Reliability Assessment of medium / large area PIN Si photodiodes for Optical Wireless Links for intra-Spacecraft communications (OWLS)

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First International Symposium
on Reliability of Optoelectronics for Space
(Cagliari, May 11-14, 2009)

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Outline

- **Motivation / Introduction**
  - **Why using COTS in Space?**
  - **COST require testing and qualification**
  - **Applications**
- **Proton radiation tests**
  - **Devices under test**
  - **Experimental Set-Up**
  - **Results**
- **Reliability Assessment Tests**
  - **Setup preparation**
  - **Pass-Fail criteria**
  - **Pre-evaluation of 4 pre-selected devices (20 Samples)**
  - **Environmental and Lifetime Evaluation Plan (75 Samples)**
- **Conclusions**

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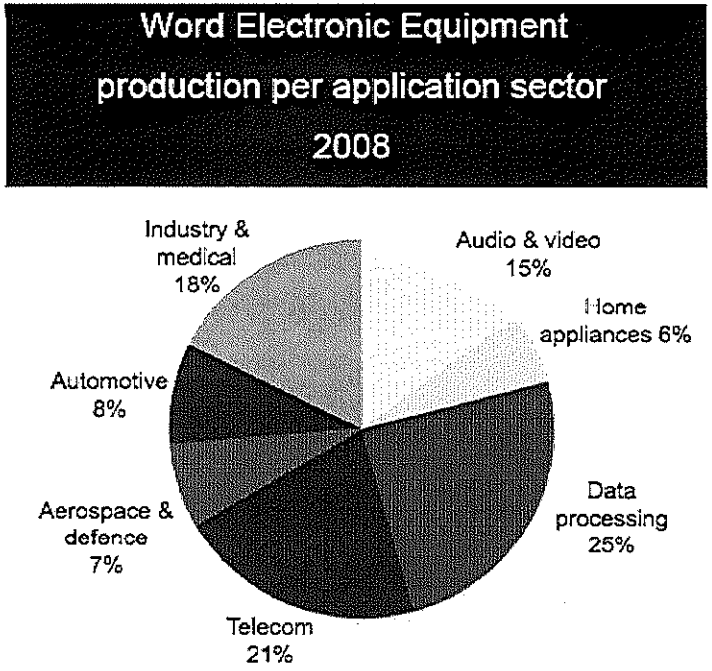
Why using COTS in Space?

- Technical requirements of optoelectronic applications for space need of "last minute" technologies.
- On the other hand, Defence and Space semiconductor & electronics market is small and decreasing every year..



- Therefore, the variety of technologies & solutions already qualified, available in D & S markets is very limited.

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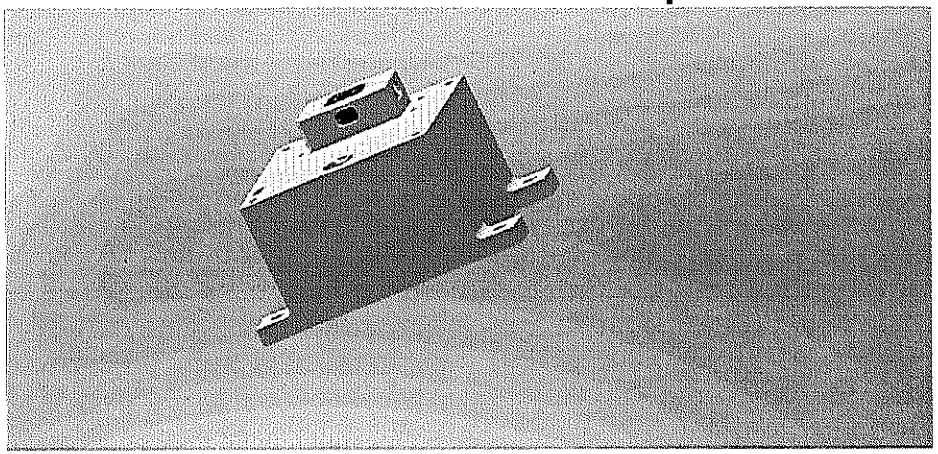
Why using COTS in Space?

- **Requirements for OWLS detectors**

	Detectors (PIN Photodiodes)			
	Technology	Active Area (mm^2)	FOV (°)	C_p @ 3.3 V (pF)
Directed LOS High Speed	Silicon / GaAlAs	< 0.5	< ±10	< 2
	Number of detectors	Spectral Filters	Optical elements	
	1	—	Focusing lens or Non Imaging Optics element (CPC)	

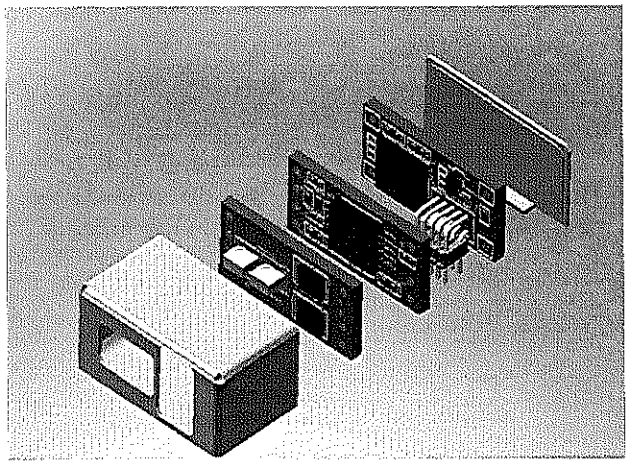
Solar Sensor with OWLS communication capabilities



Needed performances only in COTS components!!!

	Detectors (PIN Photodiodes)			
	Technology	Active Area (mm^2)	FOV (°)	C_p @ 3.3 V (pF)
Total DIFFUSION Medium & Low Speed	Silicon / GaAlAs	> 7 - 50	< ±80	< 30-120
	Number of detectors	Spectral Filters	Optical elements	
	Array of PD with different orientations is preferred	Yes (for WDMA)	Baffle & hemispheric lens to increase the collection of light	

OPTOS OWLS Module



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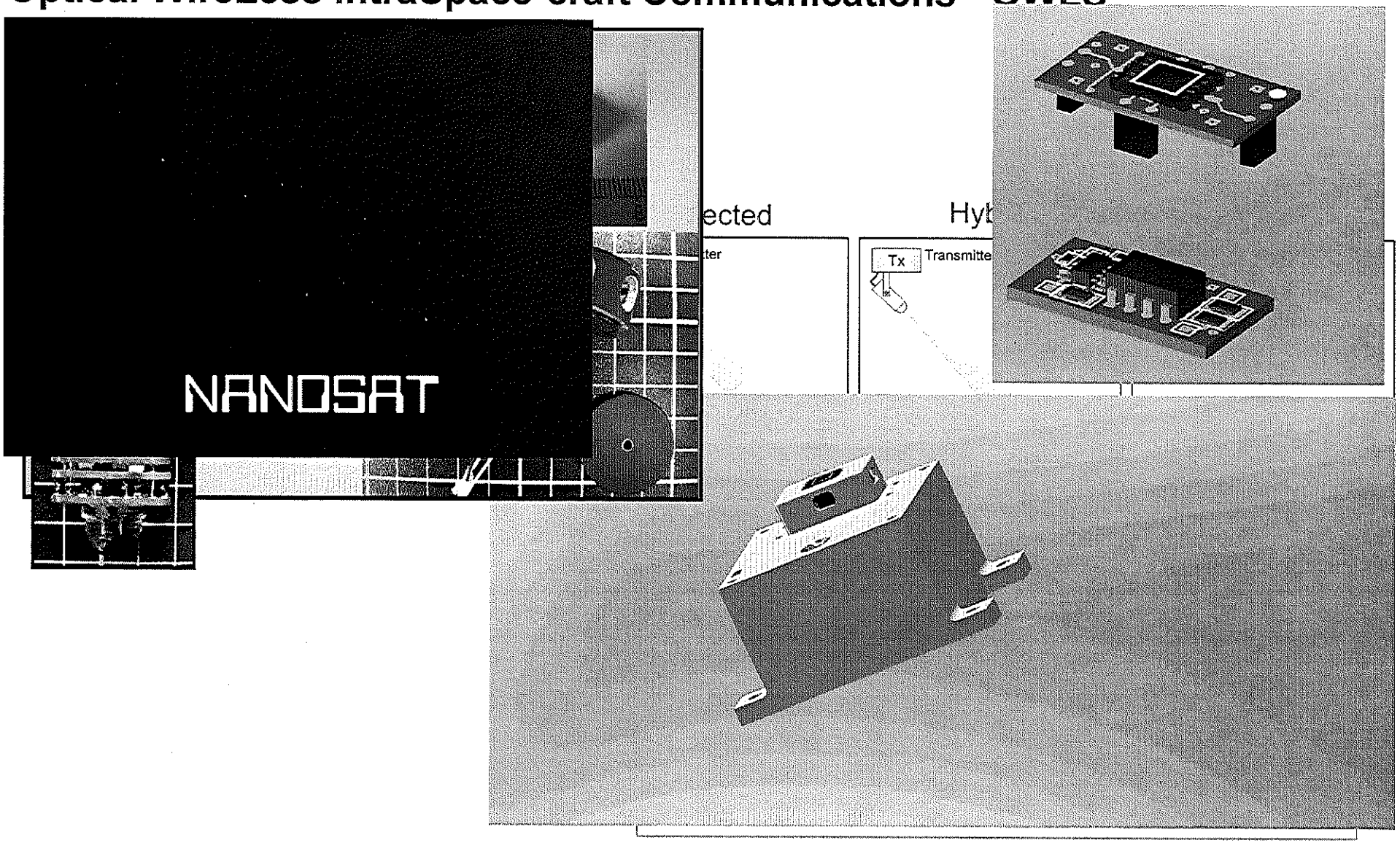
Optical WireLess intraSpace-craft Communications - OWLS



