SEE tests on power Schottky diodes

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- Introduction & Context
- Devices Under Test
- Test procedure & setup
- Heavy ions test results
- Synthesis
- Conclusion

Introduction & Context

- Silicon Schottky → traditionally considered immune to destructive SEE
- Recent works published on literature
  - ➢ shown that silicon power Schottky diodes may be sensitive to destructive events while reverse biased under heavy ion irradiation
- Previous test campains in 2015 (STM products)

Power Schottky diodes from STMicroelectronics								
Reference	Identification		Package	VRRM(V)	IF (Per diode)	IR (@VRRM) (A)	Number of sample	
STPS20100FY1	Marking	FE1652	TO-254	100	10A	150.0E-6	15	QPL product
STPS1045S1	Marking	FE1650	SMD 0.5	45	10A	100.0E-6	13	
STPS6045C2FSY1	Marking	FE1651	TO-254	45	30A	500.0E-6	15	
STPS40H100C2FY	Date code	1144A	TO-254	100	20A	10.0E-6	10	
	ST O/C #	LOTID 33125B10ZY LOTID 33125B1001						
	Trace Code	33125B10ZY						
	Bulk ID	T2R02J0SE023						
	Marking	5106-013-01 FR Beo						
STPS3045C	Marking	FE1652	TO-254	45	15A	200.0E-6	10	New generation prototype
STPS20200C	Marking	FE1653	TO-254	200	10A	15.0E-6	10	
STPS61170C	Marking	FE1654	TO-254	170	30A	60.0E-6	10	
STPS40100HR	Marking	FE1655	TO-254	100	20A	30.0E-6	10	

Introduction & Context

- Irradiations performed at GANIL
  - All QPL parts considered PASS at 75%
  - These parts are used on space mission at 75% maximum Vr
  - New prototypes are considerably more sensitive to SEB

		Xe (LET=61.02MeV.cm²/mg)			Kr (LET=27.18MeV.cm²/mg)		
		Ok	Failed PIST	Fail	Ok	Failed PIST	Fail
STMicroeletronics	STPS20100 (QPL)	75%	80%	100%			
	STPS1045 (QPL)	100%					
	STPS6045 (QPL)	100%		75%			
	STPS40100 (QPL)	70%*	75%	100%			
	STPS3045 (NEW)	< 50%**	50%	78%	78%		100%
	STPS20200 (NEW)	50%		75%	75%		100%
	STPS61170C (NEW)	40%	50%	76%	44%		59%
	STPS40H100 (NEW)	50%	65%	80%	75%		100%

