RD ALFA Microelectronics

Advancements in Radiation-Hardened Analog ICs and Qualification of αRD139A and αRD1567 under ESA GSTP.

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Topic

🔶 Advancements in Radiation-Hardened Analog ICs and Qualification of αRD139A and αRD1567 under ESA GSTP.

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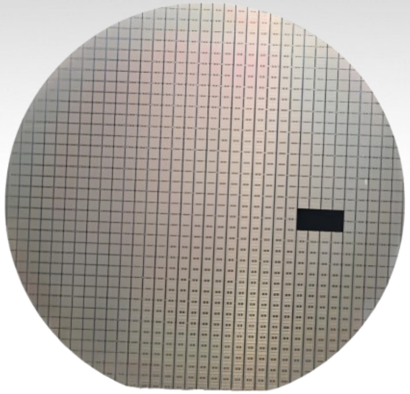
🎖 **Special gratitude to our ESA Technical Officers:**
Laurent Marchand, Lionel Bonora and Christian Poivey

Short profile



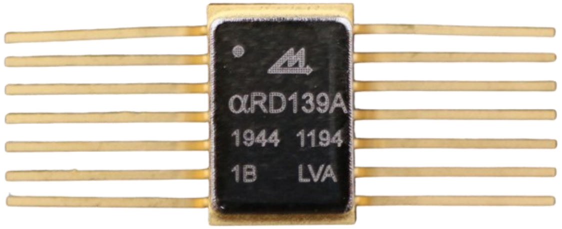
Pioneer in Electronic Technology since 1962

•Expertise:

- Analog and analog-to-digital technologies: Bi-polar, Bi-FET, complementary Bi-polar, CMOS, Bi-CMOS.

•Experience:

- Over 50 years designing and producing HiRel, RadHard, and ITAR-free analog ICs
- Regular participant in European Space Agency (ESA) projects since 2015



Core Capabilities:

•Certified high-reliability and radiation-hardened ICs manufacturing ESCC 9000.
•Applications: aerospace, defense, industrial, and commercial sectors
•Operational temperature range: -55°C to +125°C
•Rad-hard specifications: up to 450 krad TID; SEE tested
•ITAR-free products, made in Latvia
•ICs listed on European Preferred Parts List (EPPL)

ESA GSTP Project

Project name: GSTP Project “Preparation of enabling space technologies and building blocks - αRD139A and αRD1567 ICs qualification and research of analog IC elements resistance to radiation”.

Duration: 24 months (March 2022- February, 2024) Planned
Factual : March 2022- June 2024)
Agreement No: 4000137307/22/NL/GLC/zk

Main tasks:

- Study of numerous design and technological solutions for the design of radiation-hardness analog ICs.
- Qualification of the IC αRD139A following ESA requirements.
- Completion of development of the IC αRD1567 and its qualification following ESA requirements.

Advancements in Radiation-Hardened Analog ICs

Project Goal: Develop methods to monitor and improve radiation resistance in analog ICs (**Bipolar** technology), ensuring stable Total Ionizing Dose (TID) performance across production lots.

Key Insights from Literature:
•Radiation effects are well understood, with reliable models.
•Hydrogen contamination can be mitigated via controlled assembly and packaging.
•Engineering efforts focus on optimizing designs and technlogies rather than altering fundamentals.

Approach & Implementation Plan:
•Apply **wafer pre-irradiation and annealing** to enhance radiation resistance.
•Use **burn-in testing** to stabilize input current variations.
•Optimize **transistor selection** for better radiation hardness stability.
•Employ **electrical measurements (Vfb, Qss)** for production control.
•Investigated Raman spectroscopy, FTIR, and ellipsometry to detect radiation-induced defects.