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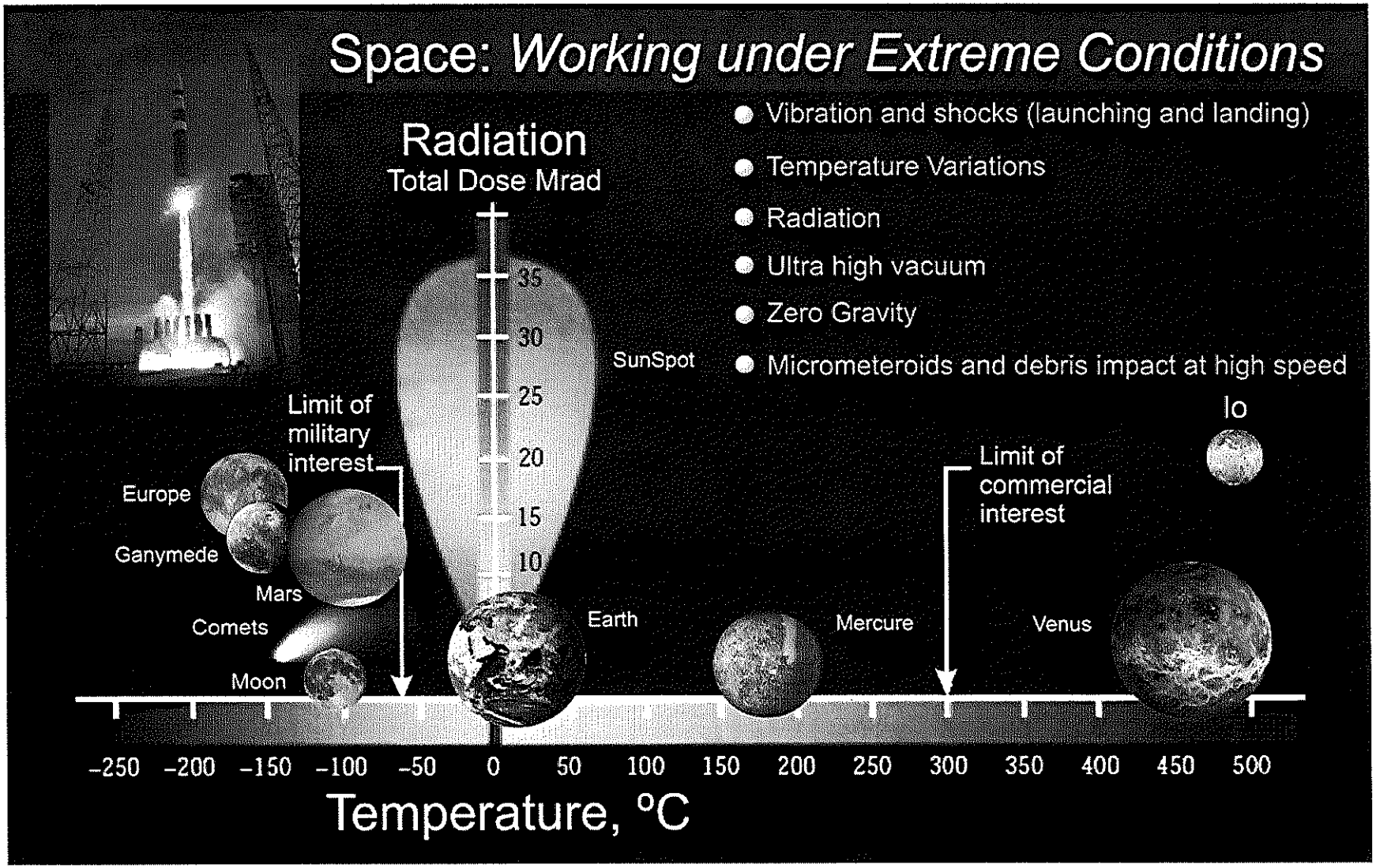
COTS – Testing and Qualification



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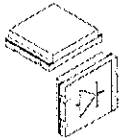
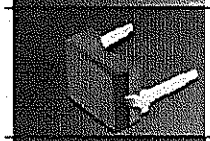
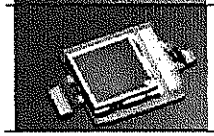
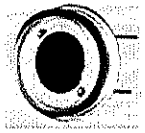
Photodiodes for OWLS – Radiation Tests

Picture	Part Number	Manufacturer	Active Area (mm^2)	Optical Filter	Responsivity max. (mA/W)	Dark current typ. (nA)	Package Style	Irradiation ID	Nº Parts irradiated
	**TEMD5010**	Vishay	7.5	No	--	2.0	Plastic	4 & 6	2 & 1
	TEMD5110	Vishay	7.5	Yes	--	2.0	Plastic	4 & 6	2 & 1
	**BPW 34**	Osram	7.0	No	620	2.0	Plastic	1,5 & 6	2,7 & 1
	**BPW 34F**	Osram	7.0	Yes	590	2.0	Plastic	1,5 & 6	2,7 & 1
	**BPW34S**	Osram	7.0	No	590	2.0	Plastic	6	1
	**PC20-7**	Pacific Silicon Sensor	20.0	No	650	0.5	Clear Glass	4	2
	**PC50-7**	Pacific Silicon Sensor	50.0	No	650	2.0	Clear Glass	4	2

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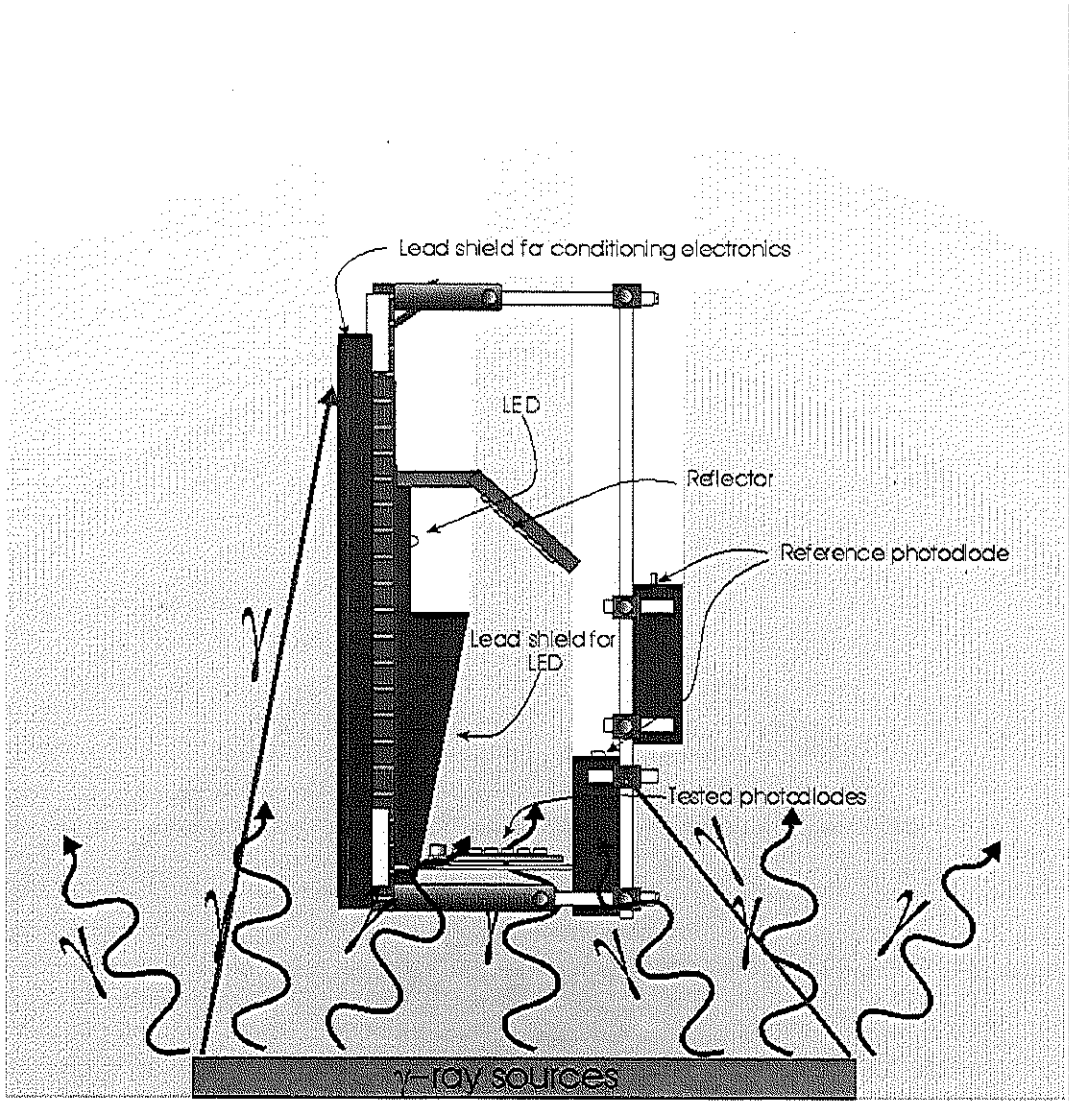
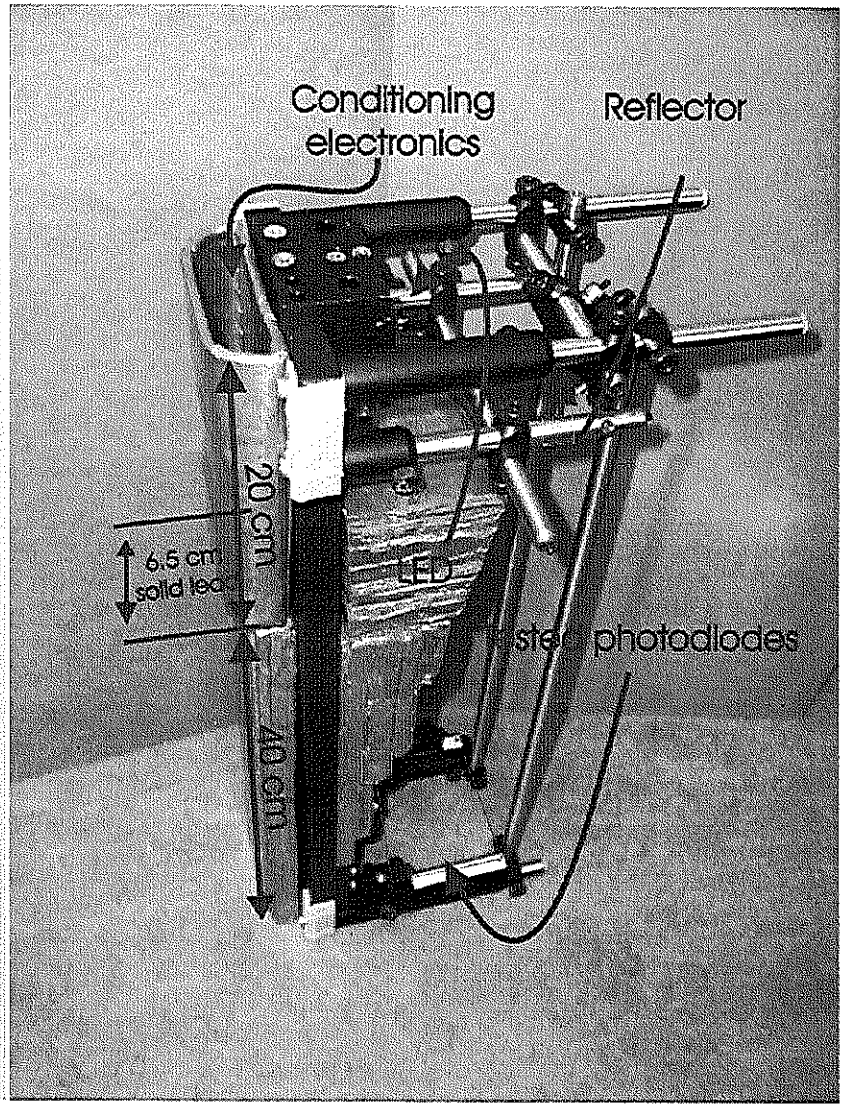
Photodiodes – Radiation Facilities and Campaigns