*2 parts pass 75%

**Not tested

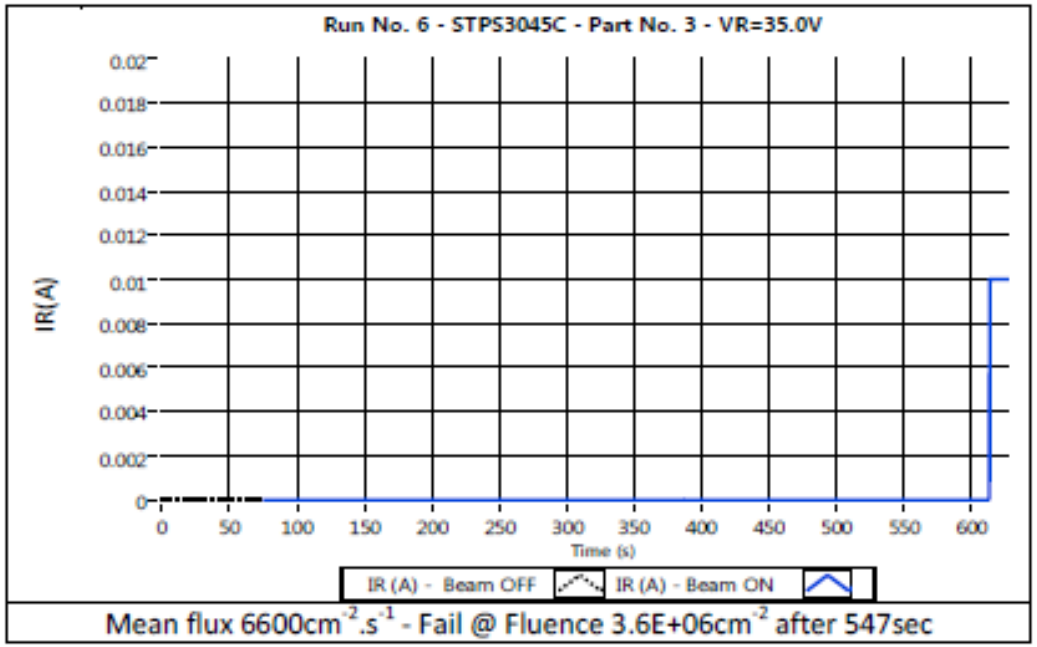
Fail : IR > IR @ VRRM

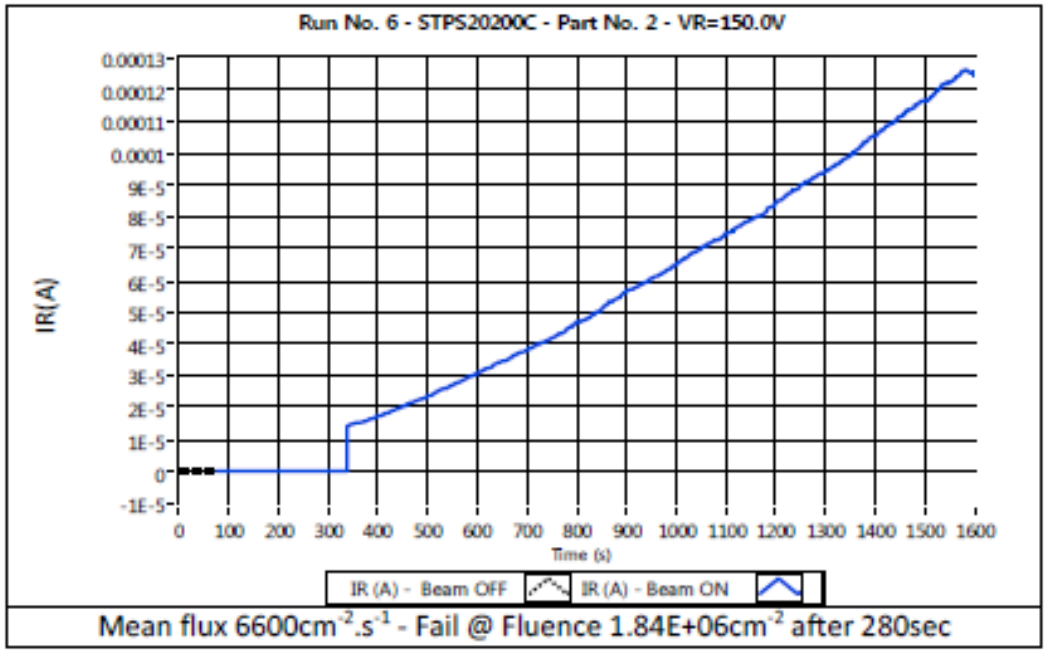
PASS: IR < IR @ VRRM

Number % : Value of the % of VRMAX

Introduction & Context

- Previous test campaign results
  - ➢ Focus on STM Schottky diode result
  - ➢ Two different failure signature were observed during the first GANIL campaign.
    - Current step was the most common.
    - Ir degradation with fluence was only observed in some of the new prototypes.





Introduction & Context

- Objective of the work
  - perform SEB test under heavy ions
  - highlight rules for the selection of radiation tolerant diodes through various characterizations
  - Different manufacturers & relevant products for space industry

- For this study parts were provided by
  - STMicroelectronics
  - Thales Alenia Space
  - Airbus Defence and Space

- The project at a glance :
  - About 40 hours of Heavy Ion beam
  - > 270 runs performed
  - > 20 references tested
  - > 100 parts irradiated

Devices Under Test (1/2)

- Selection of additional references
  - Si & SiC schottky diodes

Reference	Diode Type	SiC	Manufacturer	Package	VRRM (V)	Number of sample
STPS3045-XF54S02Y	Schottky	no	STMicroelectronics	SMD 05	45V	10
STPS80H100	Schottky	no		SMD 1	100V	10
STPS30170-XZ04P029	Schottky	no		SMD 05	170V	10
STTH60400	Ultrafast	no		SMD 1	400V	8
STTH61W04CSA1 (equivalent STTH60400)	Ultrafast	no				2
STPSC1006	Schottky	yes		TO-220-2	600V	13
STPS40M60CR	Schottky	no		TO-220-3	60V	15
STPSC10H065	Schottky	yes		TO-220-2	650V	11
STPS4045CW	Schottky	no		TO-247-3	45V	11
STPS5H100BY	Schottky	no		DPACK	100V	5

Devices Under Test (2/2)