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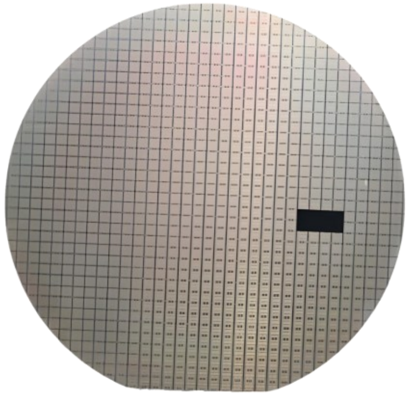
Wafer Pre-Irradiation & Annealing for Radiation Resistance

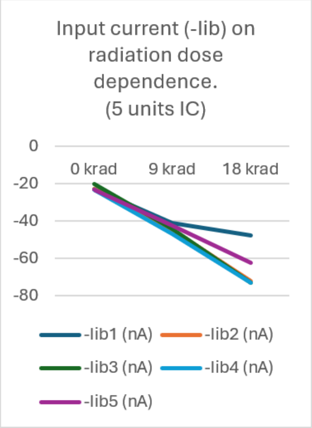
•**Objective:** Improve IC radiation resistance by applying controlled **wafer pre-irradiation** and **annealing**.
•**Approach:**
•Pre-irradiation (electrons) followed by different **annealing modes**.
•Annealing temperatures tested: **340°C – 400°C** with varying durations.

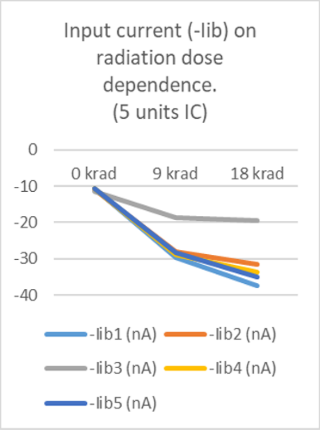
•**Findings:**
•Early-stage parameter changes at **low doses (9krad, 18krad)** predict long-term stability at **higher doses (up to 150krad)**.
•Optimized **dose + annealing combination** significantly enhances IC reliability.
•±Iib **Input Bias Current** parameter is most sensitivie to the radiation

•**Impact:**
•Enables **early prediction** of radiation performance.
•Reduces the need for **multiple qualification cycles**.
•Improves **process stability across wafer lots**.



Wafer Pre-Irradiation & Annealing for Radiation Resistance



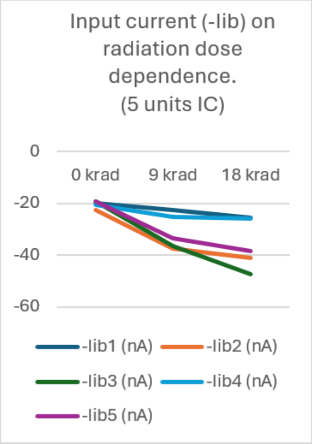


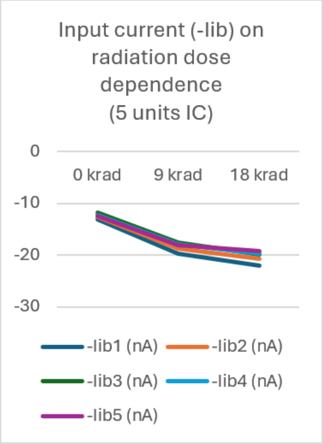
Radiation-heat treatment mode (left):

1. wafer pre-irradiation Fē= 5E13ē/cm^2
2. annealing at T=+340°C; 0,5h
3. annealing at T=+350°C; 0,5h
4. annealing at T=+360°C; 0,5h
5. annealing at T=+370°C; 0,5h

Radiation-heat treatment mode (right):

1. wafer pre-irradiation Fē= 5E13ē/cm^2
2. annealing at T=+340°C; 0,5h
3. annealing at T=+350°C; 0,5h
4. annealing at T=+380°C; 1,5h
5. annealing at T=+400°C; 1,0h





Radiation-heat treatment mode (left):

1. wafer pre-irradiation Fē= 5E13+1E14ē/cm^2
2. annealing at T=+340°C; 0,5h
3. annealing at T=+350°C; 0,5h
4. annealing at T=+360°C; 1,0h
5. annealing at T=+370°C; 0,5h

Radiation-heat treatment mode (right):

1. wafer pre-irradiation Fē=5E13ē/cm^2+1E14ē/cm^2
2. annealing at T=+340°C; 0,5h
3. annealing at T=+350°C; 0,5h
4. annealing at T=+380°C; 1,5h
5. annealing at T=+400°C; 1,0h

Evaluation of the impact of wafer pre-irradiation and thermal annealing on the stability of input bias current (±Iib) in comparators under radiation exposure.

Observations: Pre-irradiation and annealing significantly influence radiation response.

Different annealing modes lead to variations in ±IIib stabilization. Optimized annealing conditions can improve **long-term radiation hardness of ICs**.