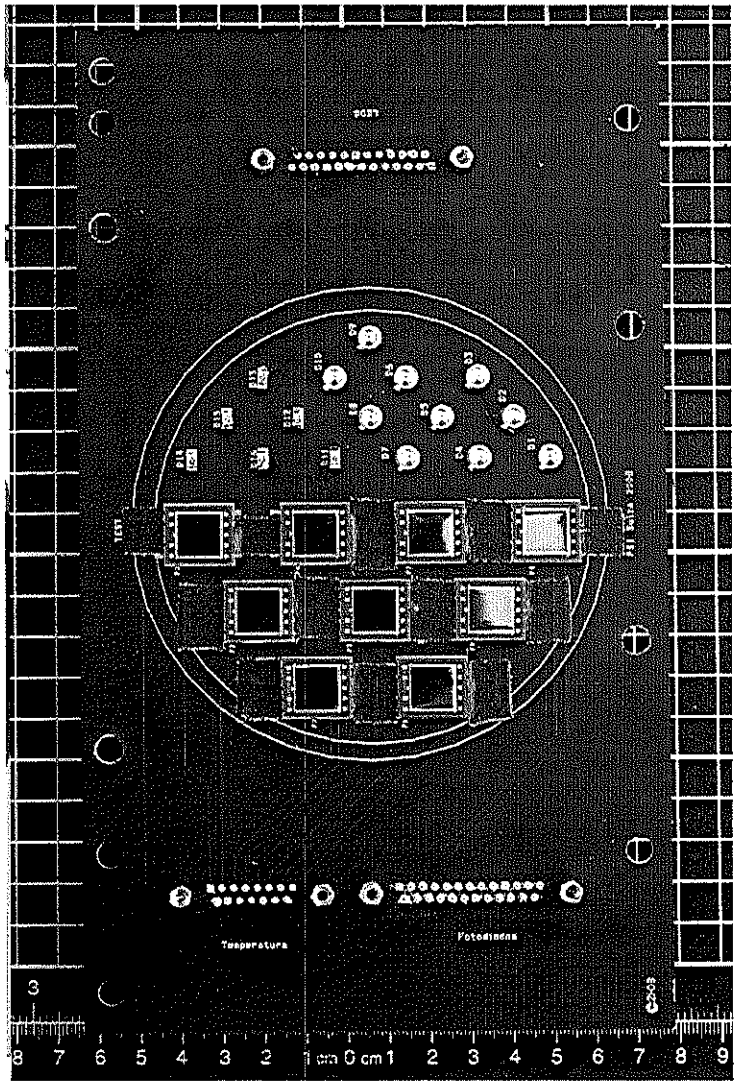
ID	Date	CODE	Institution / Facility	Country	Particle	Energy (MeV)	Maximum Fluence
1	09/14/2004	LIF	Light Ion Irradiation Facility	Belgium	Protons	~50	$2.08 \cdot 10^{12}$
2	03/03/2005	LIF	Light Ion Irradiation Facility	Belgium	Protons	~50	$2.81 \cdot 10^{12}$
3	12/07/2005	LIF	Light Ion Irradiation Facility	Belgium	Protons	~30, ~60	$2.31 \cdot 10^{12}$
4	07/09/2006	RADEF	Radiation Effects Facility	Finland	Protons	~50	$2.22 \cdot 10^{12}$
5	07/01/2006	PSI	Paul Scherrer Institut	Switzerland	Protons	~50	$5.50 \cdot 10^{12}$
6	10/26/2006	PSI	Paul Scherrer Institut	Switzerland	Protons	~50	$1.23 \cdot 10^{10}$
7	02/13/2007	PSI	Paul Scherrer Institut	Switzerland	Protons	~10, ~15, ~20, ~25, ~30, ~40, ~50, ~60	$4.10 \cdot 10^{9}$

Radiation Tests- Experimental Set-Up - Gamma Irradiation

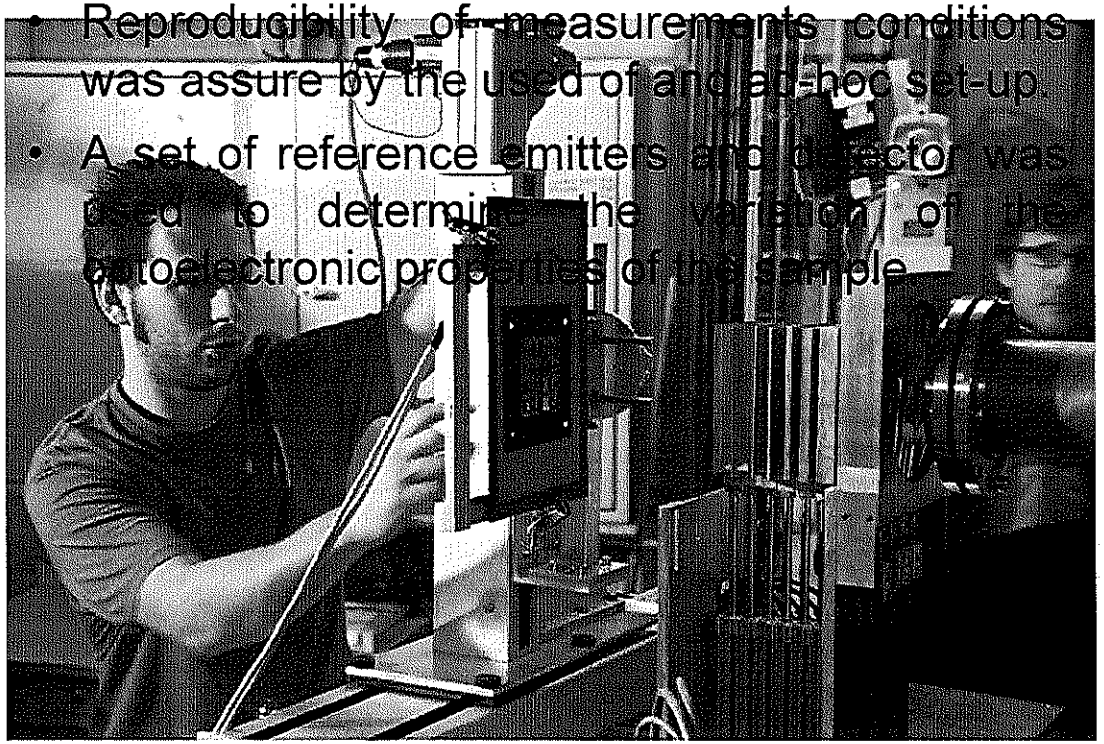




Radiation Tests- Experimental Set-Up - Proton Irradiation



- Devices under test arranged in PCB boards.
- Irradiations were carried out in air and at room temperature.
- Electro-optical properties of the PIN were measured after every irradiation step..
- Maximum proton fluences were reached in several irradiation steps.
- Reproducibility of measurements conditions was assure by the used of and ad-hoc set-up
- A set of reference emitters and detector was used to determine the variation of the optoelectronic properties of the sample



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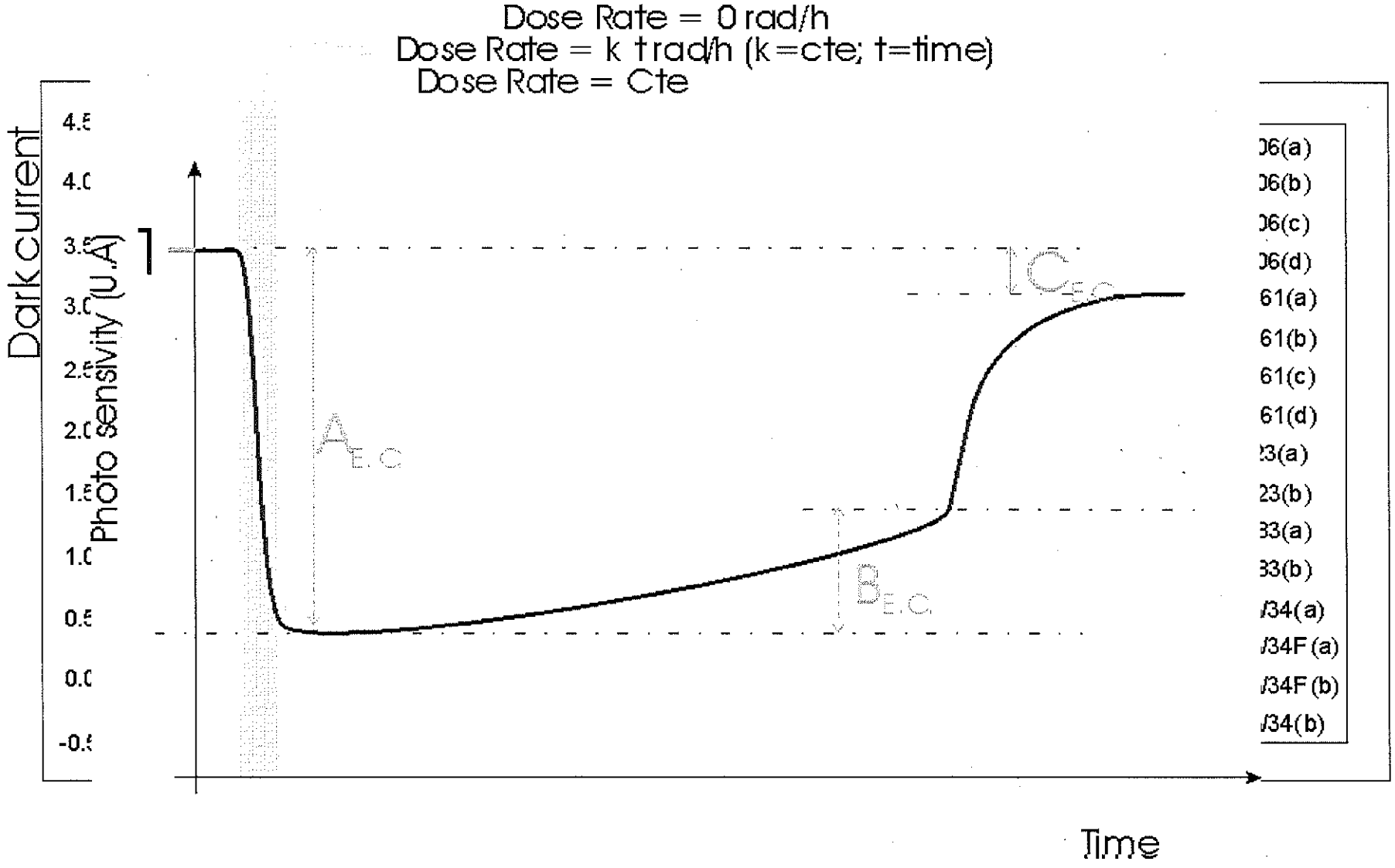
Irradiation with Gamma - Results



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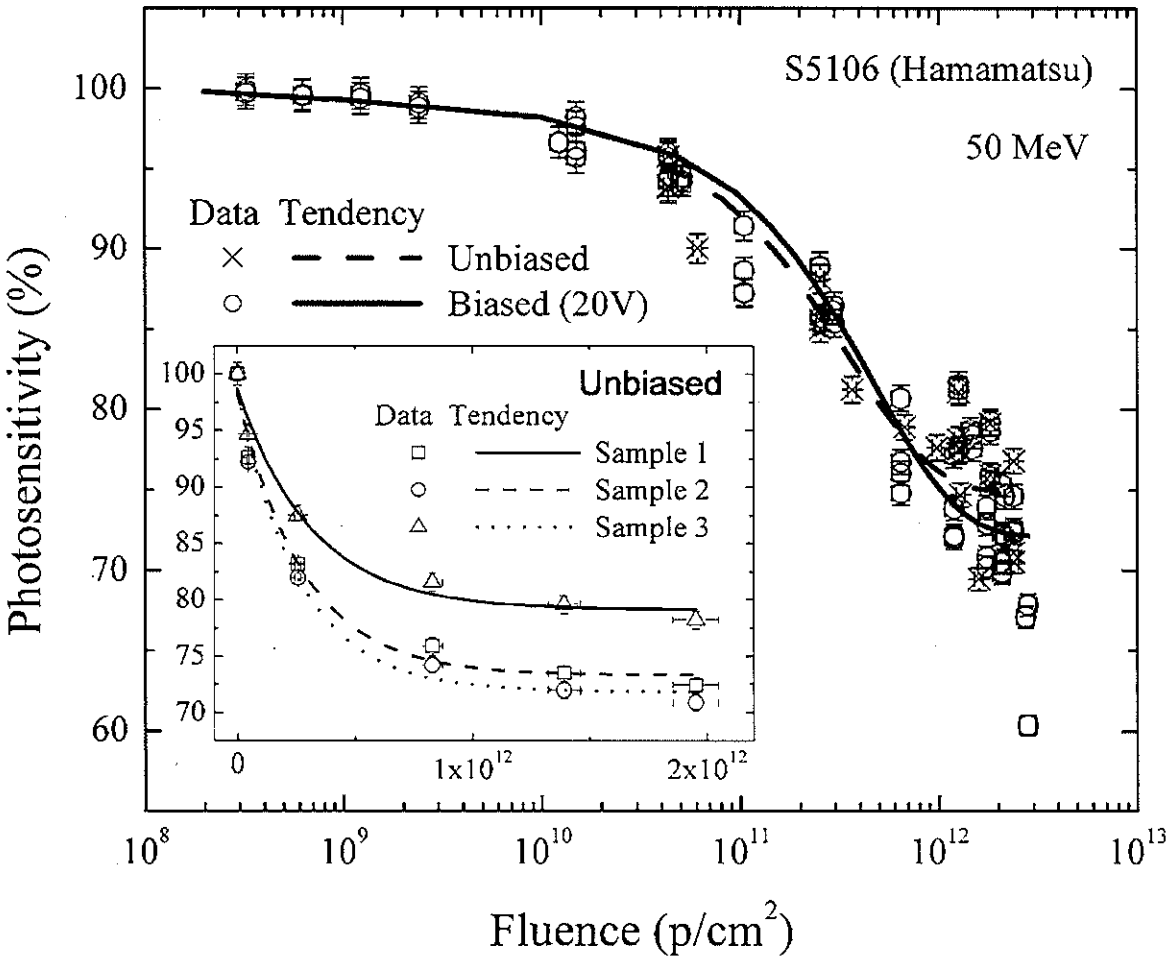
Proton Irradiation – Photosensitivity