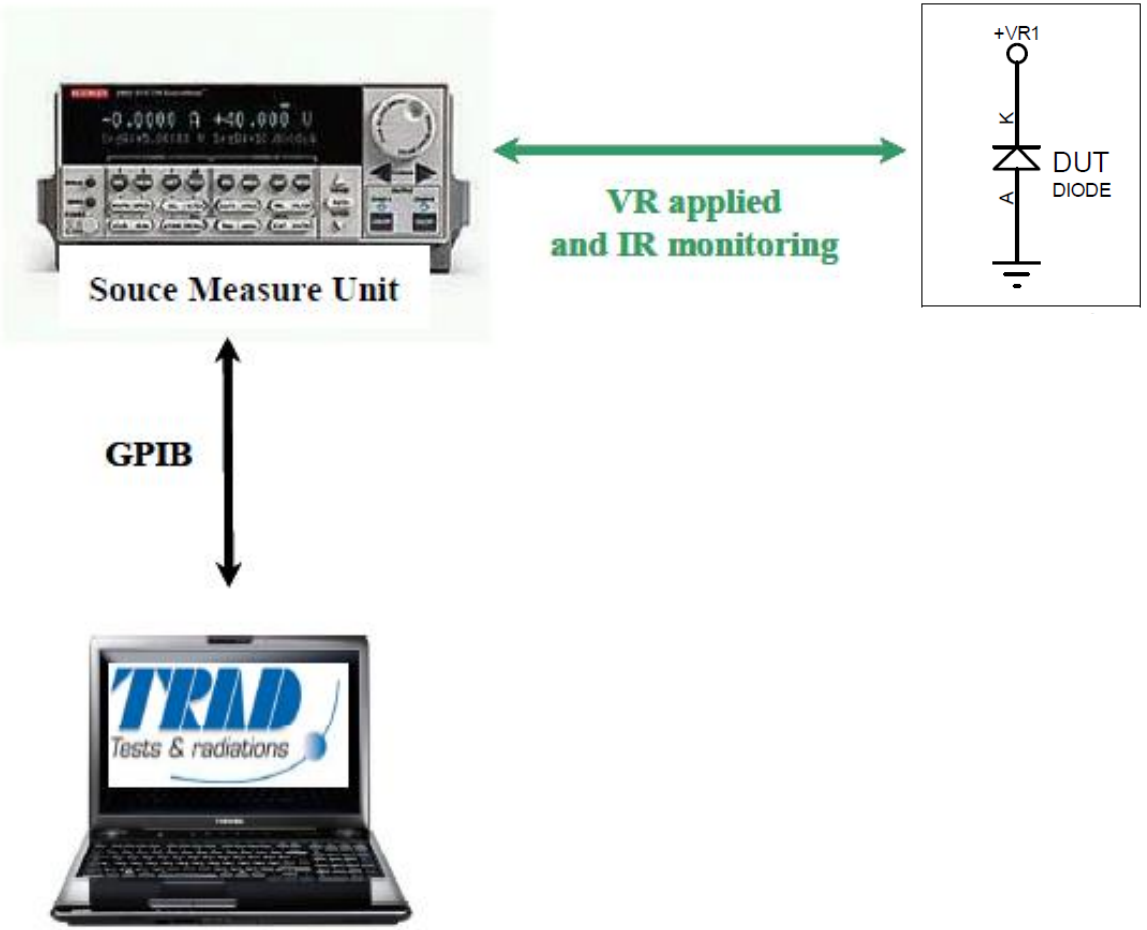
- Selection of additional references

Reference	Diode Type	SiC	Manufacturer	Package	VRRM (V)*	Number of sample
35CGQ100	Schottky	no	International Rectifier	TO-254	100V*	15
45CKQ100	Schottky	no		TO-258	100V	5
120LQ100	Schottky	no		SMD-1	100V*	12
HFB25HJ20	Ultrafast	no		SMD.5	200V	5
80CLQ150	Schottky	no		SMD-1	150V*	11
SML10SIC06SMD5	Schottky	yes	SemeLAB Limited	SMD.5	600V	6
MBRB8H100T4G	Schottky	no	On Semiconductor	D^2PACK	100V	6
BAS21LTG1	Fast Switching	no		SOT23	250V	5
1N6817	Schottky	no	Microsemi	ThinKey™2	100V*	9
SHDC124545P	Schottky	no	Sensitron Semiconductor	TO-258	150V*	12

➢ planar or trenched Schottky diodes and ultrafast rectifiers.

Test procedure & setup

- Setup considered
  - ➢ Measure leakage current behavior under irradiation on reverse-biased diodes.



- STATUS CRITERIA
  - ➢ SEB / Fail: abrupt leak of Ir during irradiation
    - ○ |Ir| > IR (@VRRM)
  - ➢ Failed PIST: abrupt leak of Ir during stress test
    - ○ |Ir| > IR (@VRRM)

Test procedure & setup

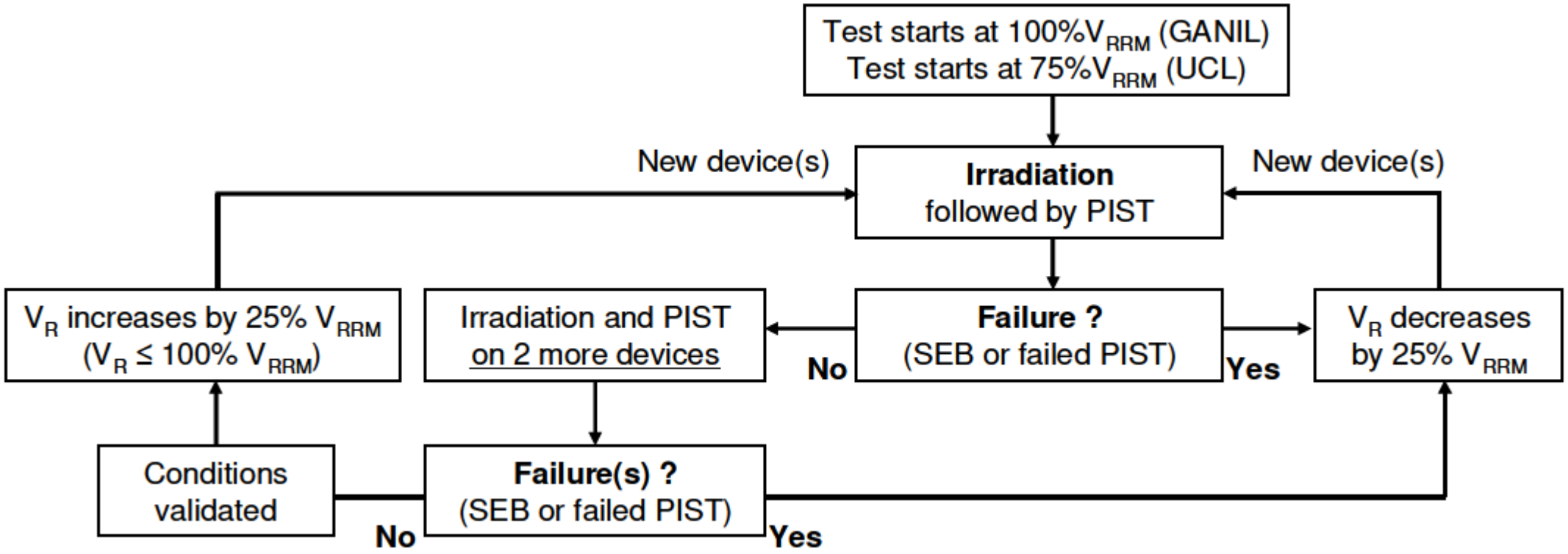
- Irradiations performed
  - Mostly at UCL
  - Complementary at GANIL

UCL BEAM CHARACTERISTICS	
Heavy Ions used :	Ions used: $^{124}Xe^{35+}$ (62.5 MeV.cm²/mg), $^{83}Kr^{25+}$ (32.4MeV.cm²/mg), $^{53}Cr^{16+}$ (16MeV.cm²/mg), Fluence: 1.10^7 cm^{-2} (in two steps 1.10^6 and 9.10^6 cm^{-2}) for Si Fluence: 3.10^5 cm^{-2} for silicon carbide diode

GANIL BEAM CHARACTERISTICS	
Heavy Ions used :	Ion: $^{136}Xe^{54+}$ Air / Al (mm / µm) : 100 / 550 Init. / final energy (MeV) : 6709.2 / 6.0 Range (µm) : 61.0 LET (MeV.cm2.mg-1) : 61.0* *comparable to the first UCL configuration in Table I and used as a reference point

Test procedure & setup

- Heavy ions test plan
  - ➢ PIST (Post-Irradiation Stress Test) : After the irradiation, a stress is applied to the diode in order to reveal any latent damage on the irradiated devices.