Conclusion: Early-stage pre-irradiation and controlled annealing can predict and enhance TID resistance, reducing lot-to-lot variability in IC production.

Burn-in Testing & Heating Impact on Radiation Resistance

Objective: Assess how **preheating at 125°C** affects **input bias current (Iib)** under irradiation.

Approach:

•**Burn-in test:** 500h-2000h at **125°C under load**.

•**Heating test:** 500h-2000h at **125°C without load**.

•**Iib measured** at **T=25°C** before and after irradiation (**9-45 krad**).

Findings:

•Heating at **125°C stabilizes Iib variations** due to irradiation.

•**No significant difference** with or without load.

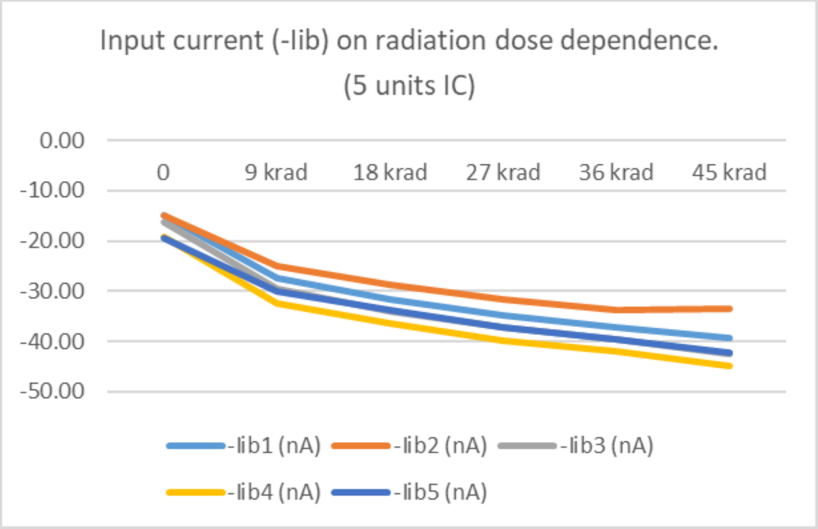
•Heating time (500h-2000h) **does not impact post-irradiation behavior**.

Conclusion:

•**Preheating at 125°C** stabilizes input current shifts.

•Load presence **does not affect radiation resistance**.

•Optimized preheating reduces **variability in IC performance**.



Optimal Transistor Type Selection for Radiation Resistance

Objective: Assess how irradiation and annealing impact the **forward current gain (β)** of PNP transistors.

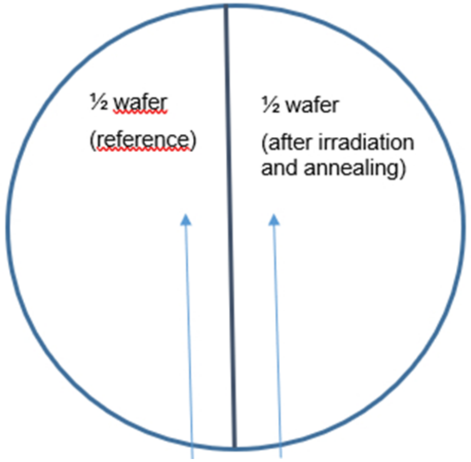
Key Experiment:

•Wafer divided into two parts:

- **Reference half:** No irradiation.
- **Test half:** Irradiated at **Fē = 5×10^{14} ē/cm^{2}** and then annealed.

•**Results:**

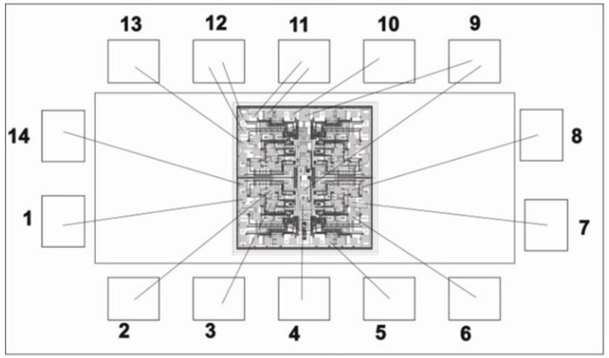
- After degradation, **β of input PNP transistors nearly returned to reference values** post-annealing.
- Confirms **annealing helps recover transistor performance.**



