dating rules?.**

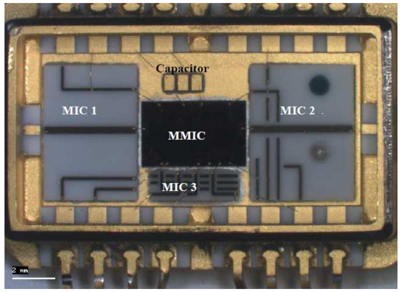
SELECTION OF EUROPEAN

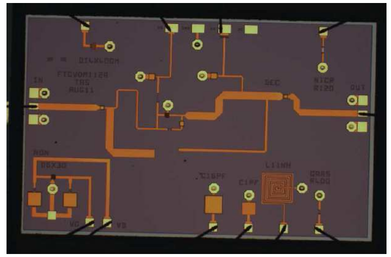
- **Under an ESA contract, TAS selected several European technologies (OMMIC D01PH pHEMT; OMMIC ED02AH pHEMT; UMS PPH25X pHEMT; UMS HP07 MESFET) and non-European ones (MITSUBISHI High Power MESFET; Sumitomo “7” Series MESFET, Sumitomo Low Noise pHEMT) to test under DC and DC+RF signals trying to achieve worst case conditions.**

Process (FOUNDRY)	ED02AH (OMMIC)	High Power GaAs MGFC (MITSUBISHI)	High Power GaAs "7" Series FL707 (SUMITOMO)	pHEMT (SUMITOMO)	HP07 (UMS)	D01PH (OMMIC)	PPH25X (UMS)
Active device	pHEMT	MESFET	MESFET	pHEMT	MESFET	pHEMT	pHEMT
Type	Low Noise	Power	Power	Low Noise	Power	Power	Power
Power density		300 mW/mm	280 mW/mm	280 mW/mm	500 mW/mm	600 mW/mm	900 mW/mm
Gate length Emitter width	0.18-0.15 µm	0.6 µm	0.6 µm	0.25 µm	0.7 µm	0.13 µm	0.25 µm
I_{DS} (gm max) or I_c HBT		40 mA/mm	170 mA/mm	140 mA/mm	300 mA/mm	400 mA/mm	170 mA/mm
Idss		160 mA/mm	170 mA/mm	140 mA/mm		360 mA/mm	450 mA/mm
BV_{DS} / BV_{CE}	5 V	12,5 V	25 V	4 V	> 14 V	> 9V	> 18V
Cut off freq.	63-73 GHz		15 GHz	31 GHz	15 GHz	100 GHz	45 GHz
V pinch	+0.2 / -0.9 V	-3 V	-2,3 V	-1,0 V	-4 V	-0.9 V	-0.9 V
Gm max / β		42 mS/mm	70 mS/mm	210 mS/mm	100 mS/mm	700 mS/mm	400 mS/mm
Noise / Gain	<0.5 dB	9dB	10 dB	1.2 dB	9.5dB @6GHz	15 dB @30GHz	
	@12 GHz	@ 3,7-4,2 GHz	@ 3,7-4,2 GHz	@12 GHz			

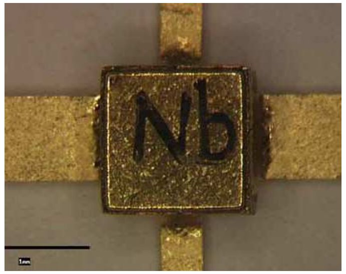
TEST SAMPLES

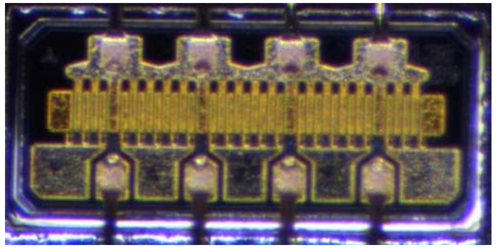
OMMIC ED02AH
TCV: FTCVOM112A
(with DEC amplifier)

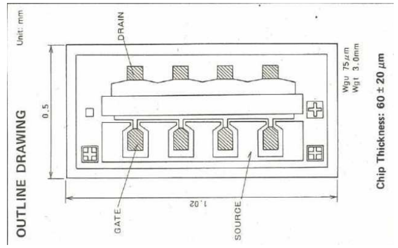




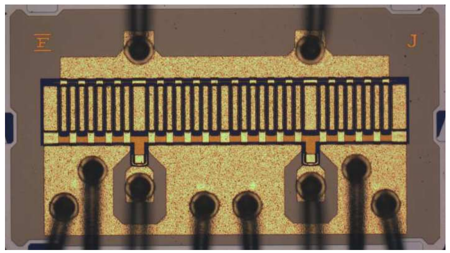
MITSUBISHI
HIGH POWER GaAs
MGF2430S

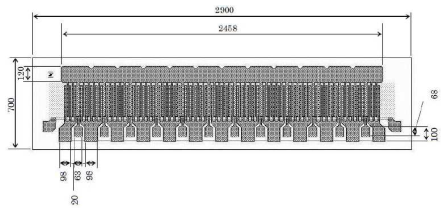




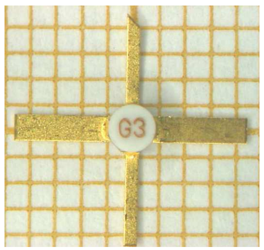


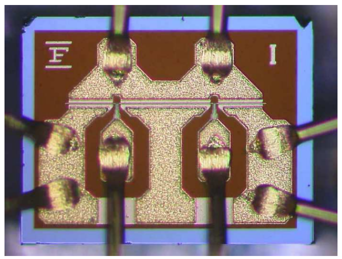
SUMITOMO
HIGH POWER GaAs
FLL120MK

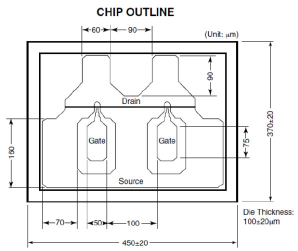




SUMITOMO
pHEMT FHX35LR

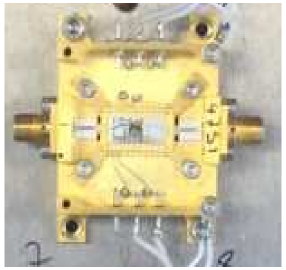


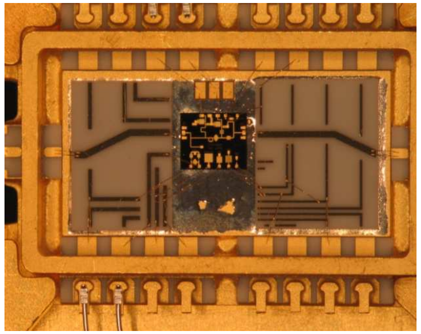




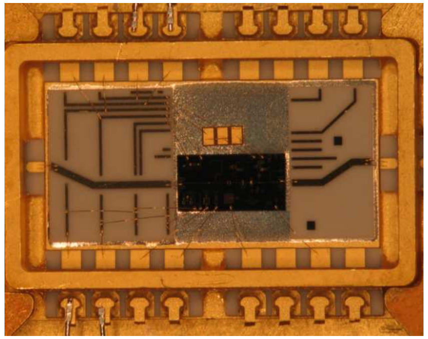
TEST SAMPLES (Cont'd)

UMS PPH25X
TCV: FTCVUM102A
(with DEC amplifier)

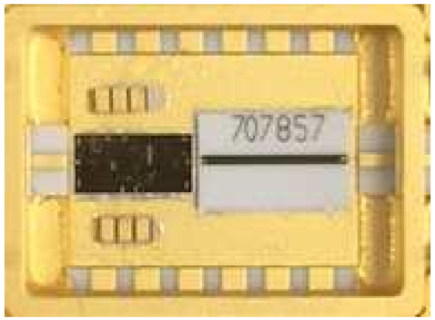




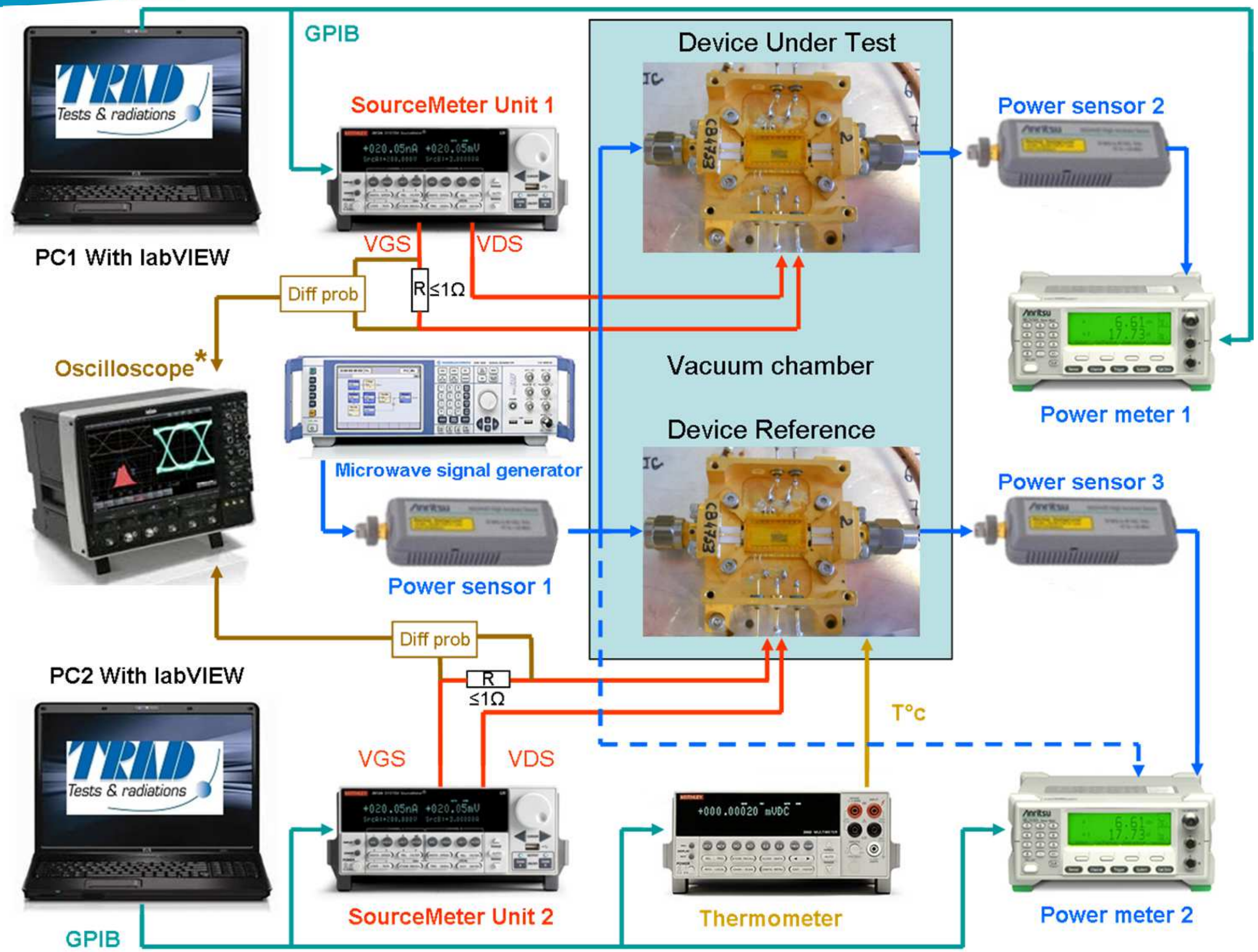
OMMIC D01PH
TCV: FTCVOM105A
(with DEC amplifier)