Heavy Ions Test Results

		Xe (LET=62.5MeV.cm²/mg)			Kr (LET=32.4MeV.cm²/mg)			Cr (LET=16MeV.cm²/mg)			Al (LET=5.7MeV.cm²/mg)		
		Ok	Failed PIST	Fail	Ok	Failed PIST	Fail	Ok	Failed PIST	Fail	Ok	Failed PIST	Fail
STMicroeletronics	STTH60400	100%											
	STPS3045	75%											
	STPS4045CW	56%		75%									
	STPS30170	50%	75%	100%	75%								
	STPS40M60CR	50%		75%	75%								
	STPS80H100				75%								
	STPS5H100BY		75%	75%	75%								
	STPSC10H065*				57%		93%	66%		100%	100%		
	STPSC1006*				50%		86%	69%		93%	93%		100%
International Rectifier	45CKQ100	100%											
	35CGQ100	100%											
	HFB25HJ20	75%		100%									
	120LQ100	75%		100%									
	80CLQ150	75%		100%									
On semi	BAS21LTG1	100%											
	MBRB8H100T4G	75%		100%									
Semelab	SML10SIC06SMD5*		29%	58%	33%		50%		42%				
diodes inc.	1N4148WQ	100%											
Microsemi	1N6817	75%											
Sensitron	SHDC124545P	100%											

** Silicone carbide diode*

- PART could be “FAIL” but not necessary “not functional”

Fail : IR > IR @ VRRM

PASS: IR < IR @ VRRM

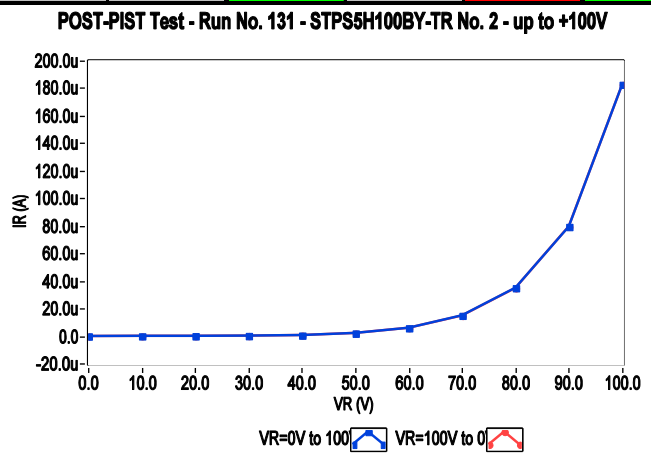
Number % : Value of the % of VRMAX

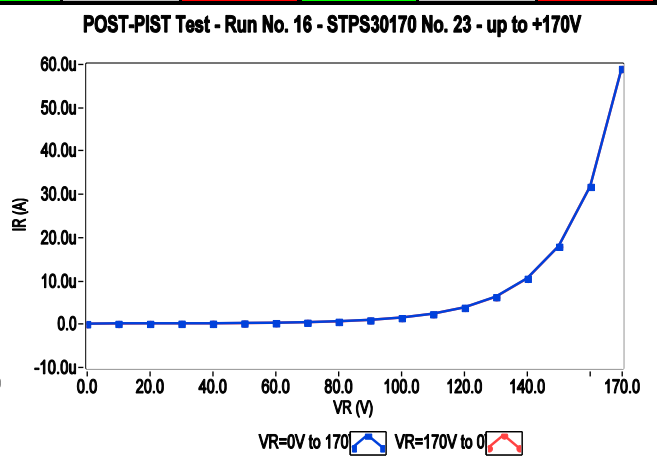
Heavy Ions Test Results

- Focus on **ST Microelectronics** results
  - ➢ 2 references "Fail" after a PIST → degradation of the leakage current

		Xe (LET=62.5MeV.cm²/mg)			Kr (LET=32.4MeV.cm²/mg)			Cr (LET=16MeV.cm²/mg)			Al (LET=5.7MeV.cm²/mg)		
		Ok	Failed PIST	Fail	Ok	Failed PIST	Fail	Ok	Failed PIST	Fail	Ok	Failed PIST	Fail
STMicroeletronics	STTH60400	100%											
	STPS3045	75%											
	STPS4045CW	56%		75%									
	STPS30170	50%	75%	100%	75%								
	STPS40M60CR	50%		75%	75%								
	STPS80H100				75%								
	STPS5H100BY		75%	75%	75%								
	STPSC10H065*				57%		93%	66%		100%	100%		
	STPSC1006*				50%		86%	69%		93%	93%		100%