Input PNP transistors

	Reference wafer (1/2)	Wafer (1/2) after radiation flow Fē = 5*10^{14} ē/cm^{2}	
	β (average)	Annealing mode	β (average)
1	370	Initial	2
2		T=300°C, 1h	8
3		T=320°C, 1h	10
4		T=350°C, 1h	13
5		T=370°C, 1h	25
6		T=390°C, 1h	70
7		T=400°C, 1h	150
8		T=420°C, 1h	200
9		T=430°C, 1h	240
10		T=440°C, 5h	300

IC 18564_Transistors assembly
Die 2433_B attachment in package
Adhesive PC87007g Ag COND



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Optimal Transistor Type Selection for Radiation Resistance

Objective: Improve the radiation resistance of analog ICs by selecting the most suitable transistor structures.

Key Considerations:

•Each transistor type degrades differently under radiation exposure.

•**Input current (±Iib)** is the most critical parameter for OpAmp and comparator radiation resistance.

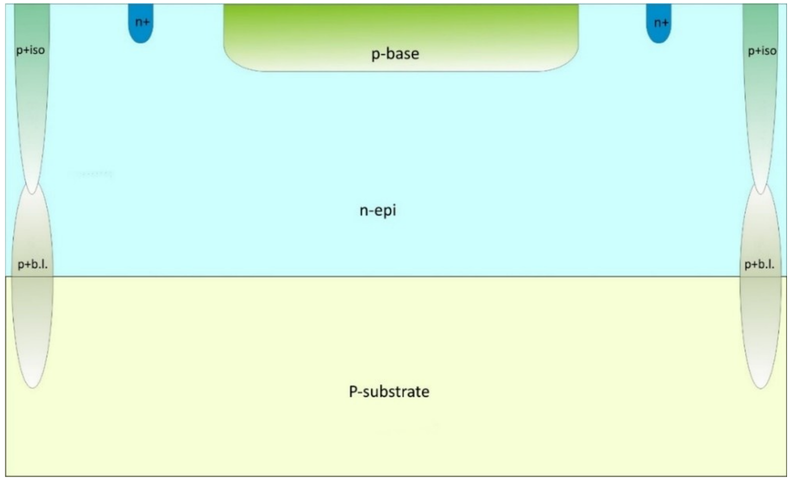
•**Forward current gain (β)** determines the long-term stability of transistor performance under radiation.

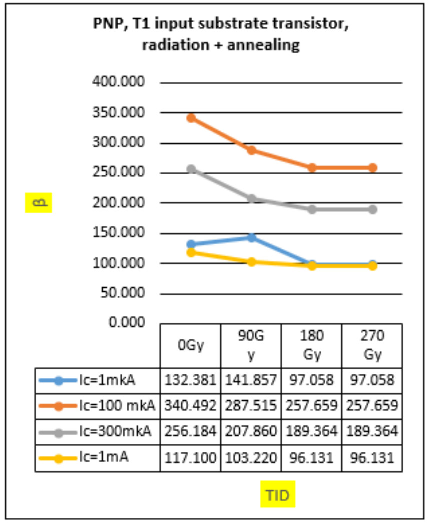
Findings

•**Substrate PNP transistors** show good radiation stability and should be used for input stages.

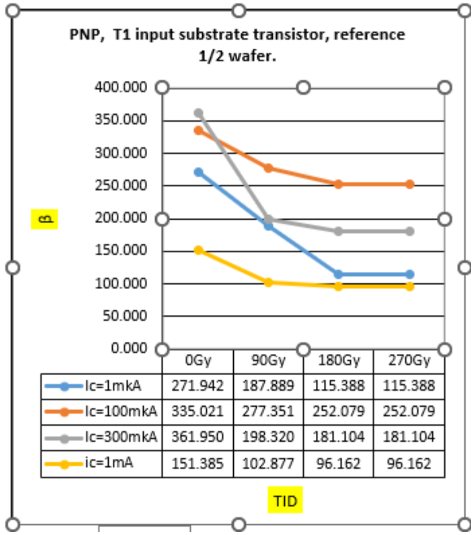
•**Initial radiation doses of 9 krad, 18 krad, and 27 krad** predict long-term stability up to **150 krad+**.

•**Radiation-thermal treatment** has a minor positive effect but does not degrade performance.