UMS HP07
TCV
(with DEC amplifier)

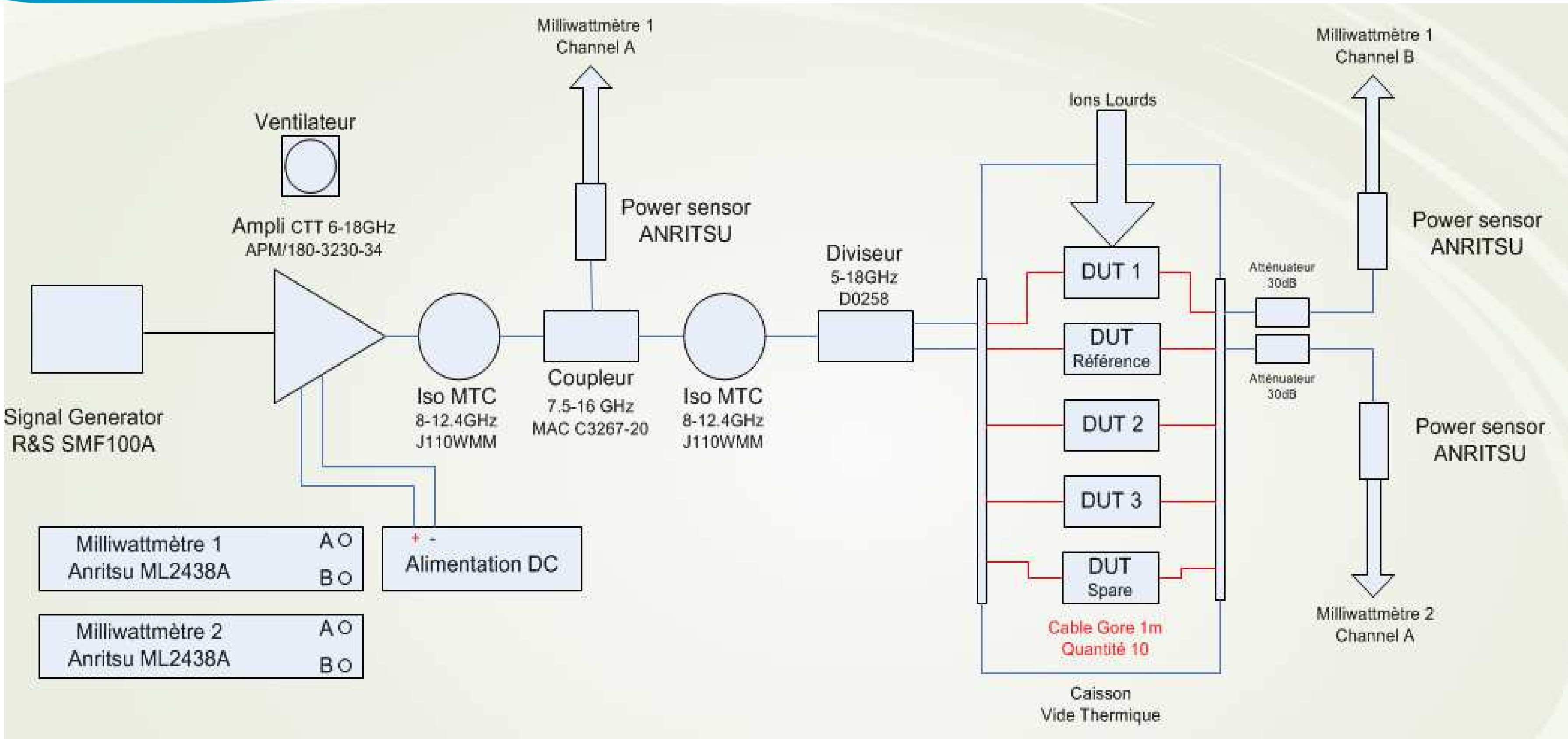


HEAVY IONS & TEST BENCH



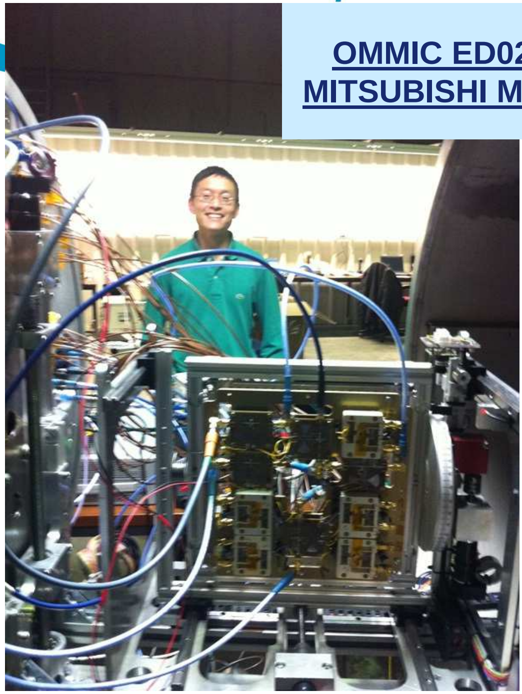
Test bench overview

HEAVY IONS & TEST BENCH

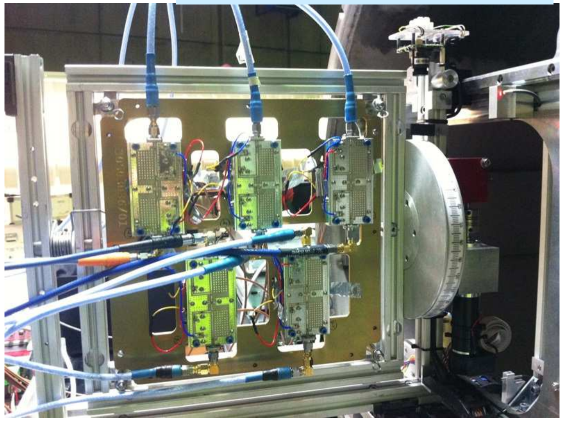


Test bench used in UCL (Belgium)

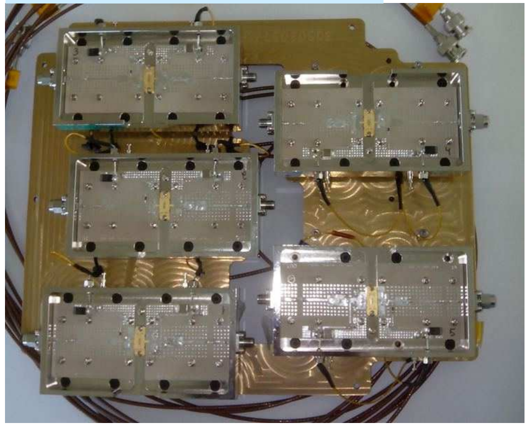
IRRADIATION CAMPAIGN



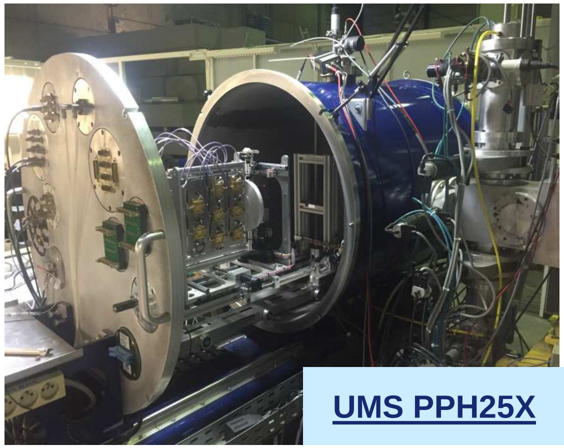
OMMIC ED02AH & MITSUBISHI MGF2430



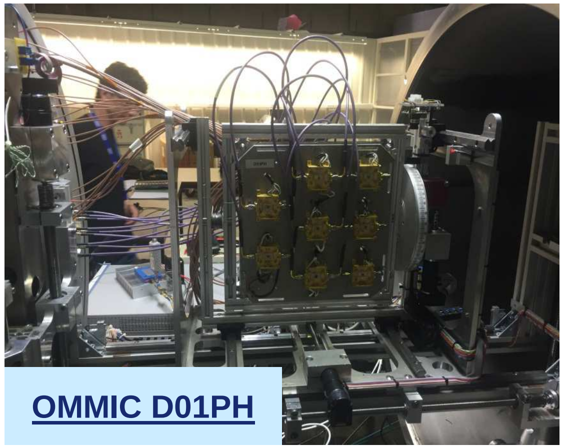
SUMITOMO pHEMT FHX35LR



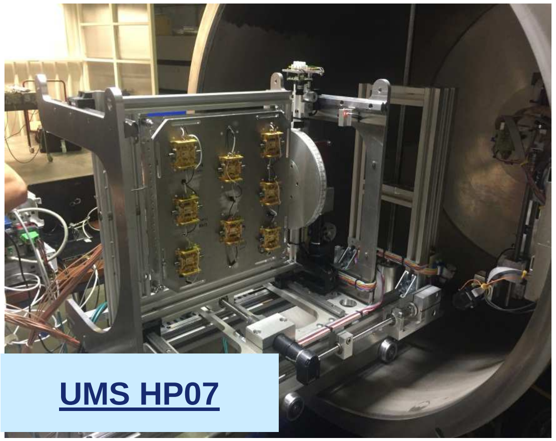
SUMITOMO FLL120MK



UMS PPH25X



OMMIC D01PH



UMS HP07

IRRADIATION CAMPAIGN

- Performed at the Heavy Ions Cyclotron Facility (HIF) at University of Louvain la Neuve in Belgium, on week 1547 (November 17th to 20th).
- Ion 124Xenon+35, 995MeV, the Highest LET value available in coctail-2: 62.5 MeV/cm^2/mg in Si (effective LET in GaAs of 44.3 MeV/cm^2/mg).
- Penetration range up to 73.1µm in Si; 49µm in GaAs. Enough for a "sensitive" thickness estimated to be <20µm (including passivation around 1000A SiN, contact metal around 5000A Al, and GaAs uniform doped channel of typical <2000um)
- Fluence starting from 10^6 to 10^7 ions/cm^2 (under orthogonal impact (no tilt).
- 7 to 12 runs per device. 7 to 10 minutes irradiation per run

- Sample size. On the same board: 3 DUT for irradiation + 1 REF biased inside the chamber + 1 attrition biased inside the chamber. Also 1 attrition outside the board (chamber).
- Electrical Measurements before and after irradiation:
  - OUTPUT CHARACTERISTIC : Ids vs (Vds, Vgs)
  - SCHOTTKY CHARACTERISTIC : Igs vs Vgs
- Continuous Monitoring during irradiation:
  - Pin (dBm) & Pout (dBm)
  - Id (A); Ig (A)
  - Temperature