- Photosensitivity degradation under 50 MeV proton irradiation
- Biased (20V) and unbiased devices tested.
- Proton fluences up to ~ 2.5 10^{12} p/cm^2 .
- Photosensivity decreases down to the 70% of the initial value.
- No differences detected between the biased and the unbiased samples.

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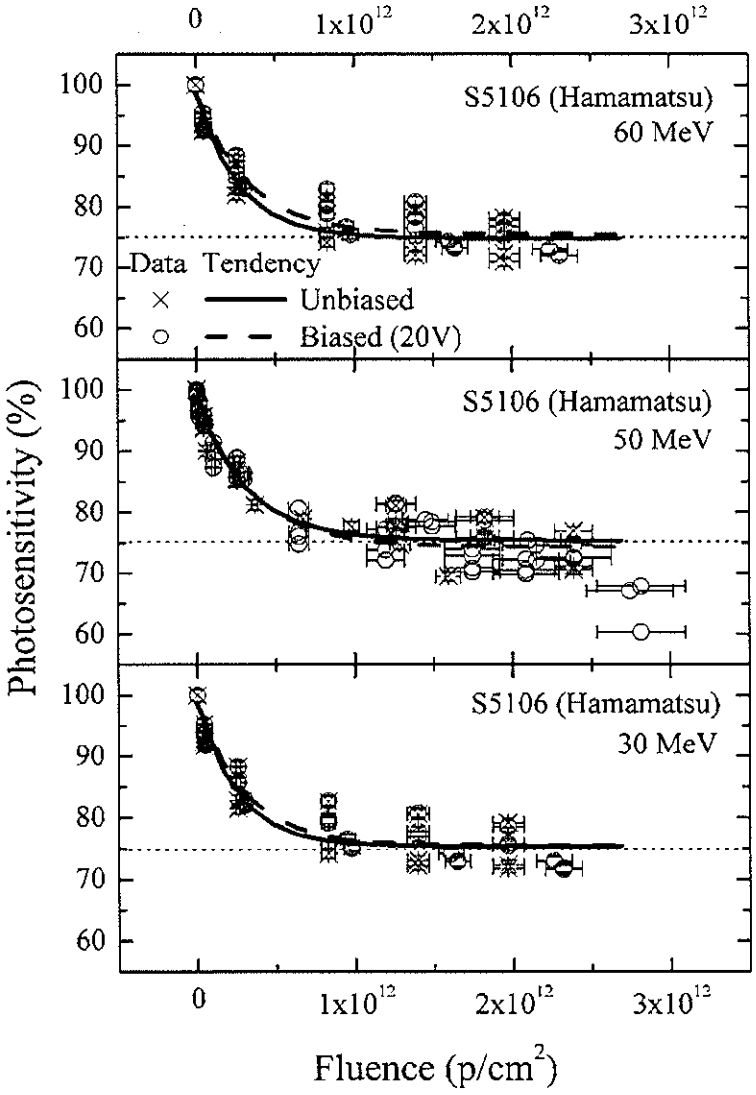
Proton Irradiation – Photosensitivity II



- No differences observed with different proton irradiation energies: ~30, ~50 and ~60 MeV.

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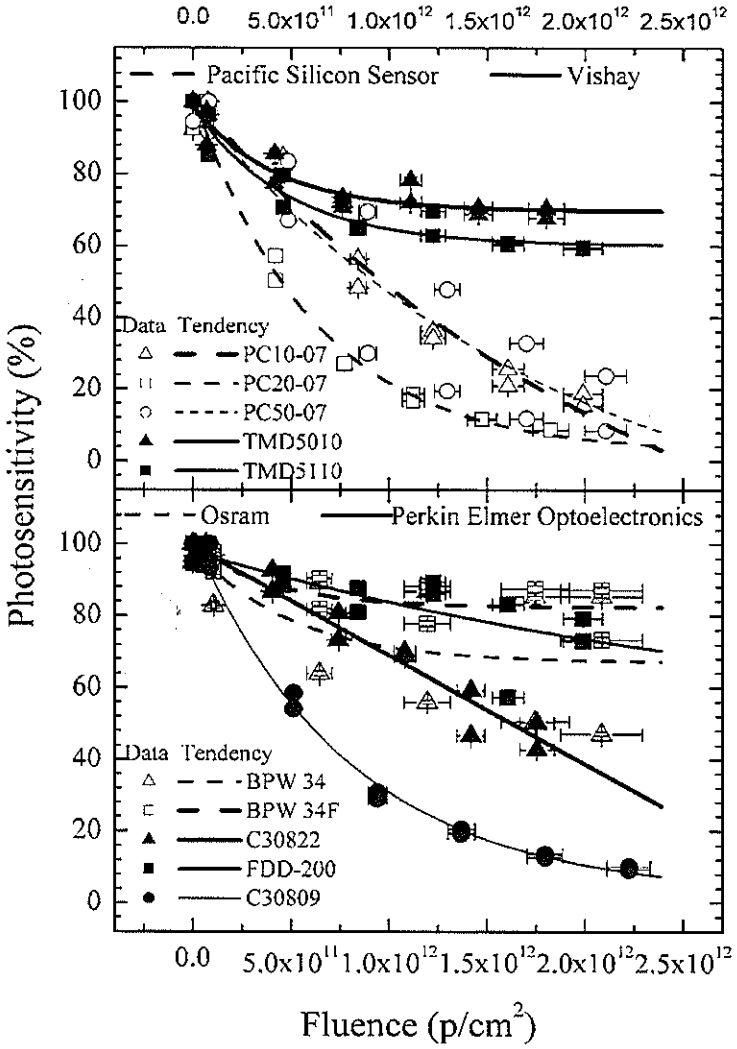
Proton Irradiation – Photosensitivity III



- The photosensivity degradation under proton irradiation highly depends on the manufacturer and technology of the irradiated photodiode.
- The TMD5010 or the BPW34 decrease their photosensivity to just the 80-70% of their initial value.
- Other photodiode types are almost destroyed after proton irradiation

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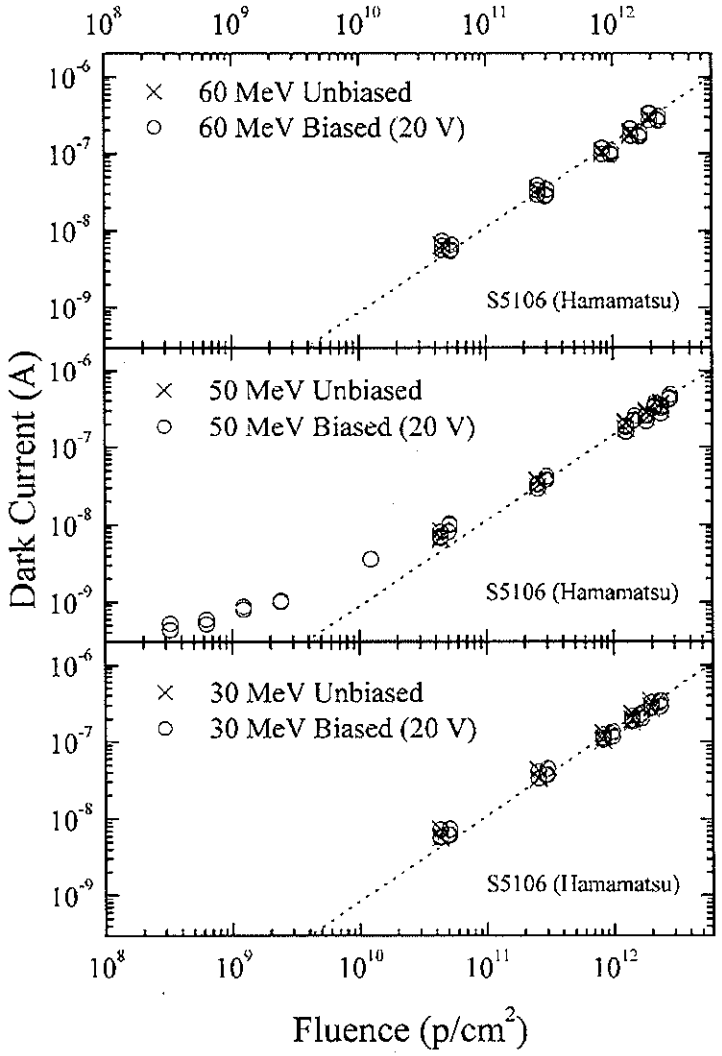
Proton Irradiation – Dark Current



- Proton irradiation produces and increase in the dark current of the photodiodes.
- Dark current increases from a few tens of nA up to some μA for proton fluences of ~ 2.5 10^{12} p/cm^2
- No differences in the dark current increment have been detected with different proton irradiation energies (~30, ~50 and ~60 MeV).
- Neither between the biased and unbiased photodiodes.