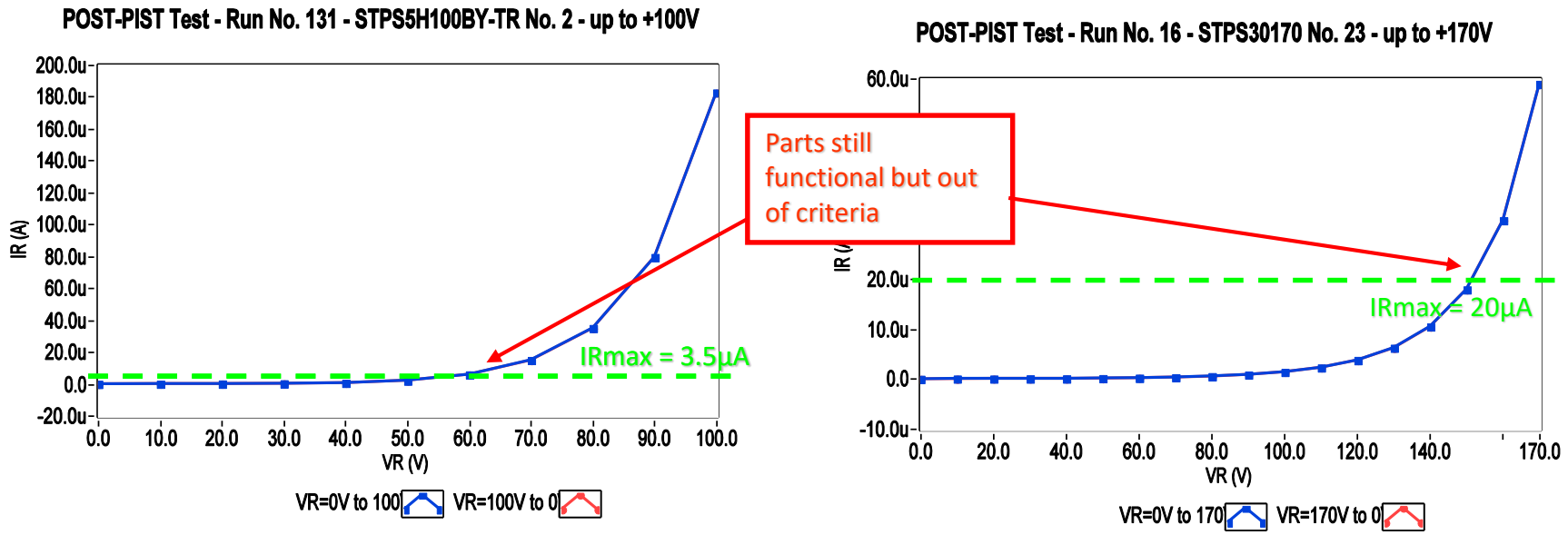
* Silicone carbide diode





Heavy Ions Test Results

- Focus on **ST Microelectronics** results
  - ➢ 2 references “Fail” after a PIST → degradation of the leakage current
  - ➢ for the example IRmax respectively equal to 3.5µA and 20µA



Heavy Ions Test Results

- Focus on **International Rectifier** results

		Xe (LET=62.5MeV.cm²/mg)			Kr (LET=32.4MeV.cm²/mg)			Cr (LET=16MeV.cm²/mg)			Al (LET=5.7MeV.cm²/mg)		
		Ok	Failed PIST	Fail	Ok	Failed PIST	Fail	Ok	Failed PIST	Fail	Ok	Failed PIST	Fail
STMicroeletronics	STTH60400	100%											
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	STPS80H100				75%								
	STPS5H100BY		75%	75%	75%								
	STPSC10H065*				57%		93%	66%		100%	100%		
	STPSC1006*				50%		86%	69%		93%	93%		100%
International Rectifier	45CKQ100	100%											
	35CGQ100	100%											
	HFB25HJ20	75%		100%									
	120LQ100	75%		100%									
	80CLQ150	75%		100%									
On semi	BAS21LTG1	100%											
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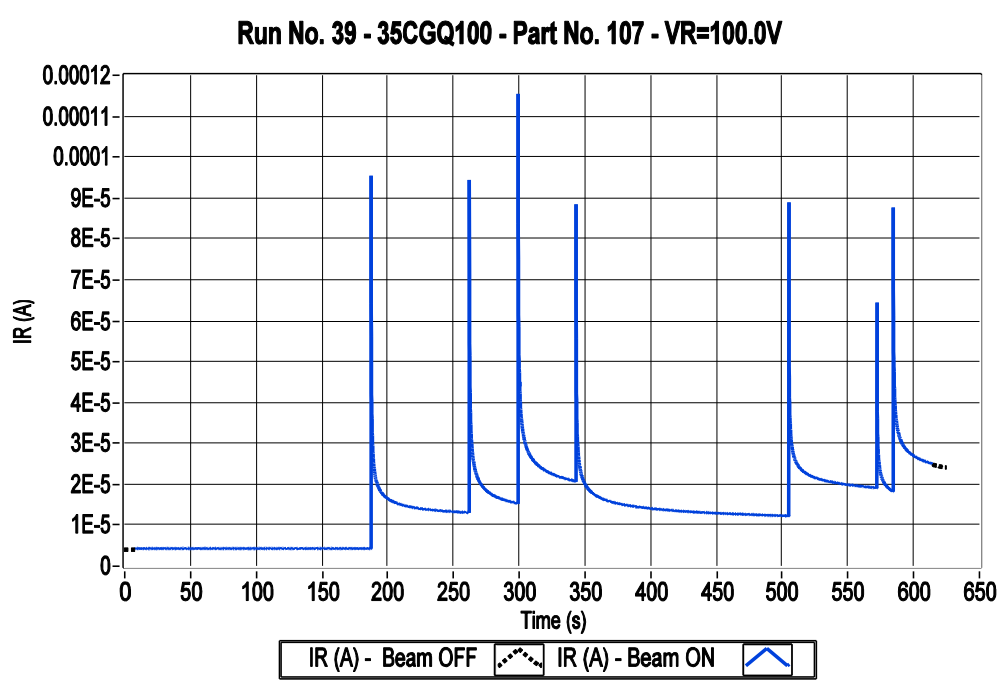
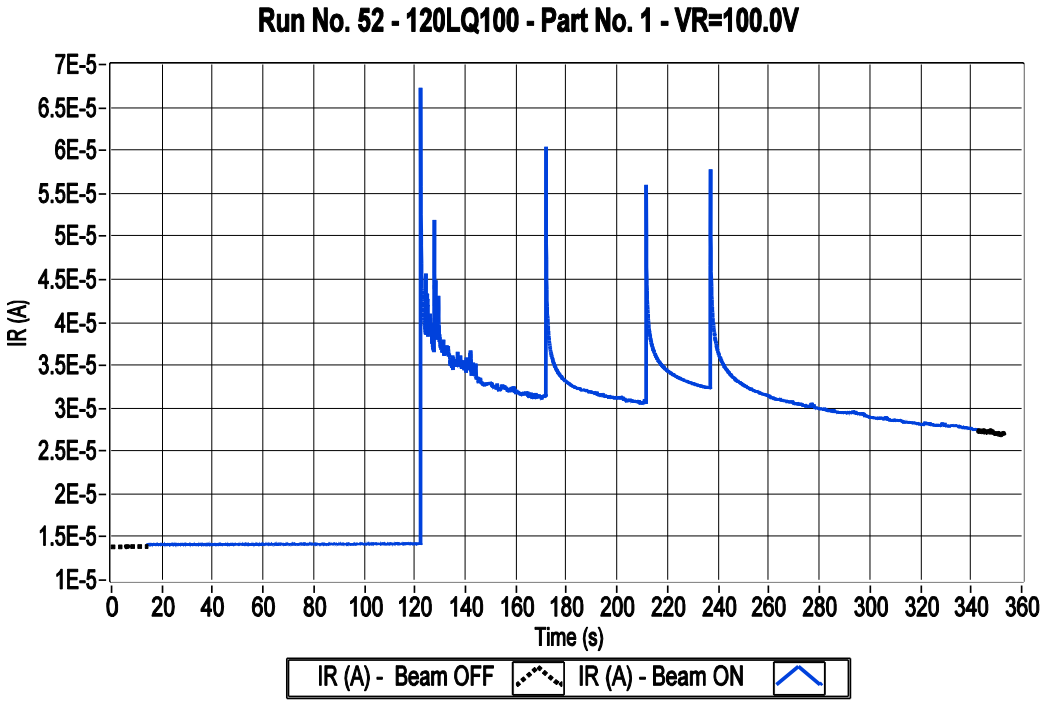
Semelab	SML10SIC06SMD5*		29%	58%	33%		50%		42%				
diodes inc.	1N4148WQ	100%											
Microsemi	1N6817	75%											
Sensitron	SHDC124545P	100%											