	0Gy	90Gy	180 Gy	270 Gy
Ic=1mkA	132.381	141.857	97.058	97.058
Ic=100 mkA	340.492	287.515	257.659	257.659
Ic=300mkA	256.184	207.860	189.364	189.364
Ic=1mA	117.100	103.220	96.131	96.131



	0Gy	90Gy	180Gy	270Gy
Ic=1mkA	271.942	187.889	115.388	115.388
Ic=100mkA	335.021	277.351	252.079	252.079
Ic=300mkA	361.950	198.320	181.104	181.104
ic=1mA	151.385	102.877	96.162	96.162

Transistor Type Comparison & Conclusions

•**Vertical PNP transistors** have the highest resistance to radiation but low breakdown voltage, making them unsuitable for inputs.

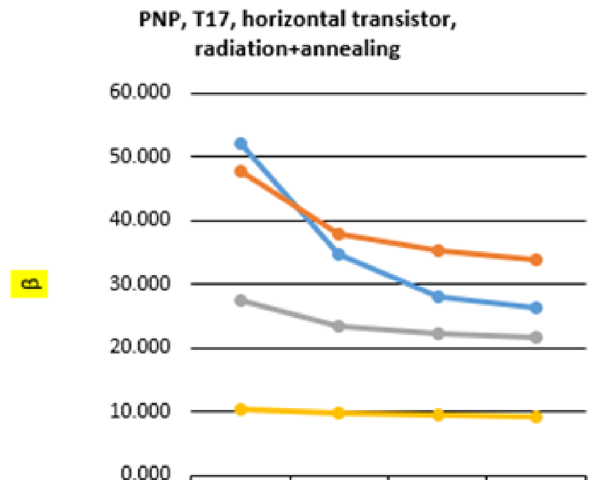
•**Horizontal PNP transistors** can be used in **less sensitive areas**, such as current mirrors.

•Some transistors were tested up to **300 krad**, confirming their behavior under extreme conditions.

Conclusion:

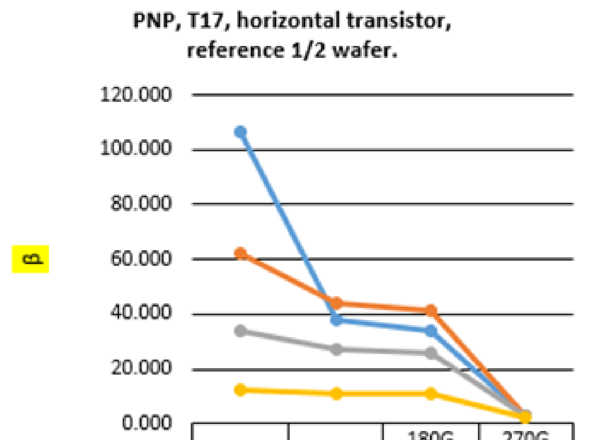
•Selecting the **right transistor structure** for each circuit position **enhances overall radiation resistance**.

•These insights help optimize IC layout and **reduce failure rates in high-radiation environments**.



	0Gy	90Gy	180Gy	270Gy
Ic=1mkA	52.217	34.745	28.127	26.220
Ic-100mkA	47.878	37.838	35.346	33.991
Ic=300mkA	27.475	23.417	22.312	21.757
Ic=1mA	10.379	9.695	9.442	9.345

TID



	0Gy	90Gy	180Gy	270Gy
Ic=1mkA	106.407	38.202	34.149	2.882
Ic-100mkA	62.441	44.034	41.302	2.956
Ic=300mkA	33.826	27.059	25.797	2.783
Ic=1mA	12.219	11.052	10.781	2.171

TID

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Evaluating Spectroscopic Methods for Radiation Defect Detection

Objective: Investigate whether **spectroscopic methods (Ellipsometry, FTIR, Raman)** can detect **radiation-induced defects** in SiO_2 and Si_3N_4 layers.