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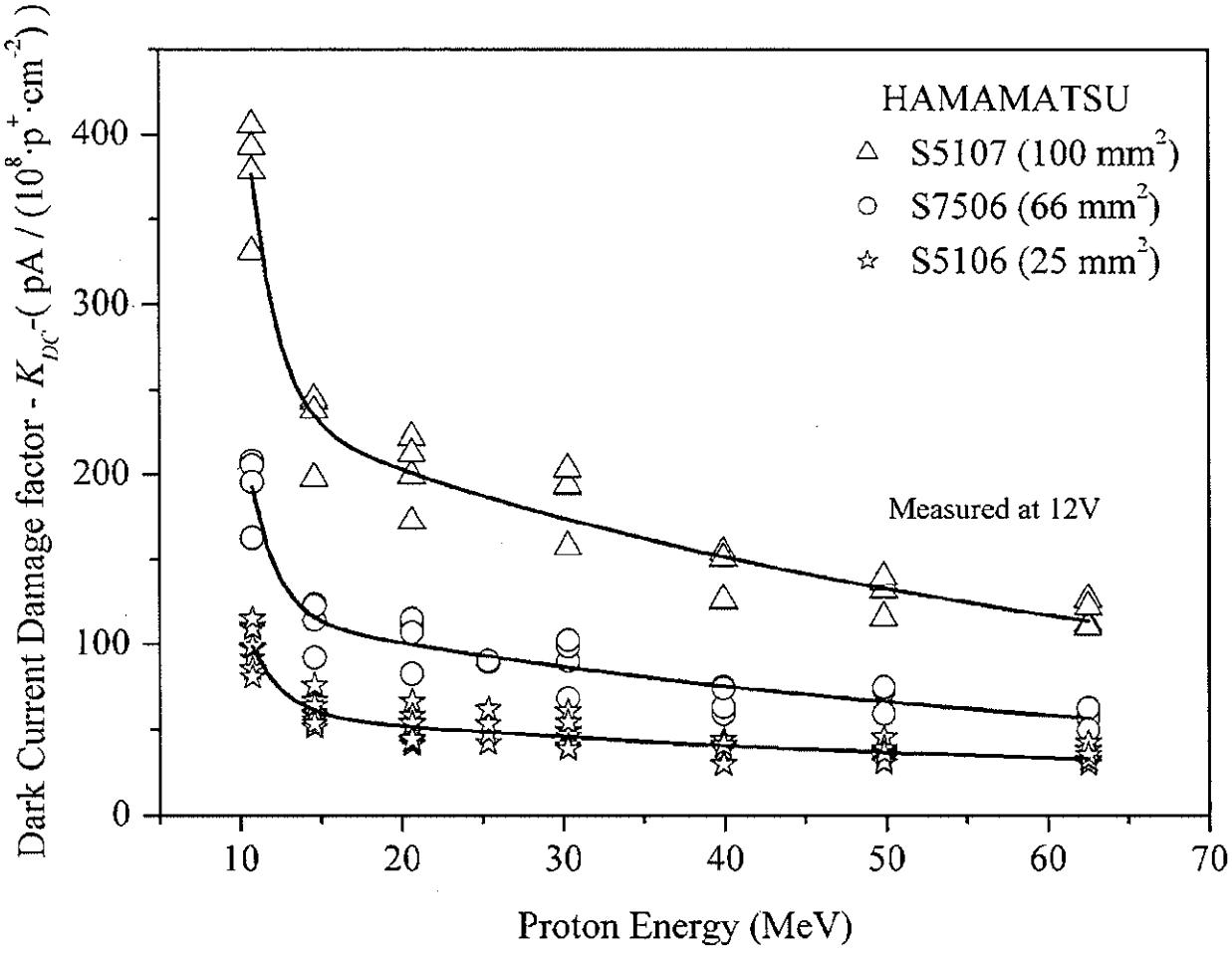
Proton Irradiation – Dark Current



- Photodiode sensibility to proton damage with energies ranging from ~30 to ~64 MeV increases with its active area.
- Dark current damage factor for Si pin photodiodes is proportional to the proton NIEL curve in Si

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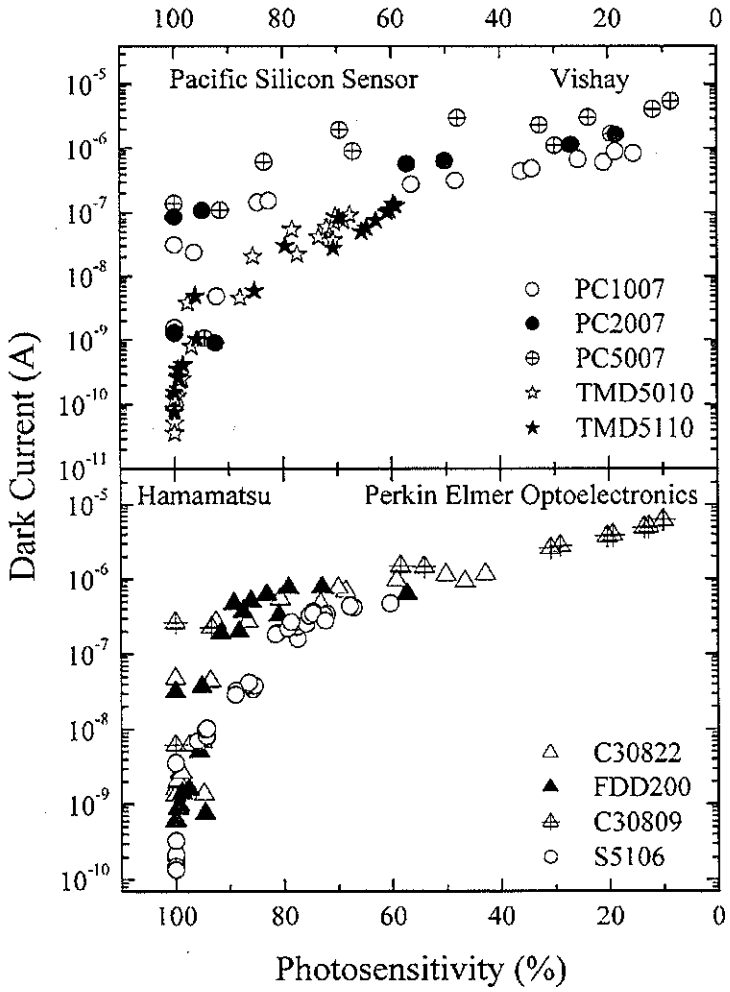
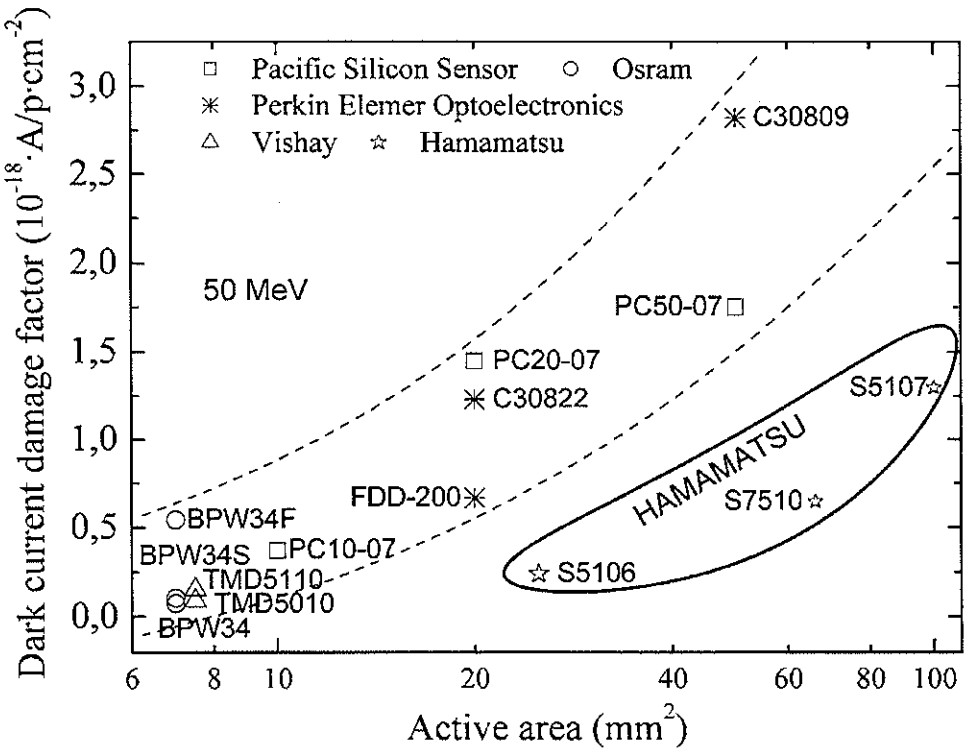
Proton Irradiation





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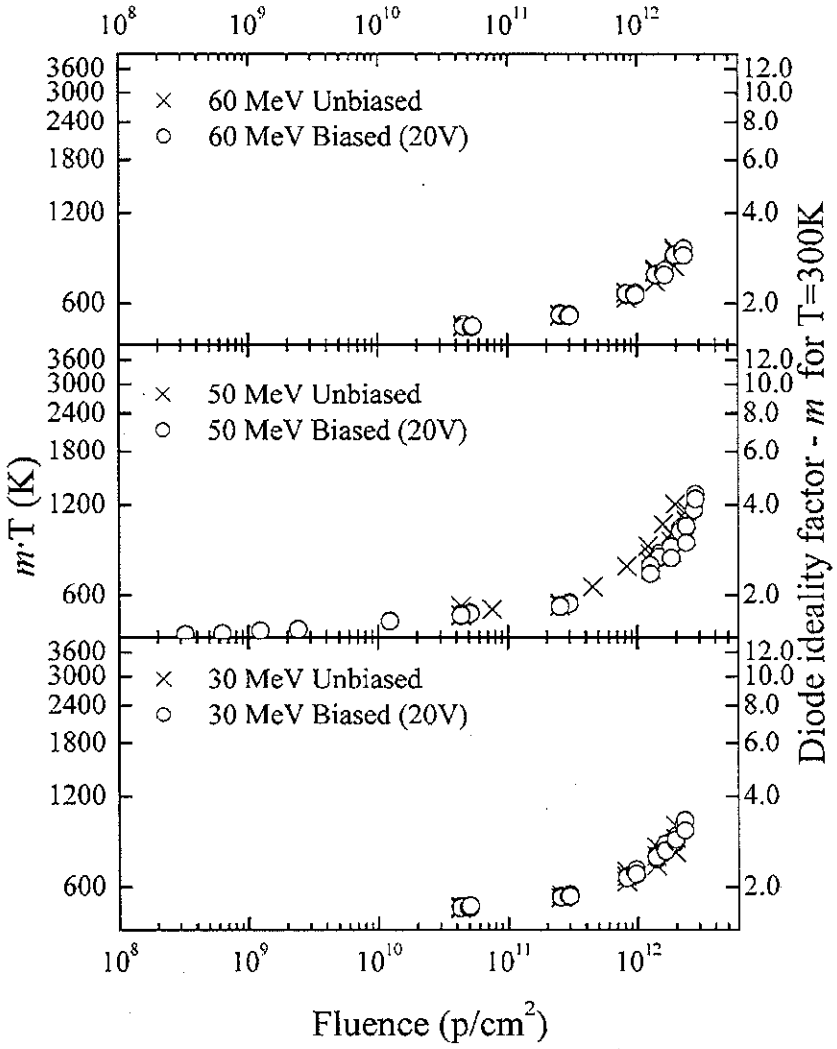
Proton Irradiation – Ideal Diode Factor



- The I-V curve of each photodiode for every irradiation step has been fitted to the real p-n junction equation:

$$I \cong I_0(e^{\frac{eV}{mk_BT}} - 1)$$

- The quality of a p-n junction decreases with an increasing m factor.
  - m = 1 Ideal diode
  - 1 < m < 2 Degradated diode
  - 2 < m Ohmic regime