* Silicone carbide diode

Heavy Ions Test Results

- Focus on **International Rectifier** results
  - Same kind of behaviour observed ion different references
  - PARTS are still functional





Heavy Ions Test Results

- Focus on **SiC diodes**
  - ➢ information on literature about the sensitivity of SiC diode (at that time)
  - ➢ SiC diodes seem more sensitive to destructive events
    - Consistent with work published in the past years

		Xe (LET=62.5MeV.cm²/mg)			Kr (LET=32.4MeV.cm²/mg)			Cr (LET=16MeV.cm²/mg)			Al (LET=5.7MeV.cm²/mg)		
		Ok	Failed PIST	Fail	Ok	Failed PIST	Fail	Ok	Failed PIST	Fail	Ok	Failed PIST	Fail
STMicroeletronics	STTH60400	100%											
	STPS3045	75%											
	STPS4045CW	56%		75%									
	STPS30170	50%	75%	100%	75%								
	STPS40M60CR	50%		75%	75%								
	STPS80H100				75%								
	STPS5H100BY		75%	75%	75%								
	STPSC10H065*				**57%**		**93%**	**66%**		**100%**	**100%**		
	STPSC1006*				**50%**		**86%**	**69%**		**93%**	**93%**		**100%**
International Rectifier	45CKQ100	100%											
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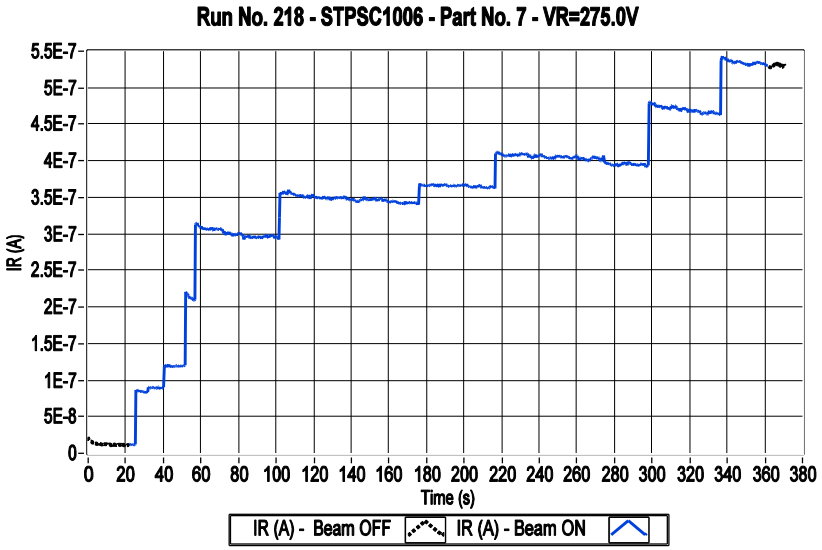
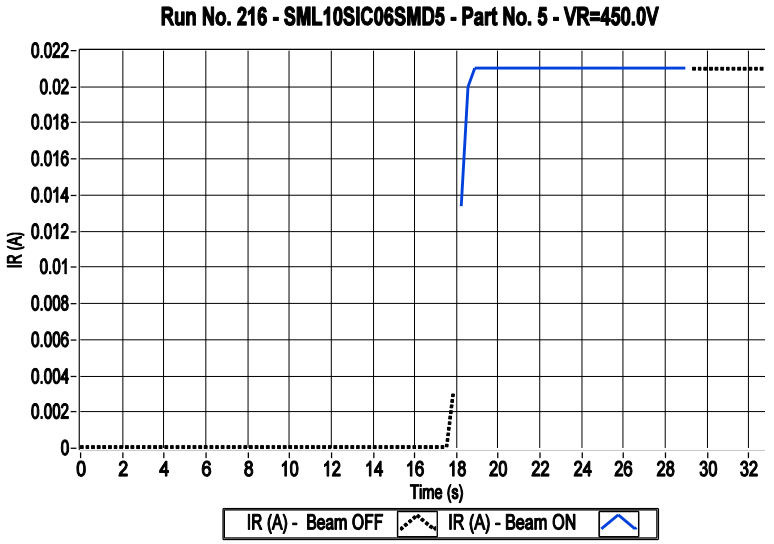
	80CLQ150	75%		100%									
On semi	BAS21LTG1	100%											
	MBRB8H100T4G	75%		100%									
Semelab	**SML10SIC06SMD5***		**29%**	**58%**	**33%**		**50%**		**42%**				
diodes inc.	1N4148WQ	100%											
Microsemi	1N6817	75%											
Sensitron	SHDC124545P	100%											