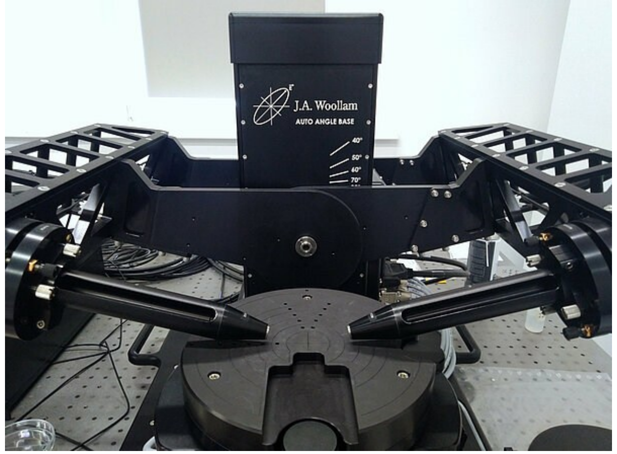
1. **Baseline measurements** of wafers before irradiation.
2. **Electron irradiation ($F_{\bar{e}} = 5 \times 10^{14}$ ē/cm^2)** applied to wafers.

Why This Matters:

- Identifying radiation-induced defects at the **wafer level** could help optimize radiation-hardening treatments.
- Spectroscopy techniques are widely used in material science but have **not been fully validated** for microelectronic thin films in radiation testing.

Key Methods:

- **Spectroscopic Ellipsometry**: Measures changes in optical properties of thin films.
- **FTIR (Fourier Transform Infrared Spectroscopy)**: Detects vibrational modes of molecules, indicating defect formations.
- **Raman Spectroscopy**: Identifies stress-induced changes in crystalline structures.




Equipment by The Institute of Solid State Physics, University of Latvia (ISSP UL

Spectroscopic Ellipsometry

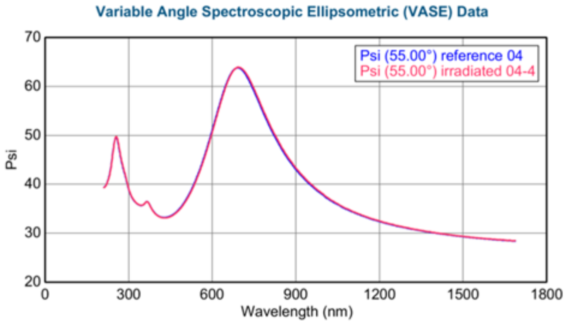
Purpose:
•Measures changes in the **optical properties** of thin films to detect structural changes.

Methodology:
•Light reflection and polarization changes are analyzed to assess material characteristics.
•Applied to **silicon wafers** with **SiO_2 and Si_3N_4 layers** before and after irradiation.

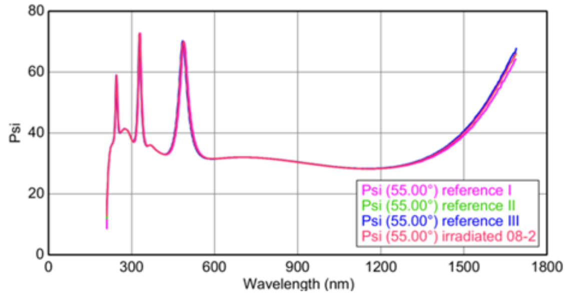
Findings:
•**No measurable changes** in optical properties after irradiation.
•Annealing at **330°C** restored any minor variations, further confirming no detectable defects.

•**Conclusion:** Spectroscopic Ellipsometry is **not effective** for detecting radiation-induced damage in microelectronic films (~100-150 nm).

Comparison of the reference sample and the irradiated sample (with SiO_2 on Si wafer)



Comparison of the reference sample and the irradiated sample (with Si_3N_4 SiO_2 on Si wafer)

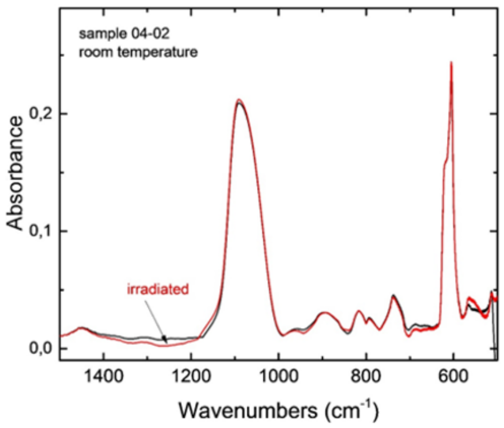


FTIR (Fourier Transform Infrared Spectroscopy)