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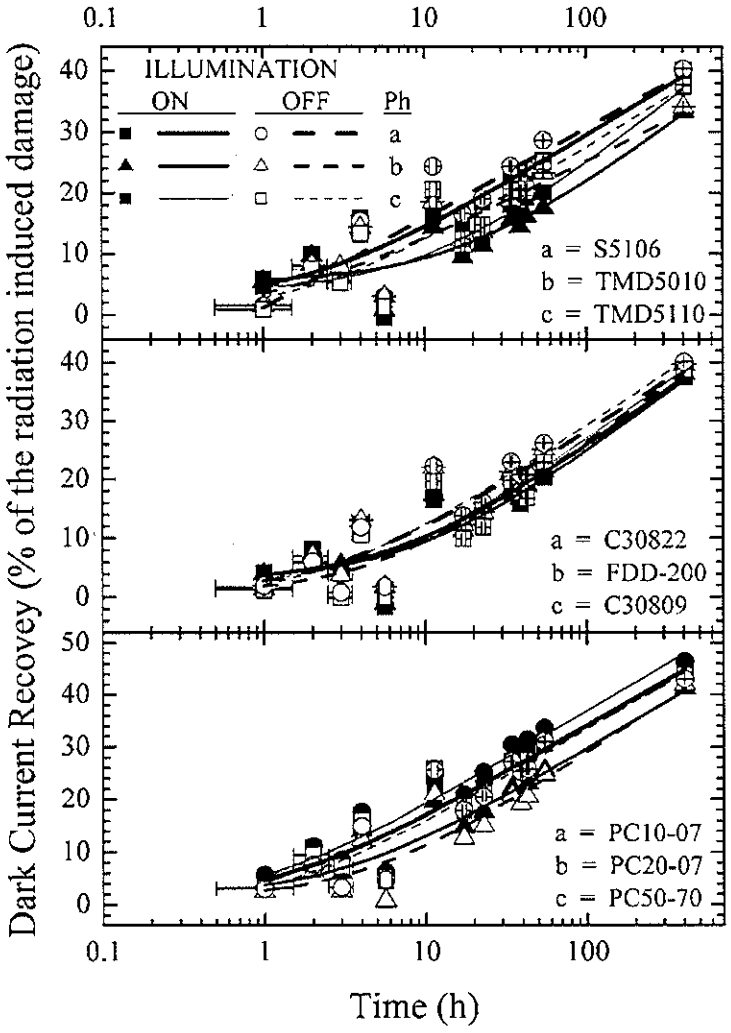

- Post-irradiation annealing of all photodiodes has been studied.
- Photosensivity recovery and dark current decrease were recorded at room temperature
- Recovery of almost the 50% of the dark current increment generated by the proton radiation.
- Recovery up to a 30% of the lost photosensivity

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Reliability Assessment Tests

- Setup preparation
  - Relative measurements
  - LabView programming
  - Validation: Repeatability
- Pass-Fail criteria
- Pre-evaluation of 4 pre-selected devices (20 Samples)
  - Based on previous test (radiation) and datasheets
- Environmental and Lifetime Evaluation Plan (75 Samples)
  - Mechanical
  - Environmental
  - Endurance

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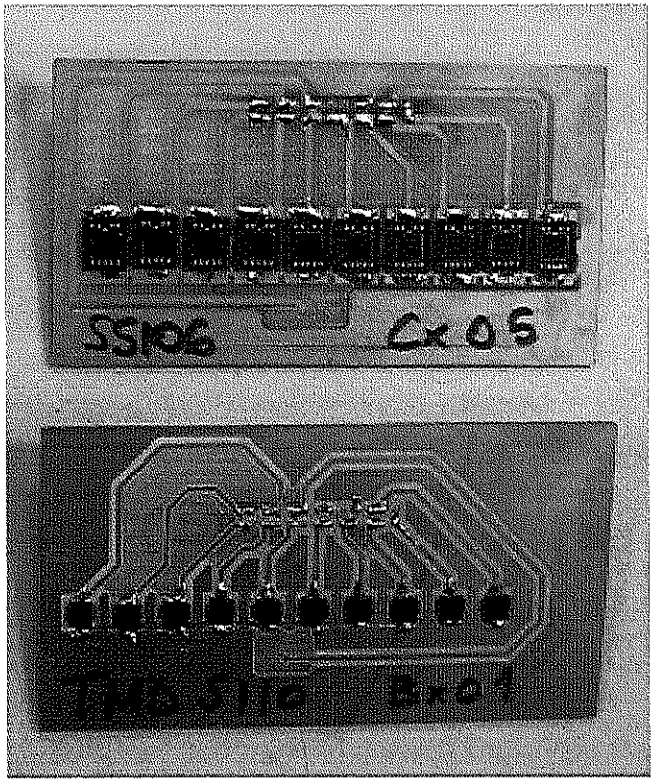
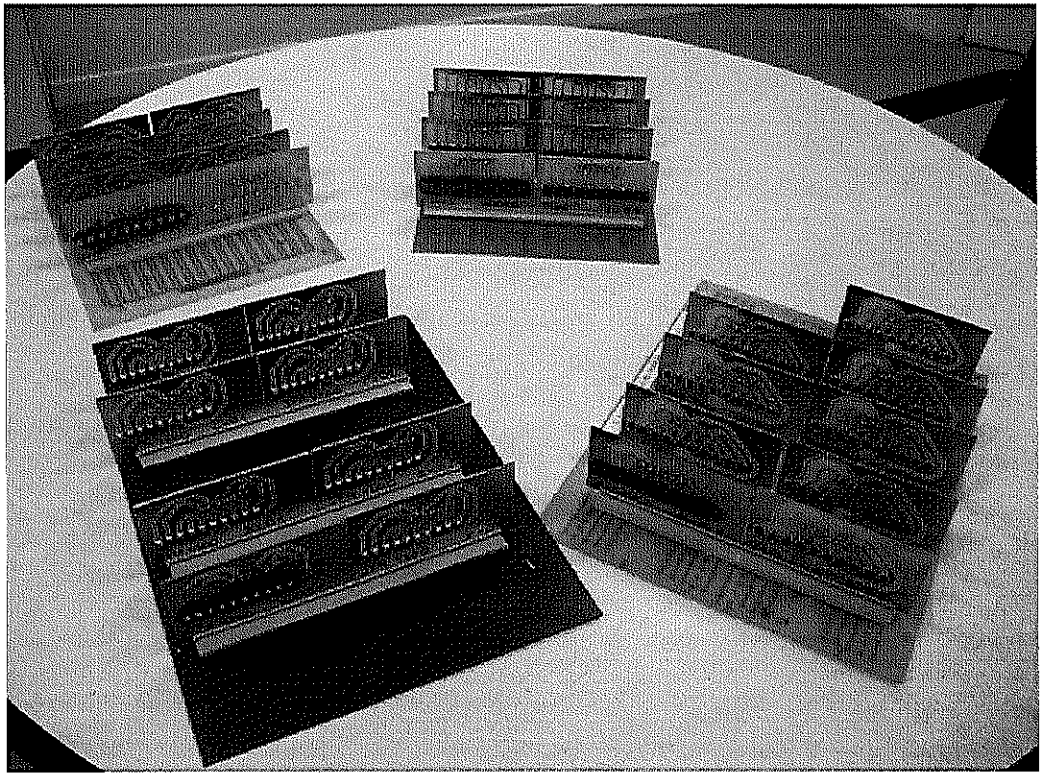
Setup preparation

- Boards of 10 samples





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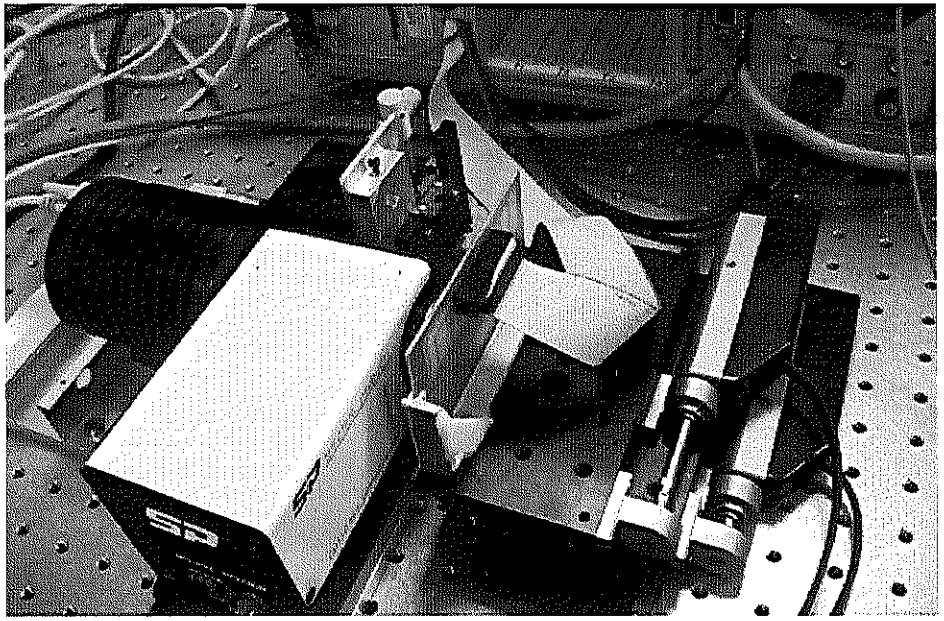
Receivers Setup preparation

- Monochromator
- Precision positioners
- Periodic lamp calibration / verification with optical power meter
- Switching matrix



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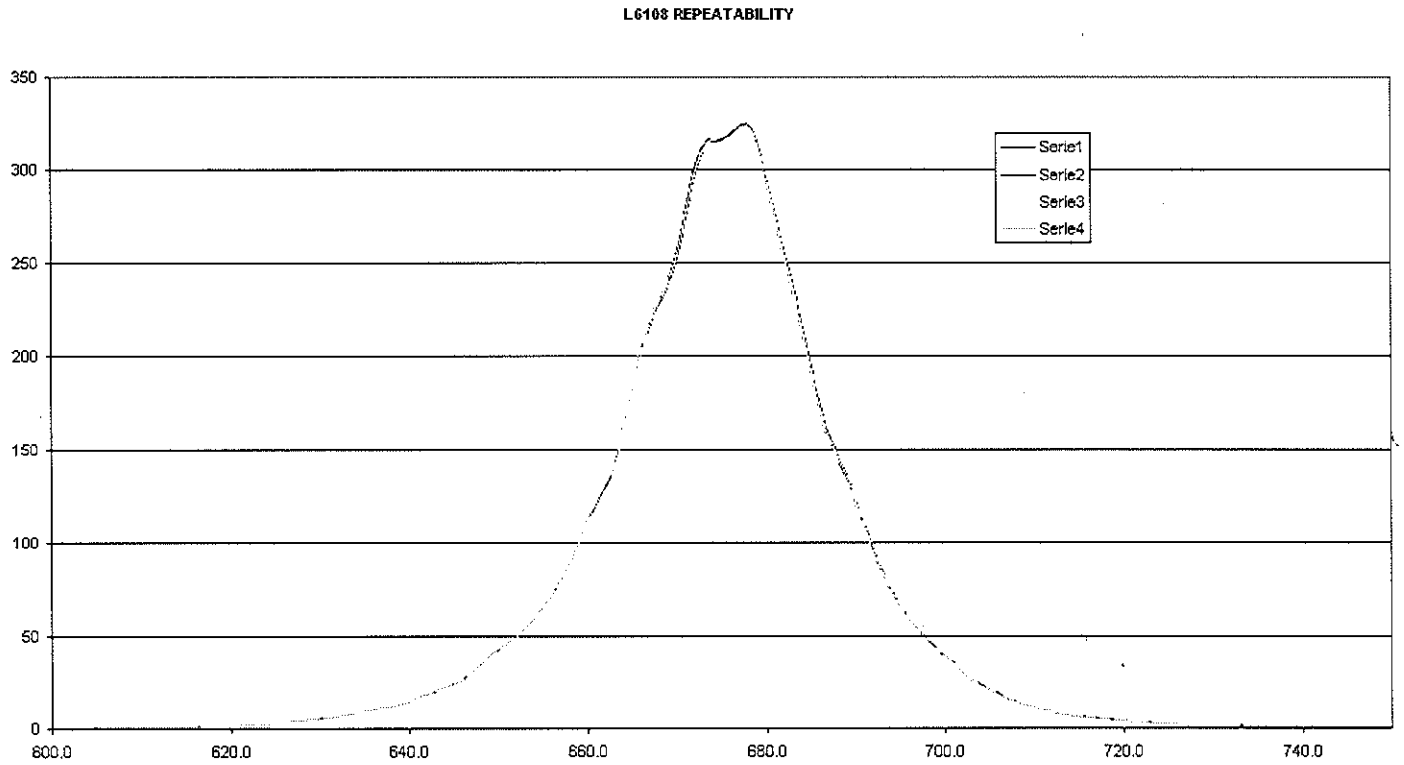
Receivers Setup preparation