Heavy Ions Test Results

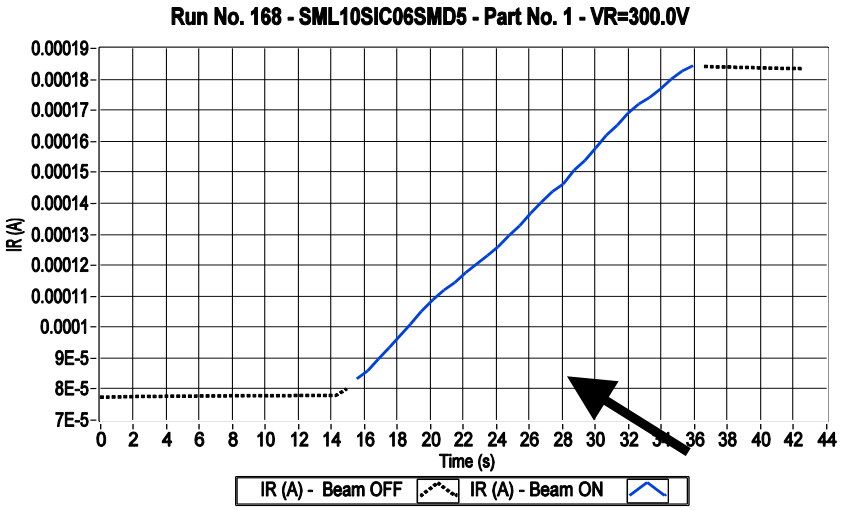
- Focus on **SiC diodes**
  - ➢ Various behavior observed
  - ➢ These signatures were observed for the 3 references of SiC diode.