MITSUBISHI MGF2430S

MITSUBISHI MGF2430S. TEST PLAN & RESULTS

Biasing

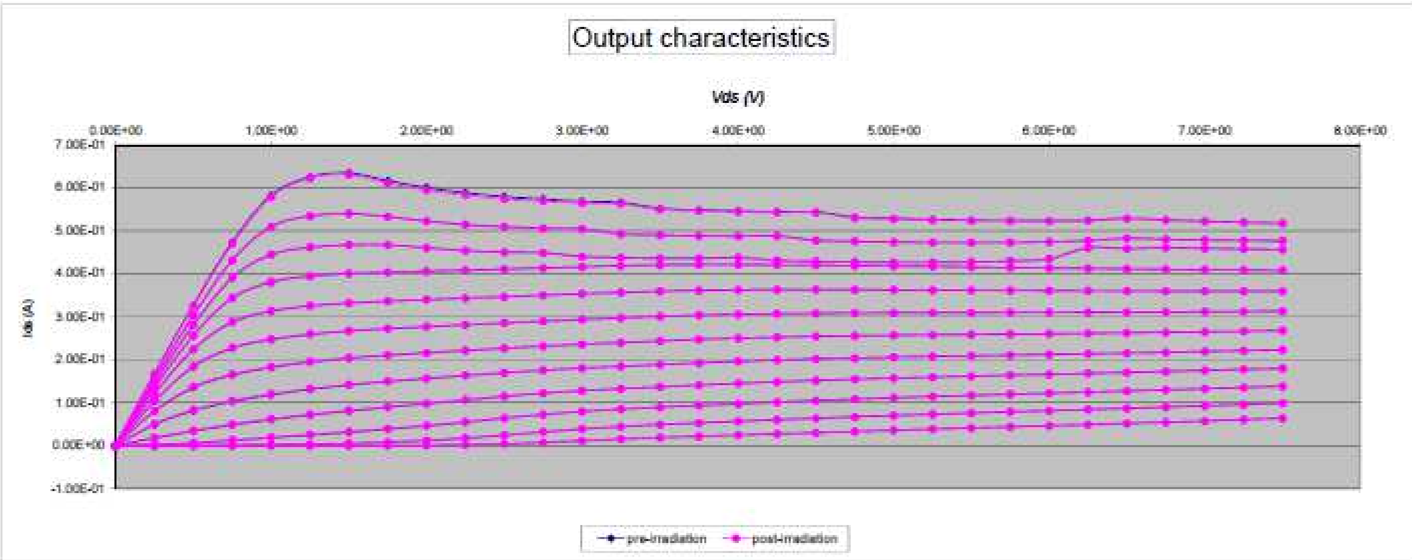
- Condition 1.1 (DC): Vgs=-4.5V, Vds 7.5V.
- Condition 1.2 (DC): Vgs=-2.25V, Vds 7.5V.
- Condition 2 (DC+RF): Vgs= -1.03V, Id=300mA, Vds=7.5V, CW Input power=25dBm, input frequency=1.85GHz. Compression Level = 6dB

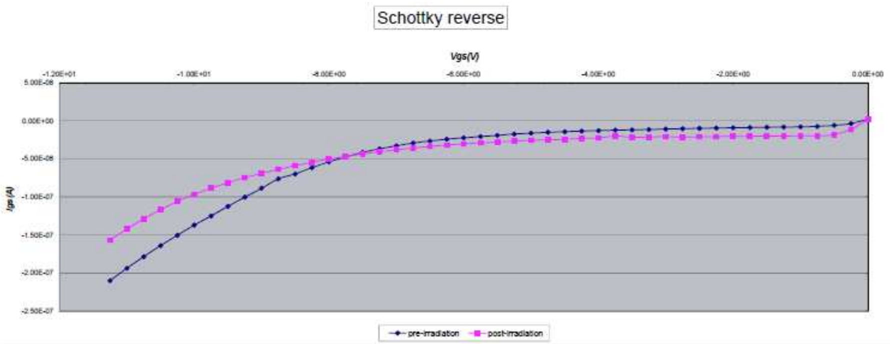
Measurements

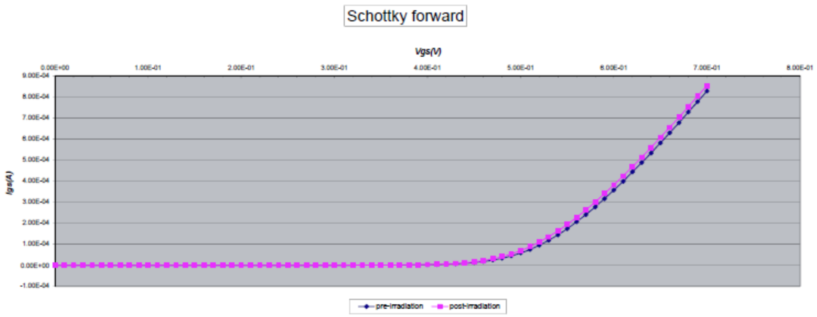
- Ids vs Vds
- Igs vs Vds
- Monitoring during irradiation: Pin & Pout; Id; Ig; Temperature

Sample	BVGD Sequence	RF Step Stress Sequence	Compliance
SN1	Reference	Reference	PASS
SN2	Step 1.1 & 1.2	Step 2	PASS
SN3	Step 1.1	Step 2	PASS
SN4	Step 1.1	Step 2	PASS

MITSUBISHI MGF2430S. STATIC CHARACTERISTICS



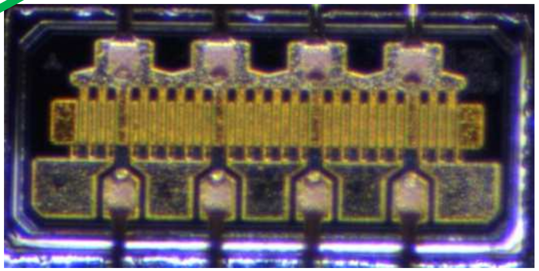


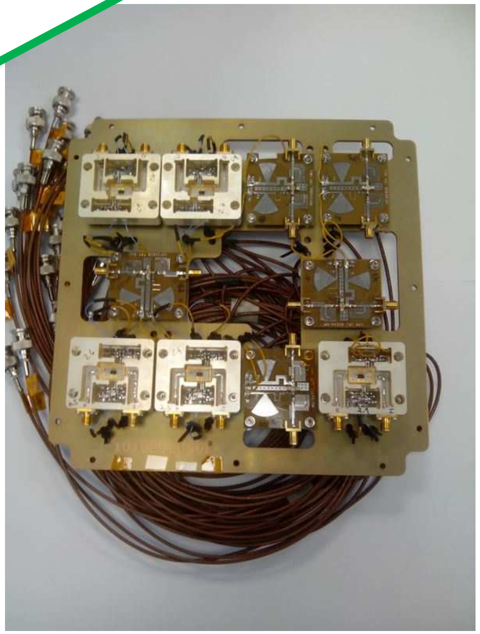


Slight difference between before and after irradiation attributed to temperature (increased during irradiation due to bad dissipation in vacuum) or test set-up

MITSUBISHI HP MGF2430S

not sensitive to heavy ions up to LET of 62.5 (MeV.cm²/mg)





SUMITOMO FHX35LR

SUMITOMO FHX35LR. TEST PLAN & RESULTS

Biasing

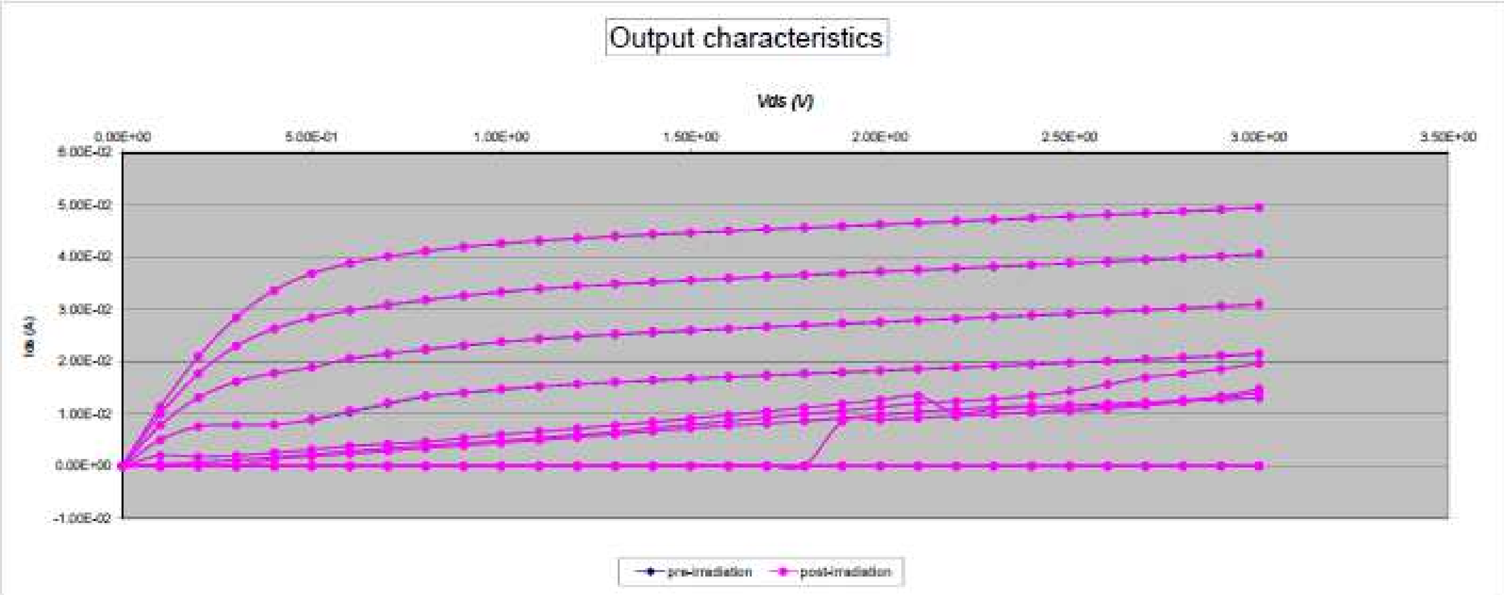
- Condition 1.1 (DC): Vgs=-2V, Vds 3V.
- Condition 1.2 (DC): Vgs=-1V, Vds 3V.
- Condition 2 (DC+RF): Vgs=-0.3, Id=22mA, Vds=3V, CW Input power=1dBm, input frequency=1.85GHz. Compression Level = 6dB

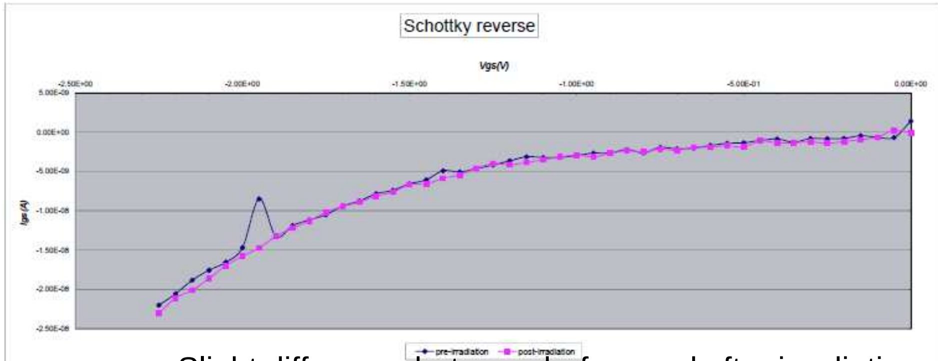
Measurements

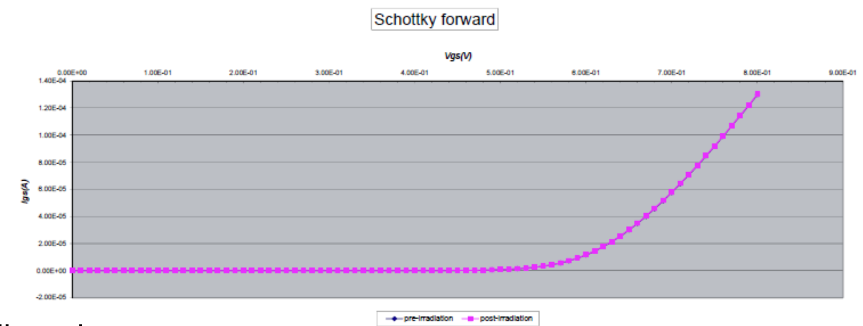
- Ids vs Bds
- Igs vs Vds
- Monitoring during irradiation: Pin & Pout; Id; Ig; Temperature