- Spectral characteristic repeatability



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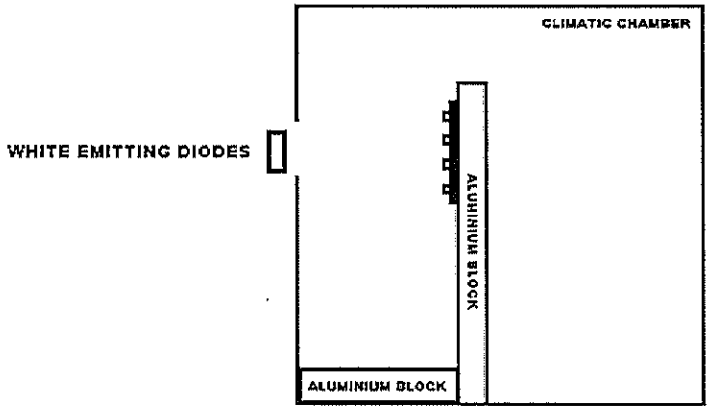
Method for relative measurements tests in temperature

The sensitivity of the receivers at different temperatures was measured by placing the emitters in a climatic chamber and measuring the response when illuminating with a controlled array of white leds. The available climatic chambers have a hold at the side and therefore the samples were placed on a PB fix to a aluminum structure. Aluminum blocks that touch the internal wall of the chamber assure the repeatability of the placement of the aluminum block.

The repeatability of the test setup was checked.



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Pass / Failure Criteria

10 % variations of the following parameters were allowed (Pass)

- Peak wavelength responsitivity $R\lambda$
- Responsitivity at +50% $R\lambda_{+50\%}$
- Responsitivity at -50% $R\lambda_{-50\%}$
- Responsitivity at +5% $R\lambda_{+5\%}$
- Responsitivity at -5% $R\lambda_{-5\%}$
- Responsitivity Wavelength width at +50% $\Delta R\lambda_{+50\%}$
- Responsitivity Wavelength width at -50% $\Delta R\lambda_{-50\%}$
- Responsitivity Wavelength width at +5% $\Delta R\lambda_{+5\%}$
- Responsitivity Wavelength width at -5% $\Delta R\lambda_{-5\%}$

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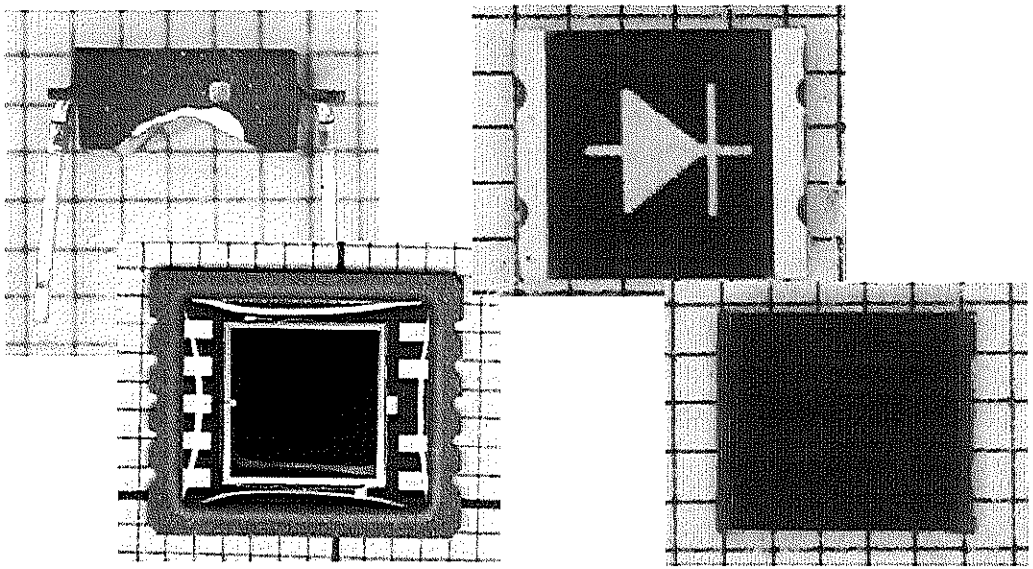
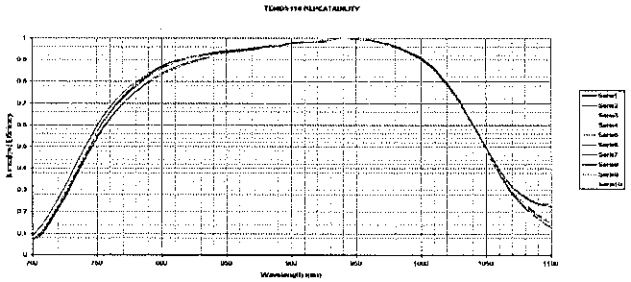
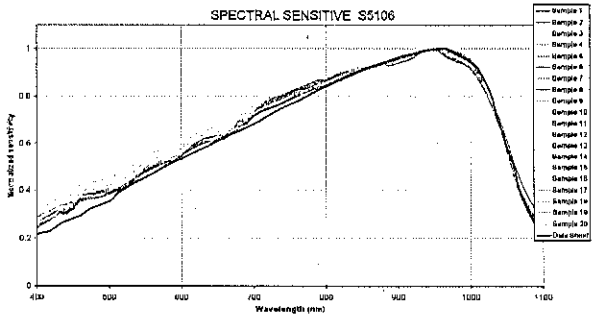
Pre-evaluation of 4 pre-selected devices

- Based on radiation results and datasheets.
- Channels: 950nm & 670nm
- Thermal cycles under vacuum (10 samples)
- Constructional analysis (2 samples)
- Outgassing (6 samples)
- Selection of 2 types for Environmental and Lifetime Evaluation Plan







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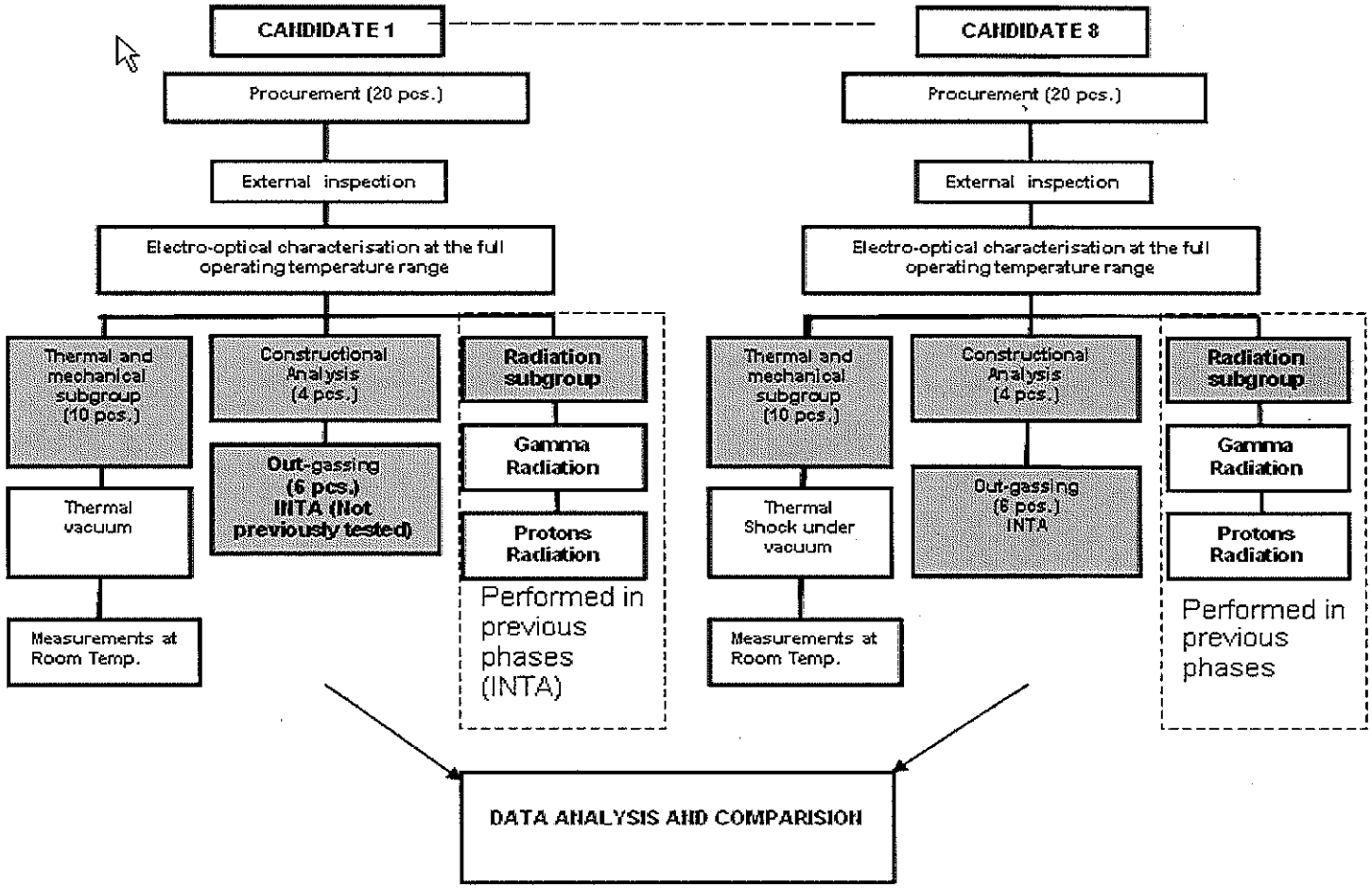
Pre-evaluation of 4 pre-selected devices (2 per channel)



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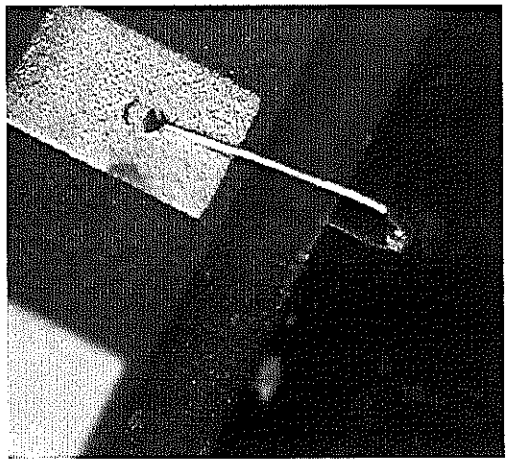
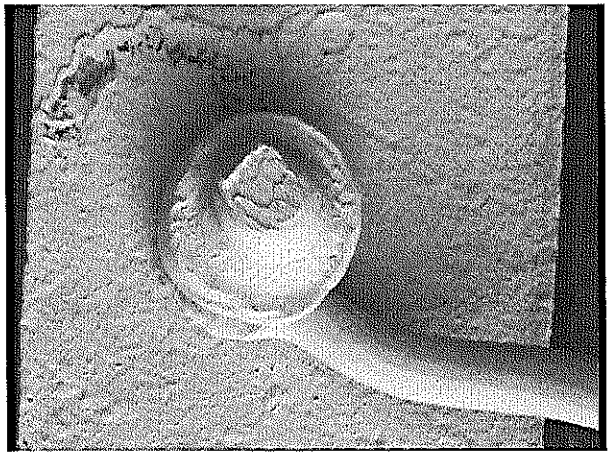
Pre-evaluation of 4 pre-selected devices (2 per channel)