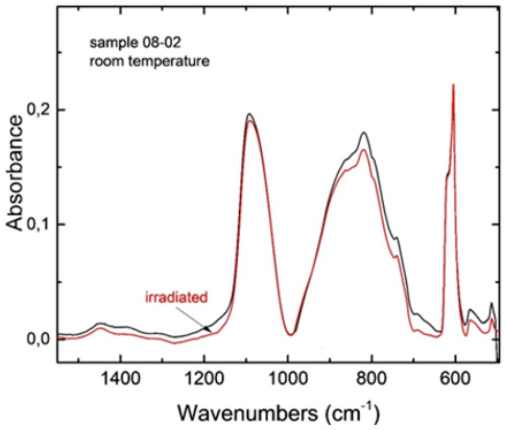
Purpose:
•Detects **vibrational modes of molecules** to identify defect formations in thin films.
Methodology:
•Measures IR absorption in **SiO_2 and Si_3N_4 layers** to track radiation-induced structural changes.
•Applied before and after **electron irradiation**

Findings:
•**No significant changes** in IR absorption spectra post-irradiation.
•No new defect-related bands observed in **800-1100 cm^{-1} range**, where defects are typically detected.
•Annealing at **330°C** restored any minor spectral variations.
•**Conclusion:** FTIR is **not effective** in detecting radiation-induced defects in microelectronic thin films.

IR spectra of non-irradiated and electron-irradiated samples (with SiO_2 on Si), measured at room temperature.



IR spectra of non-irradiated and electron-irradiated samples (with SiO_2 +Si_3N_4 on Si), measured at room temperature.



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Raman Spectroscopy

Purpose:

•Identifies **stress-induced changes** in crystalline structures due to radiation exposure.

Methodology:

•Uses **laser light scattering** to analyze structural changes in **SiO_2 and Si_3N_4 layers** before and after irradiation.

•Applied after **electron irradiation**

Findings:

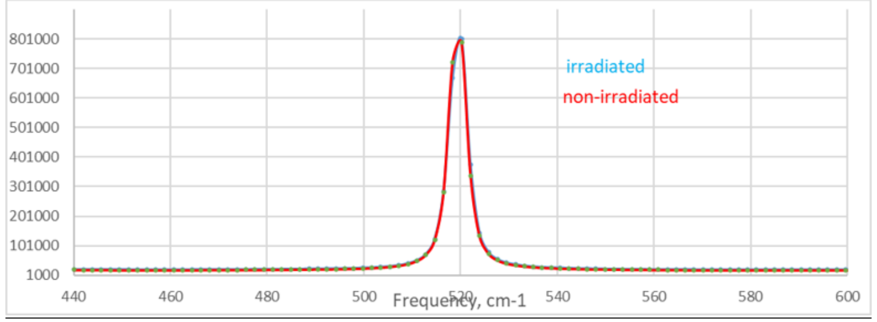
•**No measurable Raman shifts** indicating defect formations post-irradiation.

•No new stress-induced peaks observed in **defect-sensitive spectral ranges**.

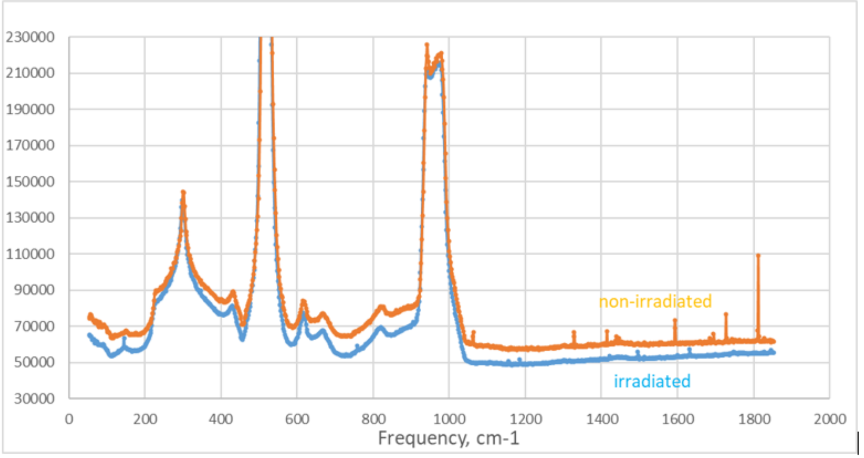
•**Annealing at 330°C** restored minor variations, reinforcing the lack of defect detection.