Sample	BVGD Sequence	RF Step Stress Sequence	Compliance
SN1	Reference	Reference	PASS
SN2	Step 1.1 & 1.2	Step 2	PASS
SN3	Step 1.1	Step 2	PASS
SN4	Step 1.1	Step 2 Step 2 with Oscilloscope	PASS

SUMITOMO FHX35LR. STATIC CHARACTERISTICS



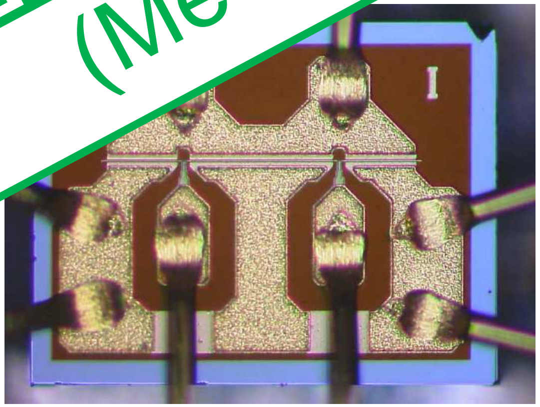


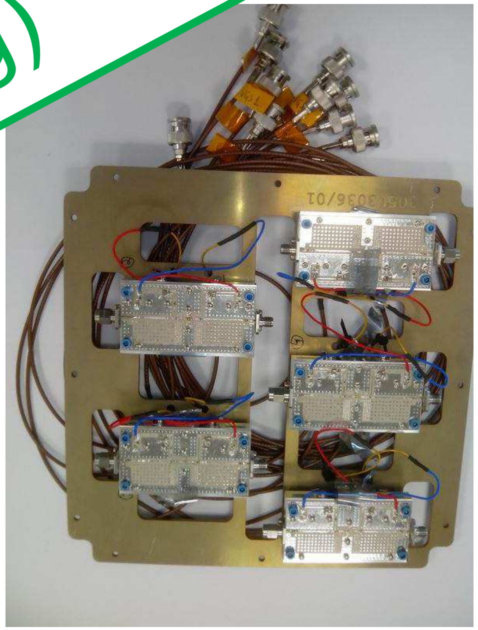


Slight difference between before and after irradiation attributed to test set-up

SUMITOMO FHX35LR pHEMT

not sensitive to heavy ions up to LET of 62.5 (MeV.cm²/mg)





SUMITOMO FLL120MK

SUMITOMO FLL120MK. TEST PLAN & RESULTS

Biasing

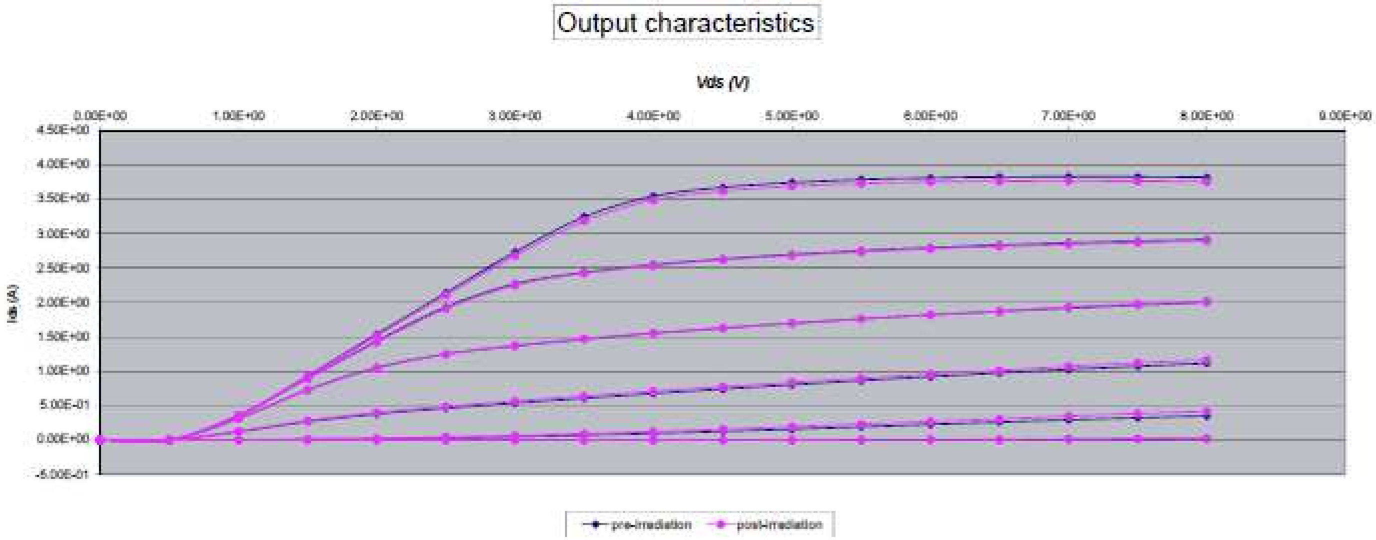
- Condition 1.1 (DC): Vgs=-3.5V, Vds 11.25V
- Condition 1.2 (DC): Vgs=-1.75V, Vds 11.25V
- Condition 2 (DC+RF): Vgs=-1.25V, Ids=2.2A, Vds=11.25V, CW Input power=11.7dBm, input frequency=2.3GHz

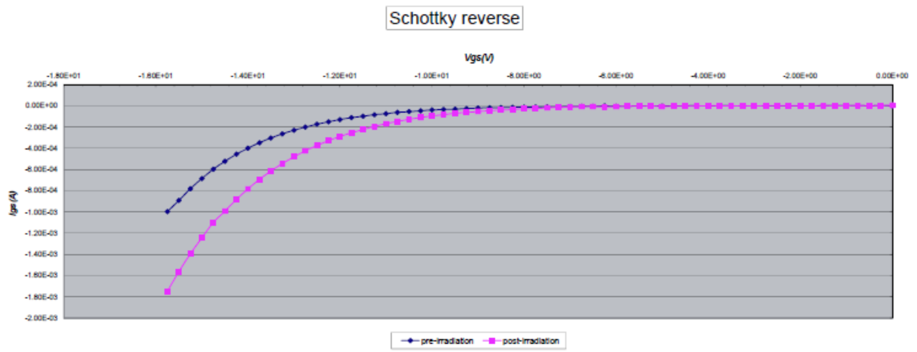
Measurements

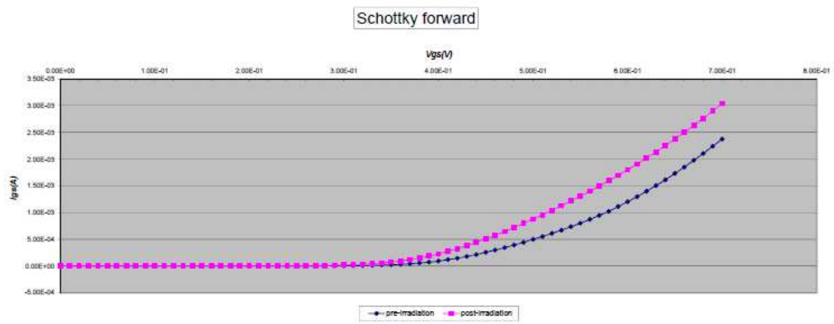
- Ids vs Bds
- Igs vs Vds
- Monitoring during irradiation: Pin & Pout; Id; Ig; Temperature

Sample	BVGD Sequence	RF Step Stress Sequence	Compliance
SN1	Reference	Reference	PASS
SN2	Step 1.1 & 1.2	Step 2	PASS
SN3	Step 1.1	Step 2	PASS
SN4	Step 1.1	Step 2 Step 2 with Scope	PASS

SUMITOMO FLL120MK. STATIC CHARACTERISTICS



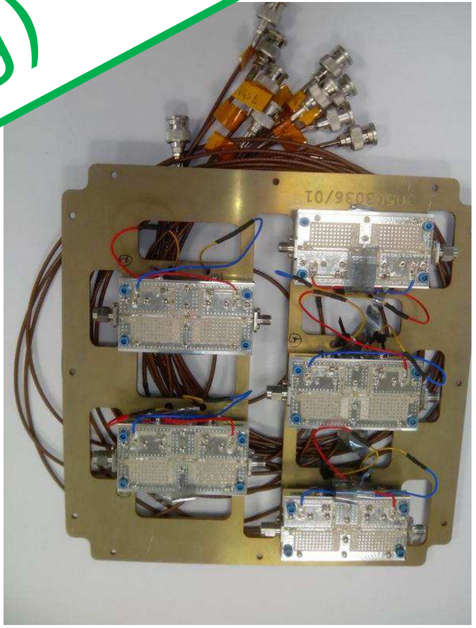


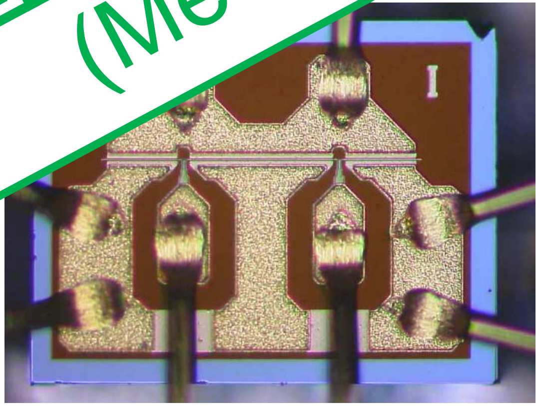


Slight difference between before and after irradiation attributed to temperature (increased during irradiation due to bad dissipation in vacuum) or test set-up

SUMITOMO HP FLL120MK

not sensitive to heavy ions up to LET of 62.5 (MeV.cm²/mg)