Degradation by step



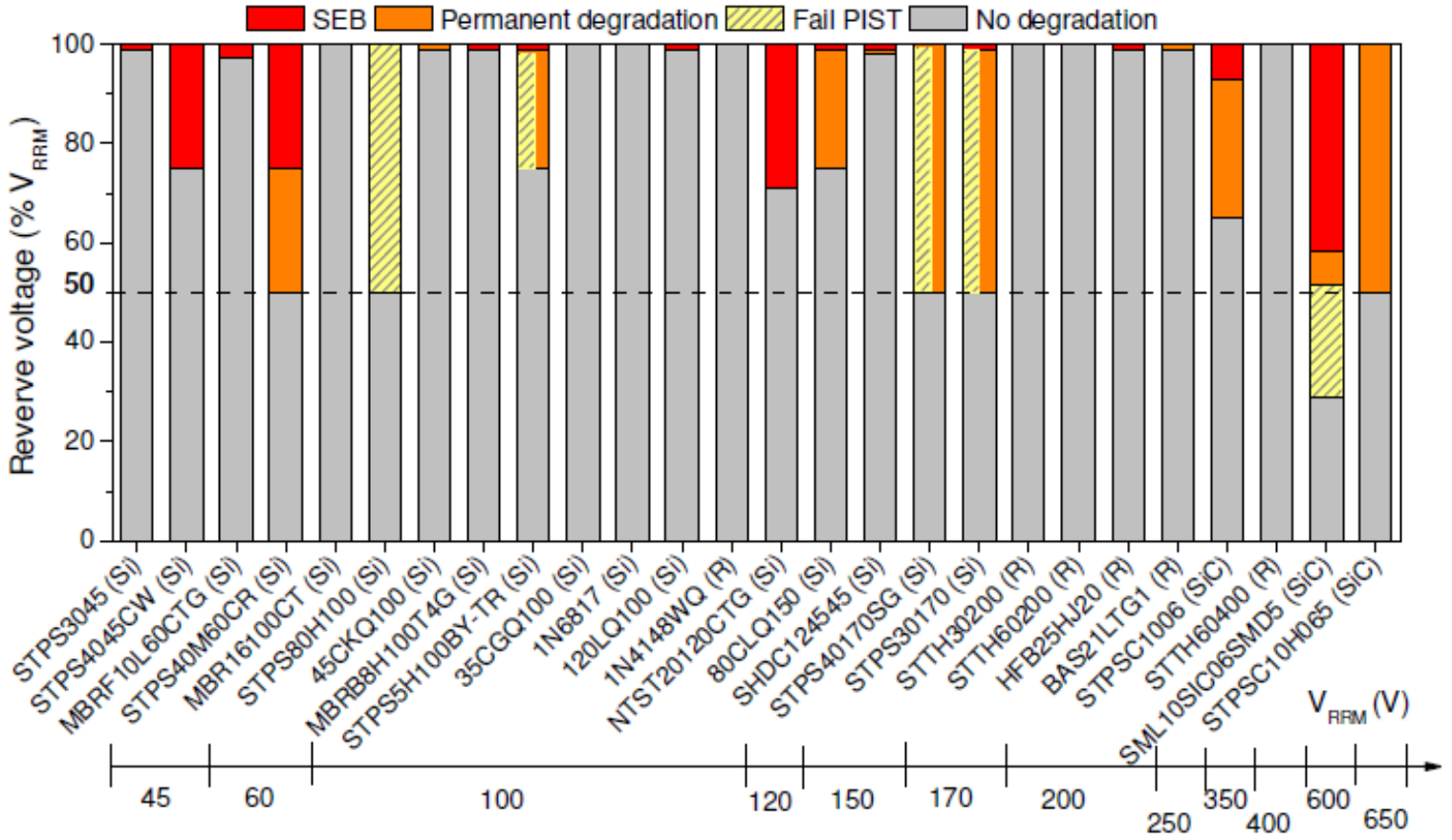
Abrupt degradation of the leakage



Increase of leakage current proportional to the fluence and flux

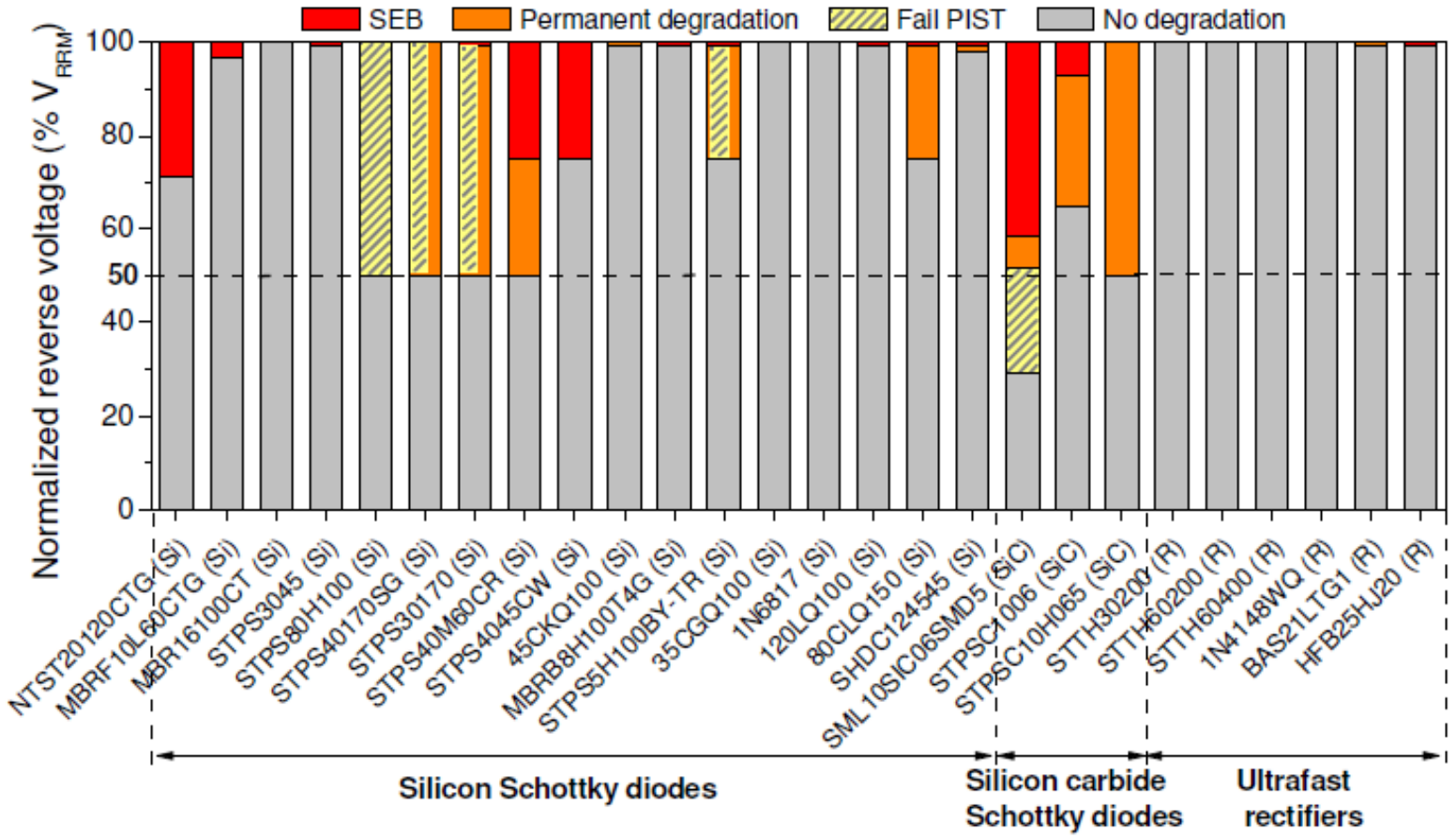
Synthesis

- normalized synthesis of SEE during irradiations or PIST, sorted by ascending VRRM
  - ➢ No relationship between VRRM and heavy ion sensitivity



Synthesis

- Test results as a function of the normalized applied reverse voltage



Synthesis

- SEE sensitivity depends on the applied reverse voltage
  - Consistent with physical phenomena, based on impact ionization triggered by high local electric field close to the Schottky junction
- 75% VRRM derating used for diodes does not ensure safe operating conditions against HI
  - The 50%VRRM derating [M.Casey,2015] [M.Casey,2016] seems to be more reliable
  - 1 exception over 23 references
- Trench-based Schottky diode (NTST20120CTG)
  - most sensitive silicon device with critical failures from VR=70%VRRM (despite better distribution of electric field)
- 3 studied SiC Schottky diodes
  - two show critical failure and permanent degradation
  - at quite low LET (32,4 MeV.cm²/mg) & at rather low VR/VRRM ratio
- Ultrafast rectifiers seem to be radiation resistant
  - 2 failures at high LET and 100 %VRRM over the 6 references

Conclusion

- More than 20 reference tested
  - ➢ half is degraded due to heavy ions irradiation
- 3 different phenomena triggered by heavy ions
  - ➢ permanent degradation, failure during irradiation and failure during post-irradiation stress (PIST).
- Derating to 50% seems more secure
- SiC diode technology seems more sensitive than Si diode technology
  - ➢ More investigation on SiC diode have to be performed in order to understand the different phenomenon observed
  - ➢ Various work published on SiC diodes in the past years
- RADECS 2018 « Analysis of Heavy Ion Irradiation Test Results on Power Diodes »,
  - ➢ M. Mauguet[1], D. Lagarde[2], L. Azema[1], E. Le Goulven[1], A. Varotsou[1], X. Marie[2], C. Boatella-Polo[3] ([1] TRAD, [2]INSA LPCNO, [3]ESA)

Thank you for your attention

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