- No failures
- Thermal vacuum was not monitored
- Selection for Evaluation phase based on datasheet and radiation performance
- General Good quality





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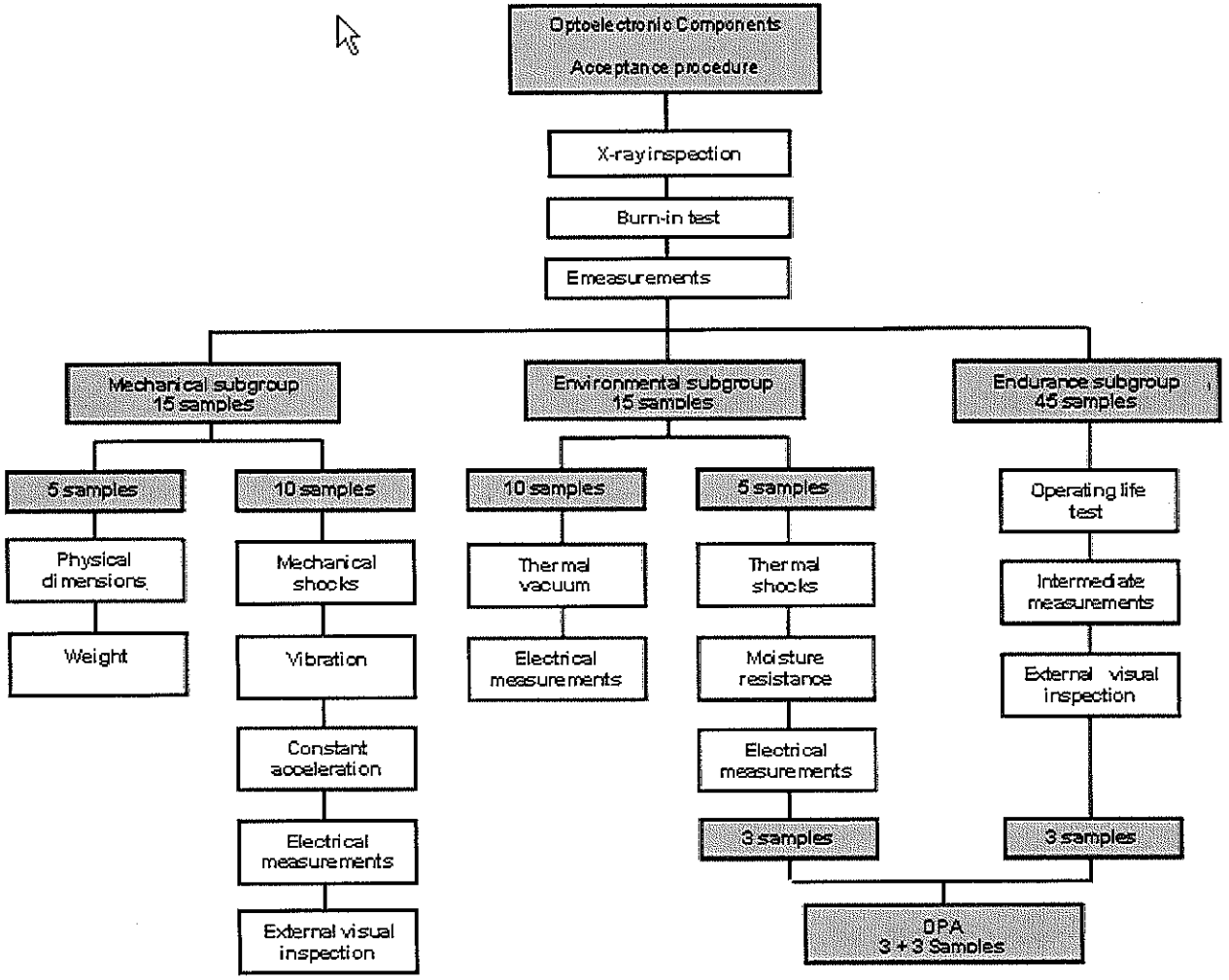
Environmental and Lifetime Evaluation Plan



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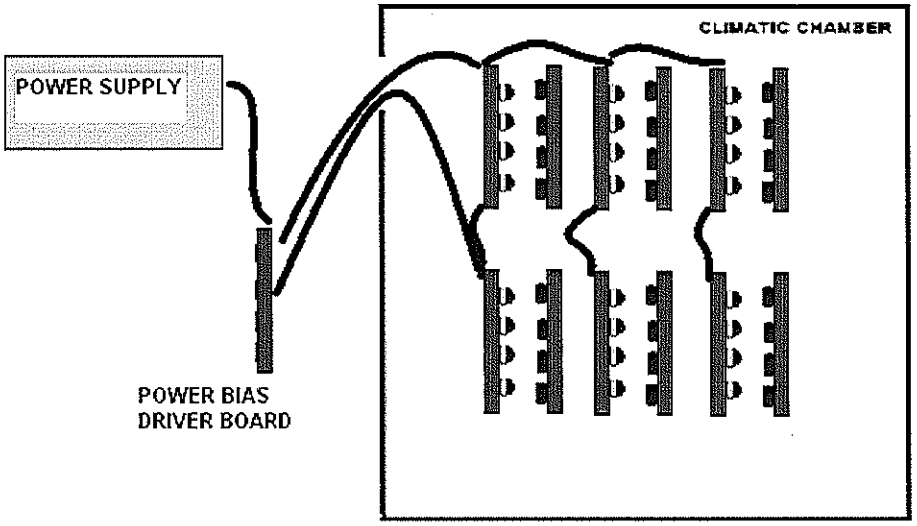
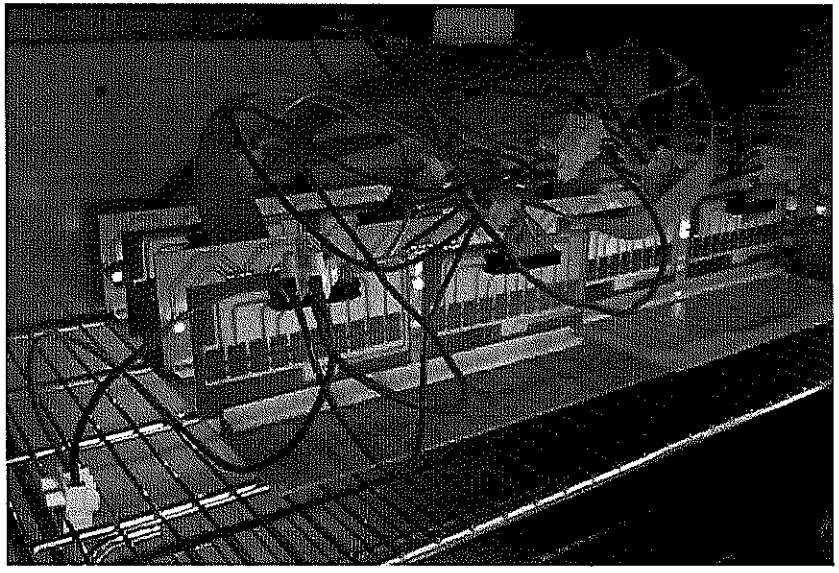
Environmental and Lifetime Evaluation Plan

- **No failures**
- **Emitters and receivers burn-in and life tests performed at the same time**





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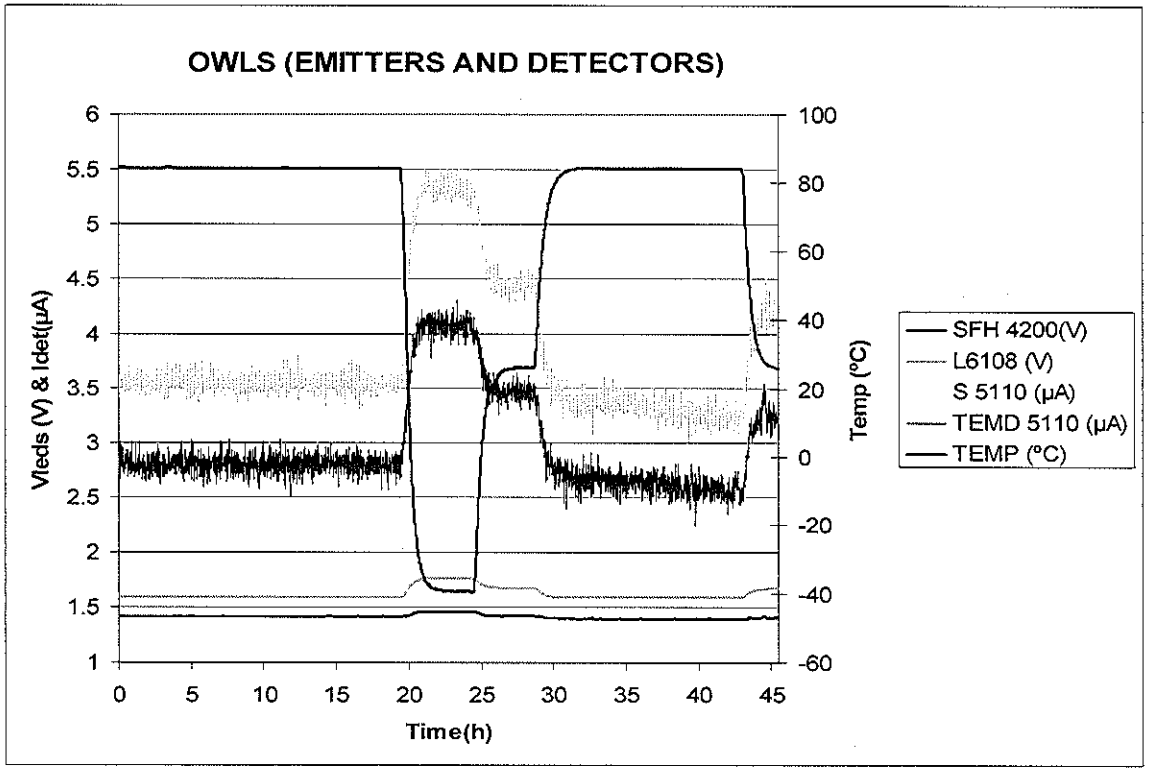
Environmental and Lifetime Evaluation Plan

- **No failures**
- **Monitored Thermal Vacuum of emitters and receivers at the same time**



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Radiation Tests – Conclusions

- **A large variety of COTS devices has been evaluated to proton displacement damage. A decrease in responsivity (photosensitivity) and an increase of the dark current are observed.**
- **Results highly depend on the manufacturer and the technology of the detector under test.**
- **It has been observed that the degradation of the photodiodes dark current, quantified via the dark current damage factor, is a good and very sensible parameter to evaluate proton displacement damage in photodiodes.**
- **The ideal diode factor has been calculated for all the tested photodiodes. It has been observed that $m > 2$ for proton fluences above 10^{12} p/cm^2 in all cases.**

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Reliability Assessment Tests Conclusions

- **No failures during pre-evaluation and evaluation tests**
- **The Quality of the high volume commercial products tested has been found to be very good.**
- **Optical measurements repeatability need an accurate positioning setup and validation.**
- **Pass / Failure criteria definition is important for having a real picture of the stability of the devices.**
- **Good radiation performance of selected types.**


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