OMMIC ED02AH TCV

OMMIC ED02AH TCV. TEST PLAN & RESULTS

Biasing

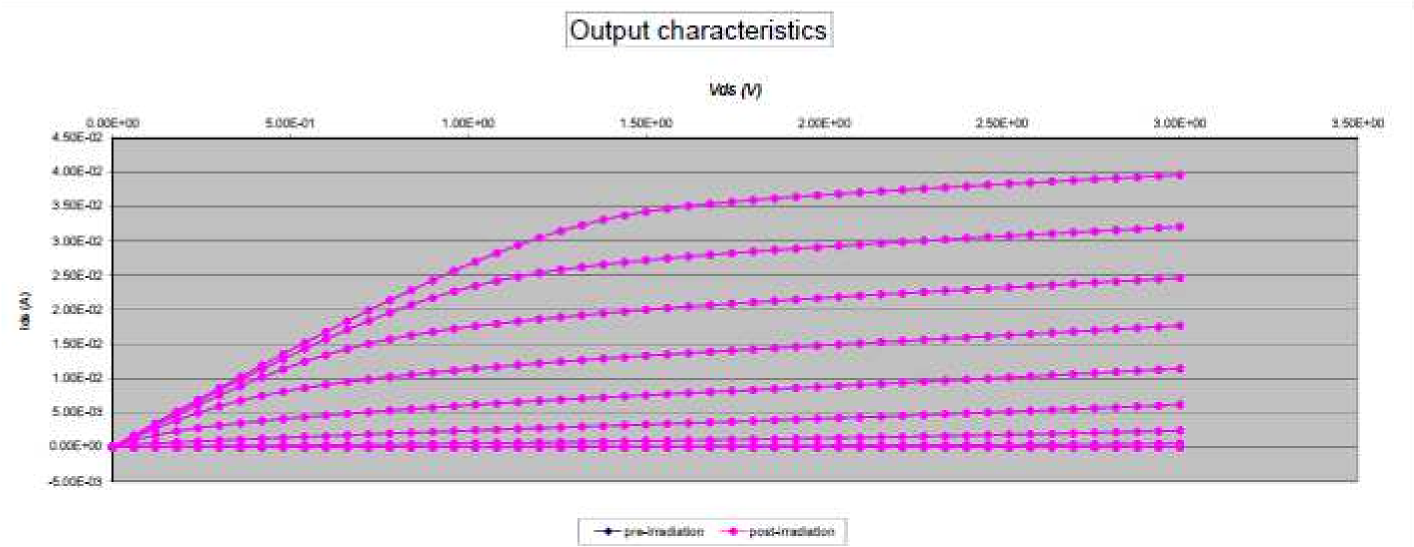
- Condition 1.1 (DC): Vgs=-3.75V, Vds 3V
- Condition 1.2 (DC): Vgs=-1.875V, Vds 3V
- Condition 2 (DC+RF): Vgs=-0.22V, Ids=22mA, Vds=3V, CW Input power=2.8dBm, input frequency=12.6GHz
- Condition 2.1: as 2 with multicarrier and CW input power = -4dBm. Multicarrier: PM modulation with subcarrier 6KHz and 1.5Rad index

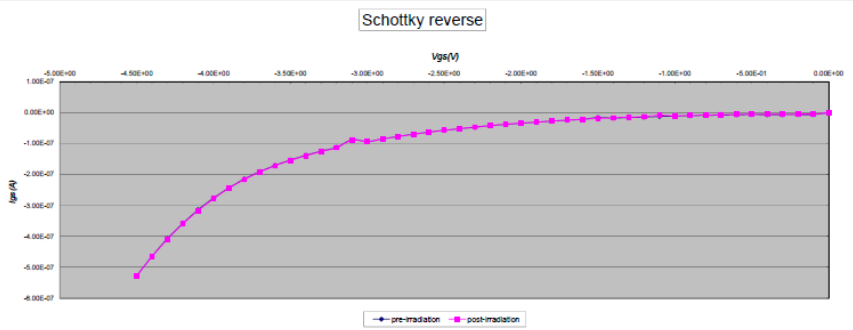
Measurements

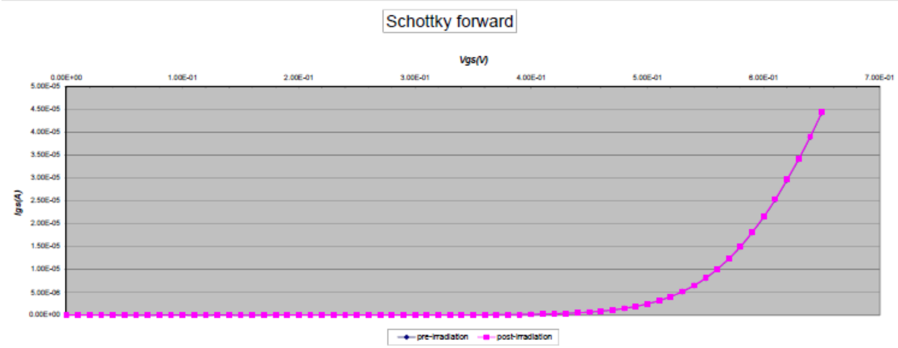
- Ids vs Bds
- Igs vs Vds

Sample	BVGD Sequence	RF Step Stress Sequence	Compliance
SN1	Reference	Reference	PASS
SN2	TCV Step 1.1 & 1.2	DEC Step 2 & 2.1	PASS
SN3	TCV Step 1.1	DEC Step 2 & 2.1	PASS
SN4	TCV Step 1.1	DEC Step 2 & 2.1	PASS

OMMIC ED02AH TCV. STATIC CHARACTERISTICS

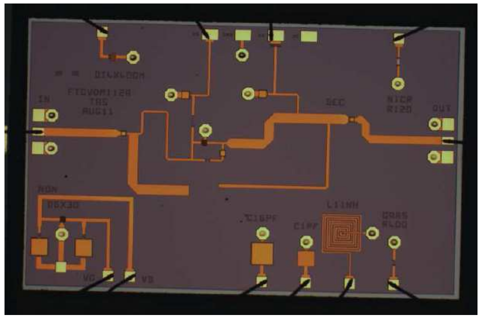


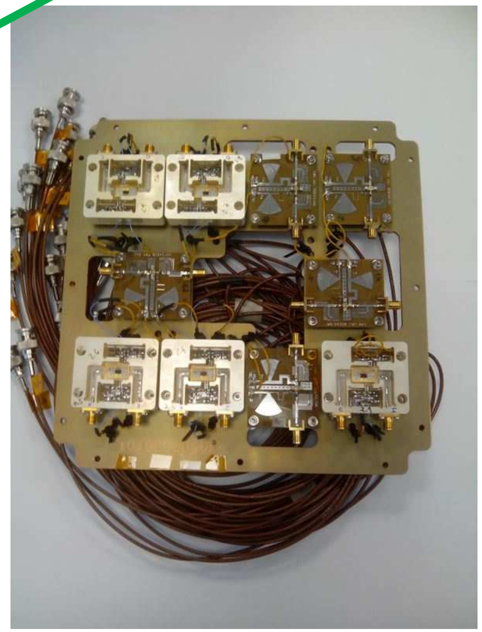




OMMIC ED02AH

not sensitive to heavy ions up to LET of 62.5 (MeV.cm^2/mg)





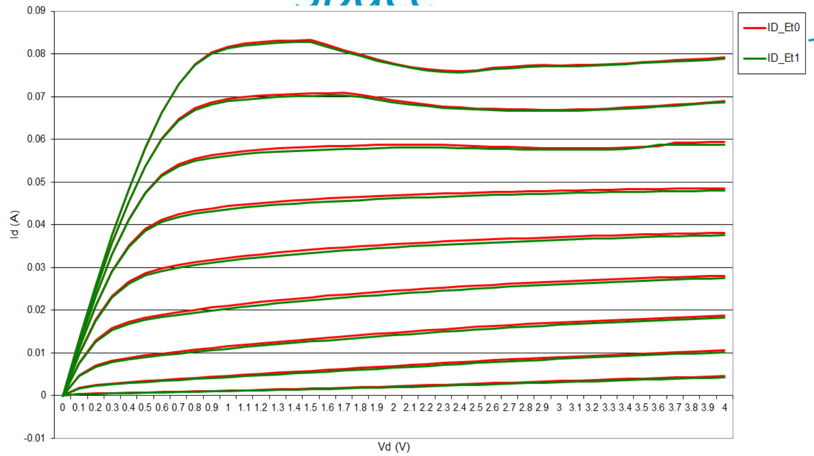
UMS PPH25X

UMS PPH25X. TEST PLAN & RESULTS

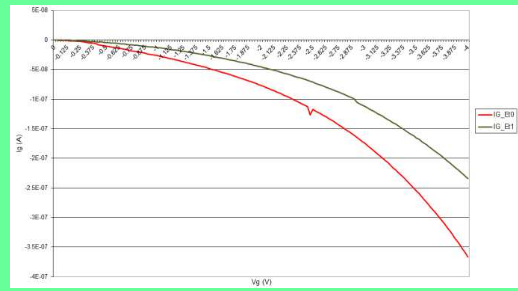
ELECTRICAL TEST CONDITIONS 1	**BVGD Sequences: On TCV devices** **Step 1-1 : TCV VDS nominal, VGD (DC) = VGD (RF) peak = -17 V (Based by retro simulation for 6dB GC) Vds=14V, Vgs=-3V**
ELECTRICAL TEST CONDITIONS 2	**RF Step Stress Sequences: on DEC devices** **For DEC VDS=7 Volts, Ids= 27 mA** **Step 2-1 : 4 dB gain comp. Pin=18,2 dBm** **Step 2-2 : 6 dB gain comp. Pin=20,4 dBm**

Sample	BVGD Sequence	RF Step Stress Sequence	Compliance
SN1	Reference	Reference	PASS
SN3	Step 1.1	Step 2.2	PASS
SN4	Step 1.1	Step 2.2	PASS
SN5	Step 1.1	Step 2.2	PASS

UMS PPH25X. STATIC CHARACTERISTICS

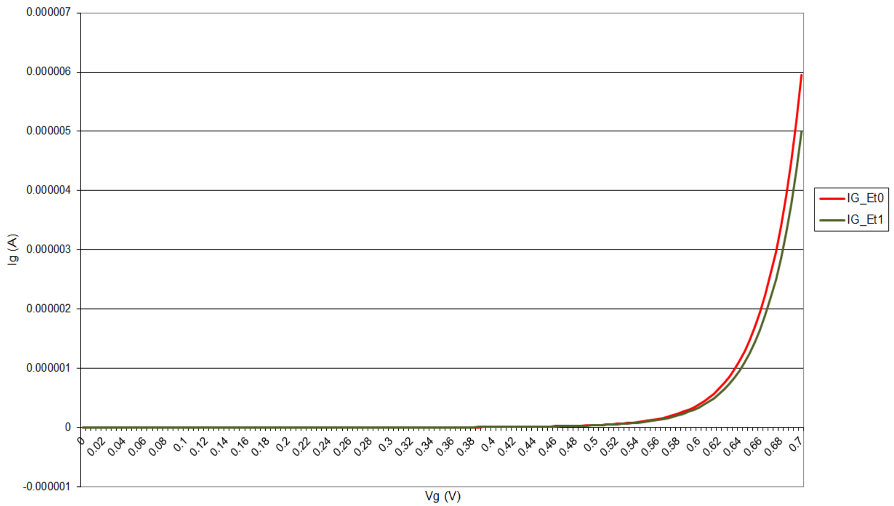


Output characteristic typical – SN3

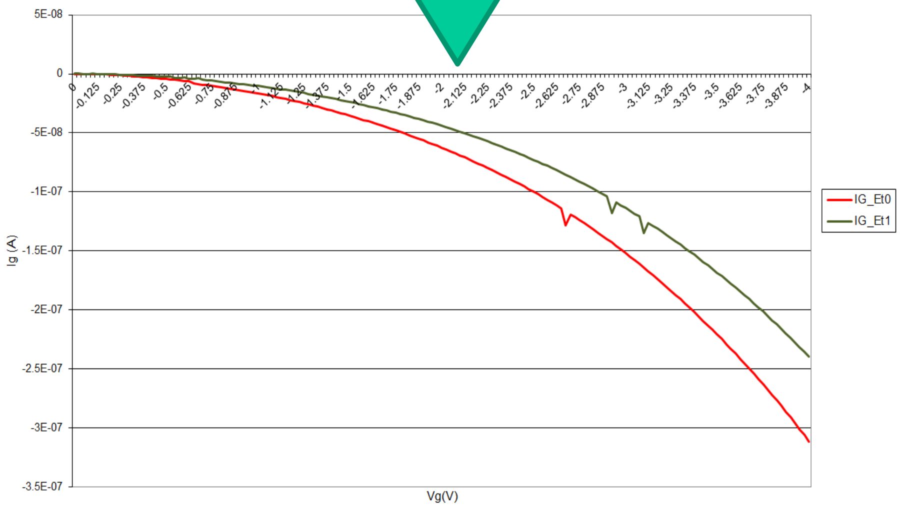


Reverse Shottky characteristic SN1 – Control Sample

Same electrical conditions without Heavy Ions



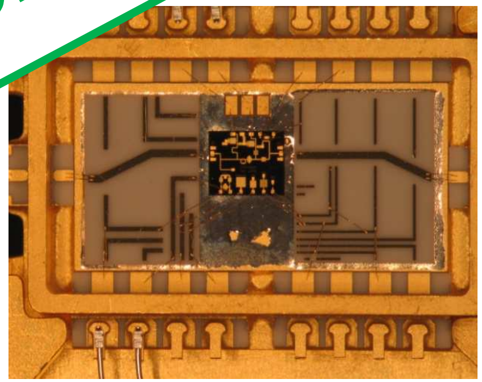
Forward Shottky characteristic typical – SN3



Reverse Shottky characteristic typical – SN3

UMS PPH25X

not sensitive to heavy ions up to LET of 62.5 (MeV/cm^{-2}/mg)



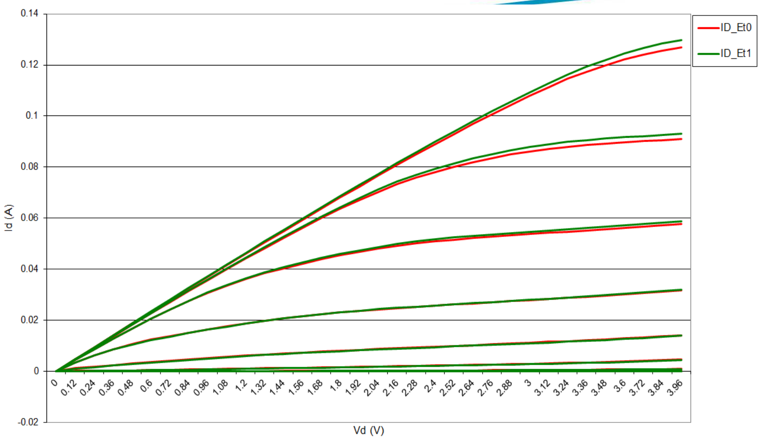
OMMIC D01PH

OMMIC D01PH. TEST PLAN & RESULTS

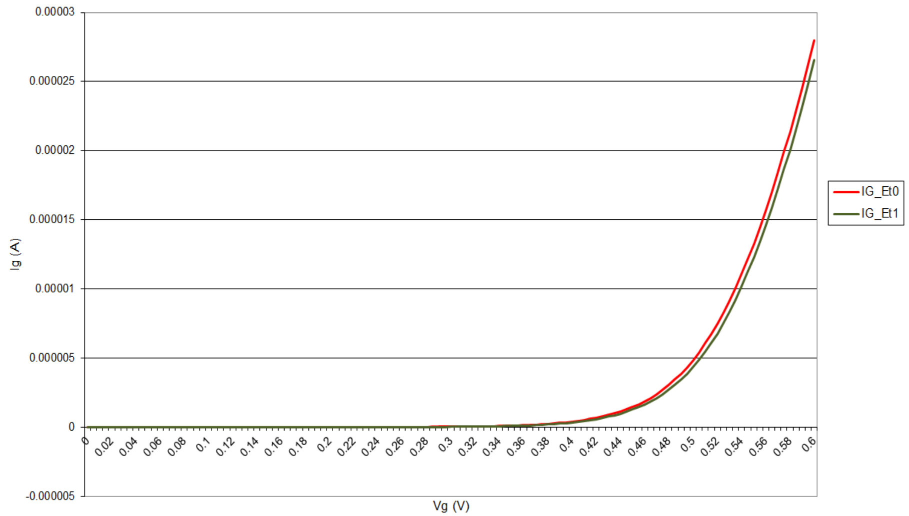
ELECTRICAL TEST CONDITIONS 1	**BVGD Sequences: On TCV devices** **Step 1-1 : TCV VDS nominal, VGD (DC) = VGD (RF) peak = -6.5 V (Based by retro simulation for 6dB GC)** **Vds=4V, Vgs=-2.5V**
ELECTRICAL TEST CONDITIONS 2	**RF Step Stress Sequences: on DEC devices** **For DEC Vds=4 V, Ids=58 mA** **Step 2-1 : 4 dB gain comp. Pin=15dBm** **Step 2-2 : 6 dB gain comp. Pin=17,25dBm**

Sample	BVGD Sequence	RF Step Stress Sequence	Compliance
SN1	Reference	Reference	PASS
SN3	Step 1.1	Step 2.2	PASS
SN4	Step 1.1	Step 2.2	PASS
SN5	Step 1.1	Step 2.2	PASS

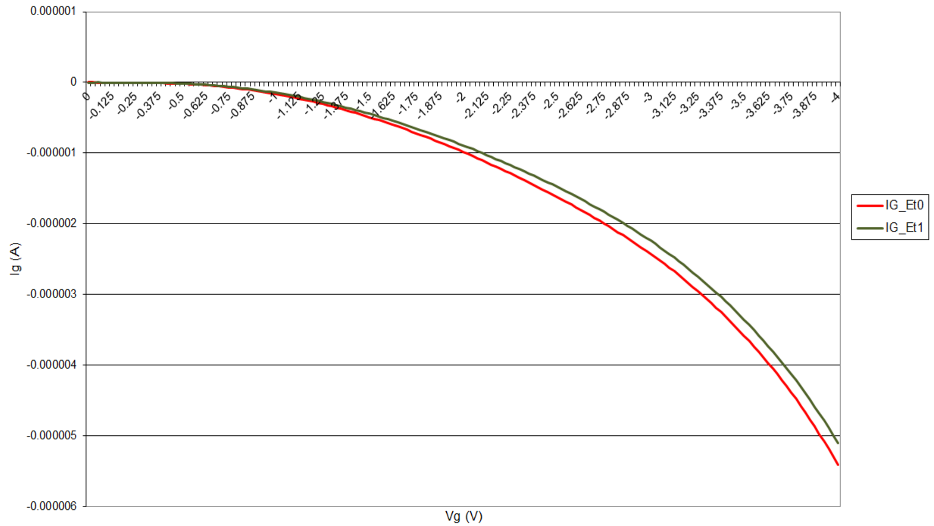
OMMIC D01PH. STATIC CHARACTERISTICS



Output characteristic typical – SN3



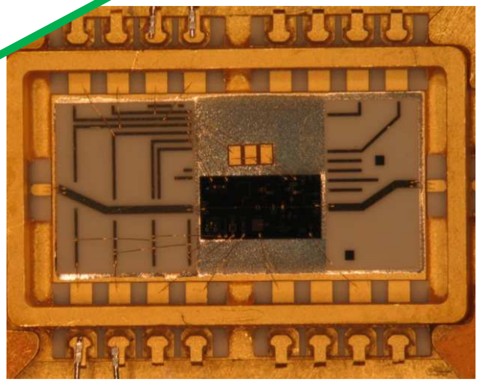
Forward Shottky characteristic typical – SN3

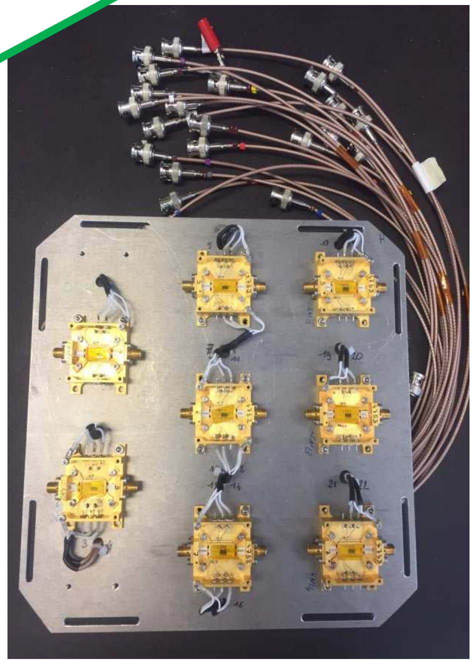


Reverse Shottky characteristic typical – SN3

OMMIC D01PH

not sensitive to heavy ions up to LET of 62.5 (MeV.cm²/mg)





UMS HP07

UMS HP07. TEST PLAN

ELECTRICAL TEST CONDITIONS 1	**BVGD Sequences: On TCV devices** **Step 1-1 : 100% ROR : Vds=9V, Vgs=-9V** **Step 1-2 : 75% AMR : Vds=7.5V, Vgs=-7.5V** **Step 1-3 : 100% AMR : Vds=10V, Vgs=-10V**
ELECTRICAL TEST CONDITIONS 2	**RF Step Stress Sequences: on DEC devices** **For DEC VDS=7 Volts, Ids= 270 mA** **Step 2-1 : 4 dB gain comp. Pin=10 dBm** **Step 2-2 : 6 dB gain comp. Pin=13 dBm**

A sensitivity have been observed on HP07 process during californium test (LET 40) in TRAD building.
(Note that sensitivity already seen in late 90's during heavy ions testing performed by TASF/CNES at Vgd<vgdmax)

→ **We have decided to begin the heavy ions campaign with a different LET in order to define a threshold :**

→ LET 10 : ARGON
→ LET 20 : NICKEL
→ LET 32 : KRYPTON

UMS HP07. RESULTS. ARGON (LET 10)

ELECTRICAL TEST CONDITIONS 1	**BVGD Sequences: On TCV devices** **Step 1-1 : 100% ROR : Vds=9V, Vgs=-9V** **Step 1-2 : 75% AMR : Vds=7.5V, Vgs=-7.5V** **Step 1-3 : 100% AMR : Vds=10V, Vgs=-10V**
ELECTRICAL TEST CONDITIONS 2	**RF Step Stress Sequences: on DEC devices** **For DEC VDS=7 Volts, Ids= 270 mA** **Step 2-1 : 4 dB gain comp. Pin=10 dBm** **Step 2-2 : 6 dB gain comp. Pin=13 dBm**

Sample	BVGD Sequence	RF Step Stress Sequence	Compliance
SN1	Reference	Reference	PASS
SN2	Step 1.1 Step 1.2 Step 1.3	Step 2.1 Step 2.2	PASS
SN4	Step 1.3	Step 2.2	PASS
SN5	Step 1.3	Step 2.2	PASS

UMS HP07. RESULTS. NICKEL (LET20)

ELECTRICAL TEST CONDITIONS 1	BVGD Sequences: On TCV devices Step 1-1 : 100% ROR : Vds=9V, Vgs=-9V Step 1-2 : 75% AMR : Vds=7.5V, Vgs=-7.5V Step 1-3 : 100% AMR : Vds=10V, Vgs=-10V
ELECTRICAL TEST CONDITIONS 2	RF Step Stress Sequences: on DEC devices For DEC VDS=7 Volts, Ids= 270 mA Step 2-1 : 4 dB gain comp. Pin=10 dBm Step 2-2 : 6 dB gain comp. Pin=13 dBm

sensitive to heavy ions LET 20 in RF SS

Sample	BVGD Sequence	RF Step Stress Sequence	Compliance
SN1	Reference	Reference	PASS
SN5	Step 1.3	Step 2.2	PASS
SN4	Step 1.3	Step 2.2	FAIL
SN2	Step 1.3	Step 2.1	FAIL

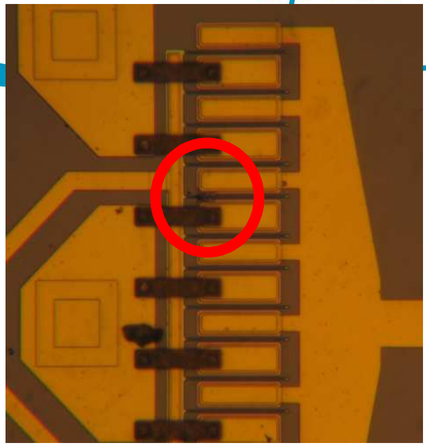
UMS HP07. RESULTS. KRYPTON (LET32)

ELECTRICAL TEST CONDITIONS 1	BVGD Sequences: On TCV devices Step 1-1 : 100% ROR : Vds=9V, Vgs=-9V Step 1-2 : 75% AMR : Vds=7.5V, Vgs=-7.5V Step 1-3 : 100% AMR : Vds=10V, Vgs=-10V
ELECTRICAL TEST CONDITIONS 2	RF Step Stress Sequences: on DEC devi For DEC VDS=7 Volts, Ids= 27 mA Step 2-1 : 4 dB gain comp. Pin=10 dBm Step 2-2 : 6 dB gain comp. Pin=13 dBm

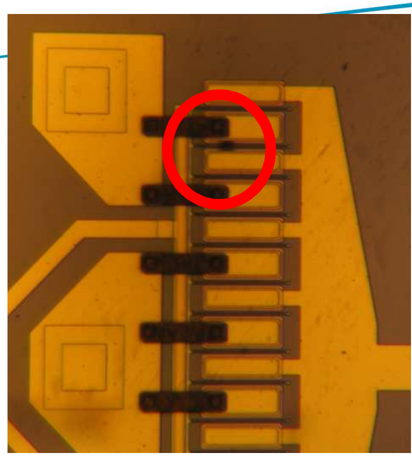
sensitive to heavy ions LET 32 in BVGD

Sample	BVGD Sequence	RF Step Stress Sequence	Compliance
SN1	Reference	Reference	PASS
SN6	Step 1.3		PASS
SN7	Step 1.3		FAIL
SN8	Step 1.2		FAIL
SN5		Step 2.1 with scop	FAIL

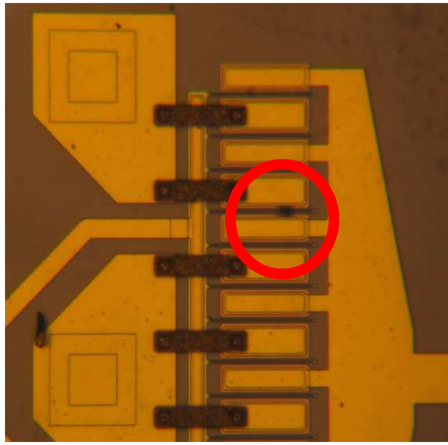
UMS HP07. SENSITIVE TO HEAVY IONS



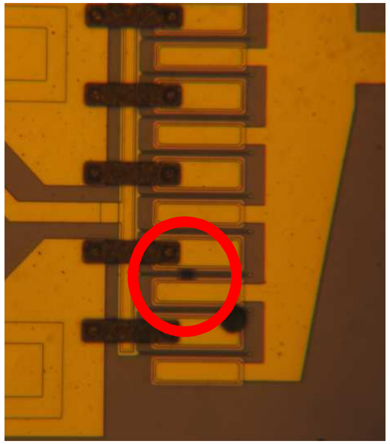
SN10 – Step 2.2 - Californium



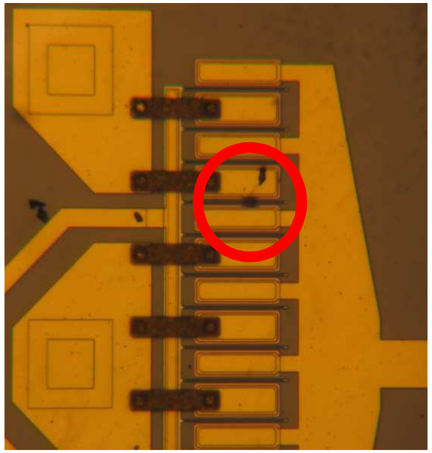
SN6 – Step 2.2 - Californium



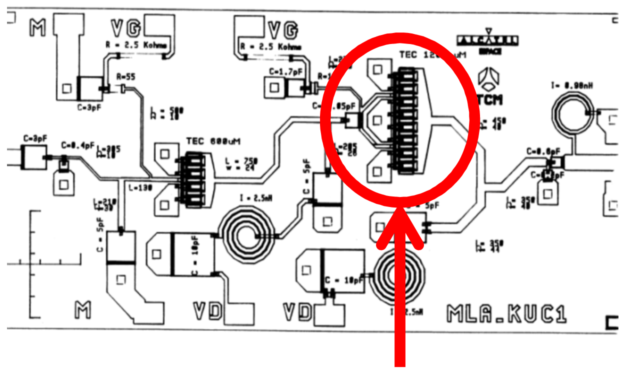
SN3 – Step 2.2 - Californium



SN2 - Step 2.1 (LET20)

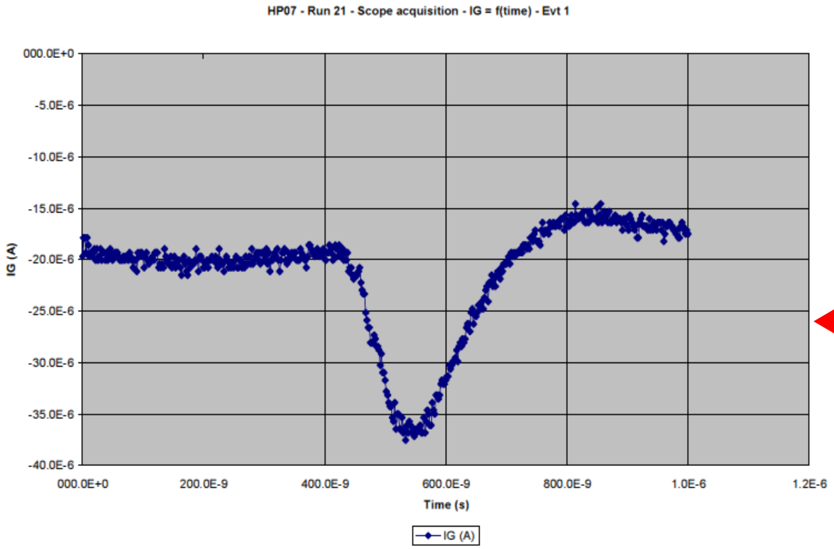


SN4 - Step 2.2 (LET20)

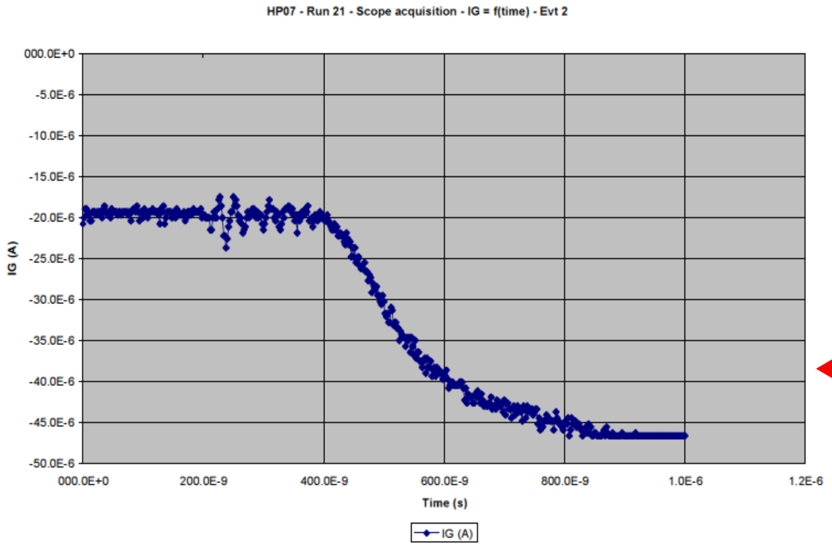


Stage 2

UMS HP07. EVENTS OBSERVED WITH SCOPE ACQUISITION



Event observed before the failure.



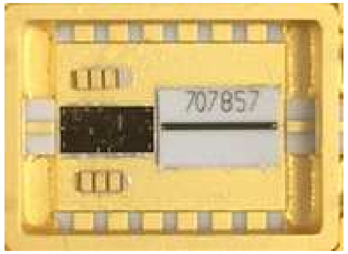
Event observed during the failure.

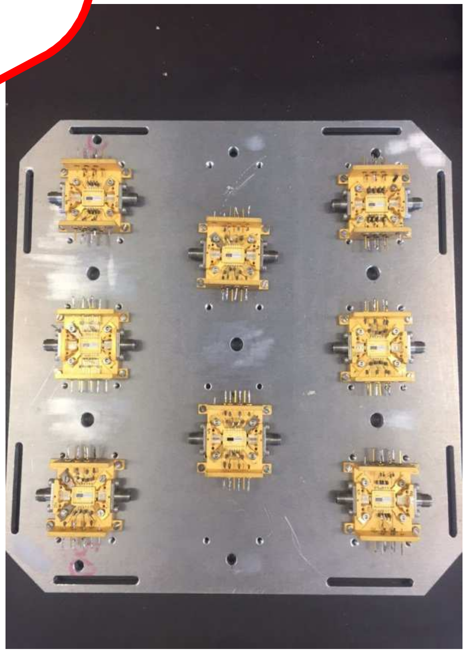
UMS HP07

Sensitive to heavy ions :

BVGD : Maximum LET 20

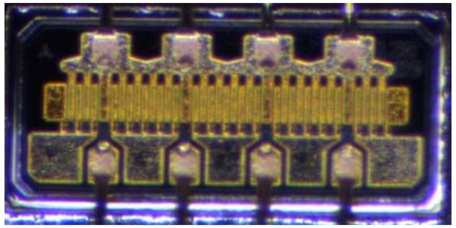
RF SS : Maximum LET 10

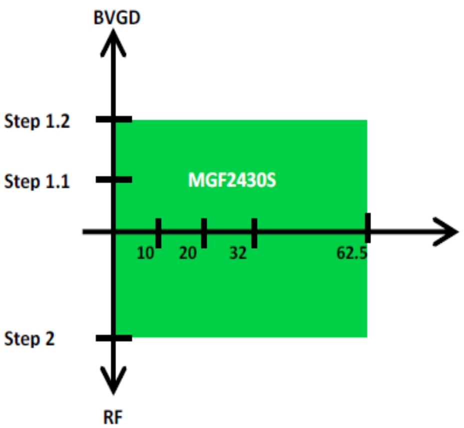




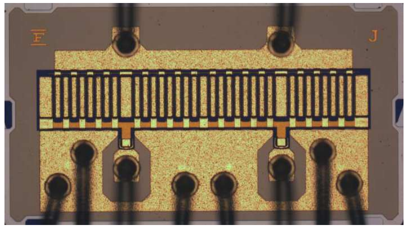
SAFETY OPERATING AREA (1)

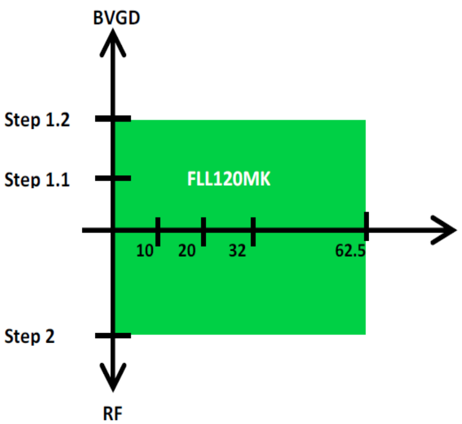
MITSUBISHI HP MGF2430S



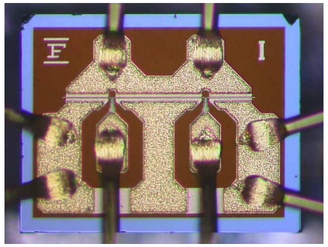


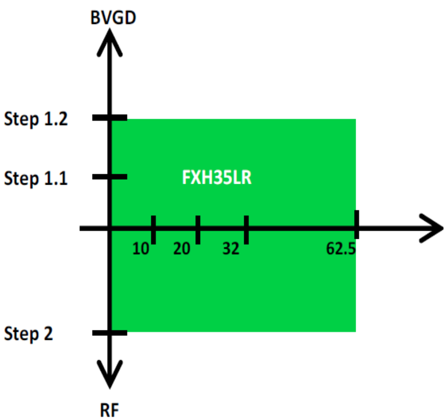
SUMITOMO HP FLL120MK



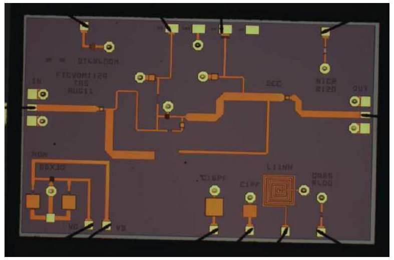


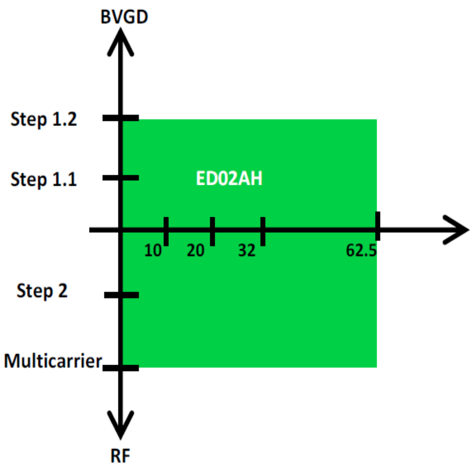
SUMITOMO LNA FHX35LR





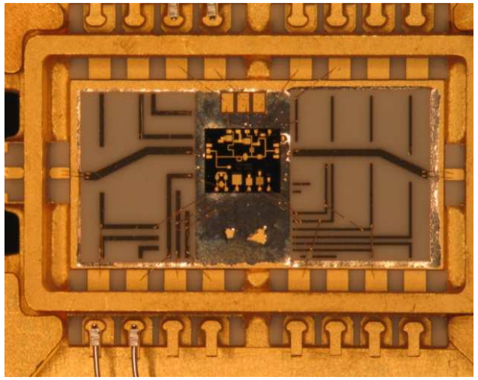
OMMIC ED02AH TCV

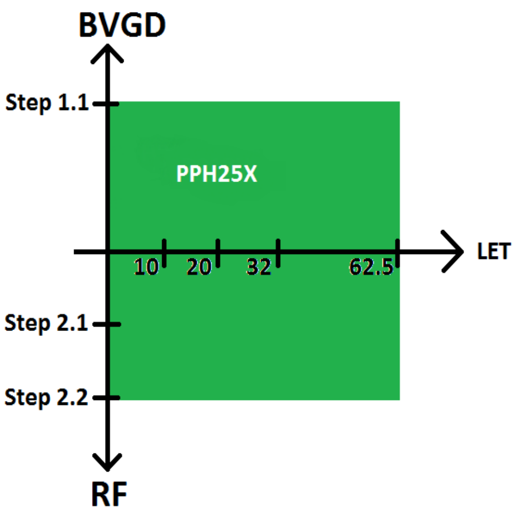




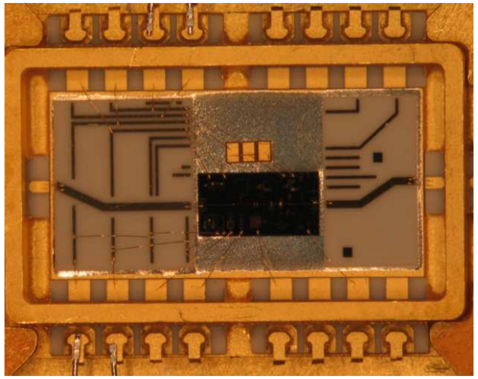
SAFETY OPERATING AREA (2)

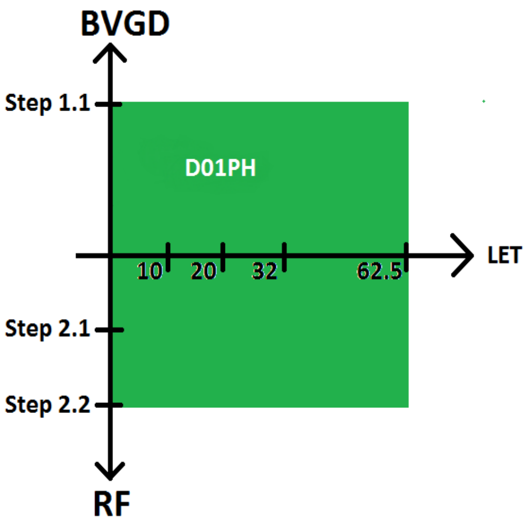
UMS PPH25X



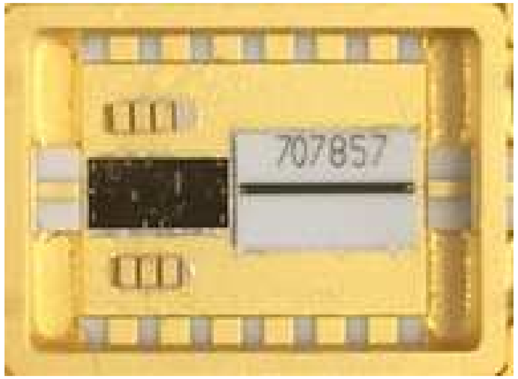


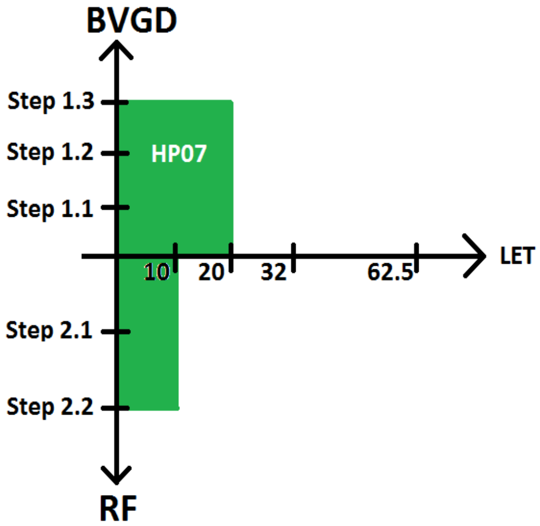
OMMIC D01PH





UMS HP07





CONCLUSION . RESULTS (1)

MITSUBISHI HP MGF2430S

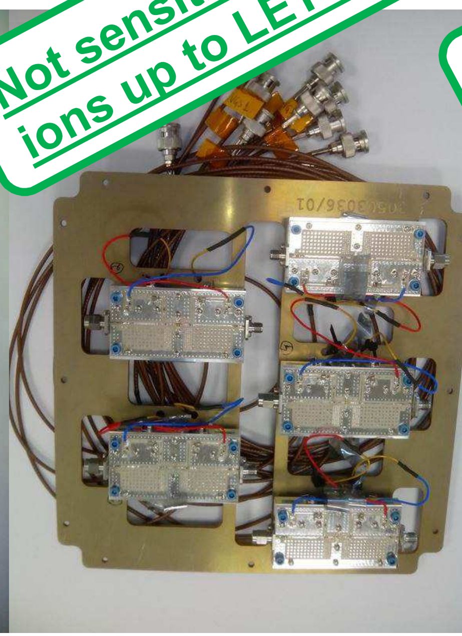
Not sensitive to heavy ions up to LET of 62.5

SUMITOMO HP FLL120MK

Not sensitive to heavy ions up to LET of 62.5

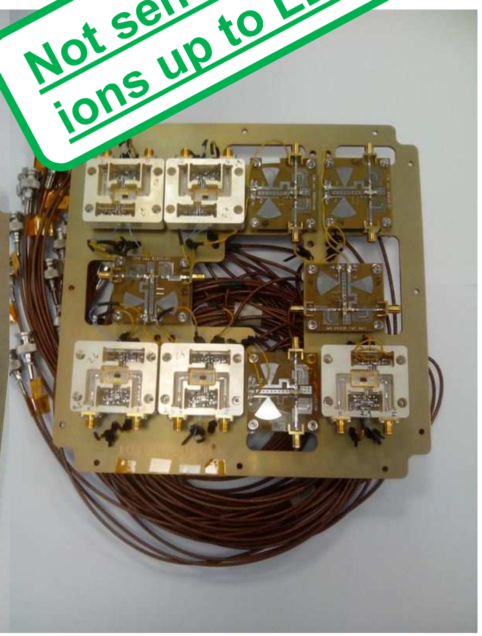
SUMITOMO LNA FHX35LR

Not sensitive to heavy ions up to LET of 62.5



OMMIC ED02AH TCV

Not sensitive to heavy ions up to LET of 62.5



CONCLUSION. RESULTS (2)

UMS PPH25X

OMMIC D01PH

UMS HP07

CONCLUSION. METHODOLOGY, DERATING, LEASONS LEARNED

- **Are radiation tests under DC sufficient ? and if RF, what RF signals?,**
  - ✓ **RF step stress test (increasing compression level) under heavy ions is recommended**
- **Do we need to test other technologies than power MESFET like HEMT, pHEMT?,**
  - ✓ **No sensitivity seen on pHEMT but cannot be extended to others without data**
- **Do we need to test per device, per lot, per function, per technology process ?**
  - ✓ **Consistency with previous data seems to show that testing per technology is satisfactory.**
- **What Test vehicle (TCV, DEC, MMIC) ?**
  - ✓ **TCV with DEC is OK**