•**Conclusion:** Raman Spectroscopy is **not effective** for identifying radiation-induced defects in microelectronic films.

Comparison of the reference sample and the irradiated sample (with Si_3N_4 on SiO_2 on Si wafer)



Silicon 520 cm-1 fundamental vibration band.



Silicon two-phonon oscillation bands.

Electrical Measurements for Radiation Resistance Assessment

Objective: Identify a reliable method for assessing radiation resistance after spectroscopic methods failed.

Approach:

•Measured **flat band voltage (Vfb)** and **total charge density (Qss)** before and after irradiation.

•Used **HP4061A Automated System, Signatone S-1160 Probe Station, HP 4275A LCR Meter**.

Key Findings:

•**Irradiation (Fē = 1×10^{14} ē/cm^{2})** caused significant degradation in **Vfb and Qss**.

•**Annealing (350°C, 1h in N2)** partially restored values, improving radiation resistance.

Conclusion:

•**Vfb and Qss measurements provide a precise method** for radiation-hardness evaluation.

•**Optimizing irradiation & annealing modes** enhances IC reliability.

Spectroscopy Fails & The Need for Electrical Measurements

Key Takeaways:

•**Spectroscopic methods (Ellipsometry, FTIR, Raman) are ineffective** for detecting radiation-induced defects in microelectronic thin films (~100-150nm).

Conclusion:

•**Spectroscopy is not a viable method** for radiation defect detection in analog ICs.

•**Electrical measurements (Vfb, Qss) are far more reliable** for assessing radiation hardness.

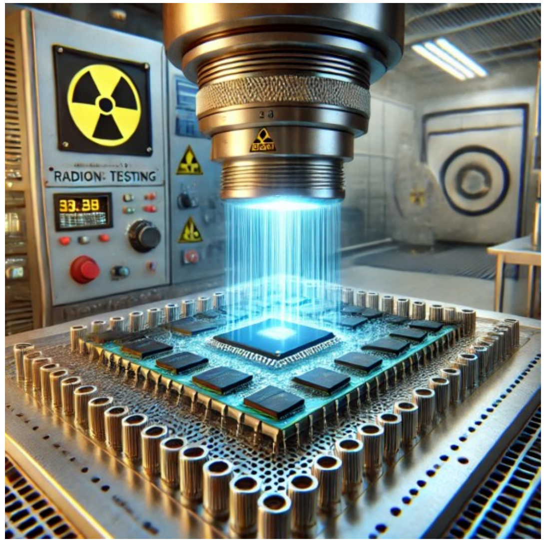
•**Wafer pre-irradiation combined with annealing** is the most effective way to predict and enhance radiation resistance.

Next Steps:

•Focus on **electrical parameter monitoring** for process control and qualification.

•Develop standardized **pre-irradiation and annealing protocols** to improve lot-to-lot consistency in IC production.

•Move away from ineffective spectroscopic evaluations in future radiation-hardness studies.



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Qualification of αRD139A and αRD1567 ICs

Project: Achievements:

- Redesigned αRD1567 IC, improving yield and performance.

•**Equipment Development:**

- Created and documented measurement and testing equipment.
- Developed methods for measuring IC parameters.

•**Qualification:**

- TID level of αRD1567 IC 50krad.
- TID level of αRD139A IC 100krad.
- Both Ics were tested for SEE.
- ICs Qualified according to ESCC 9000 standards SPQ flow.

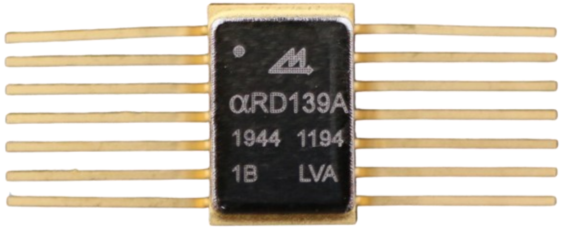
•**TRL Advancement:**

- Increased TRL from 4 to 7, ready for ESA missions.
- αRD1567 IC TRL 9 as currently being used by Thales Alenia Space

•**Market Impact:**

- Collaborated with Thales Alenia Space.
- Positioned ICs for ESA EPPL inclusion.

Conclusion: The project successfully advanced αRD139A and αRD1567 ICs, enhancing their radiation resistance and readiness for the European Space Industry.

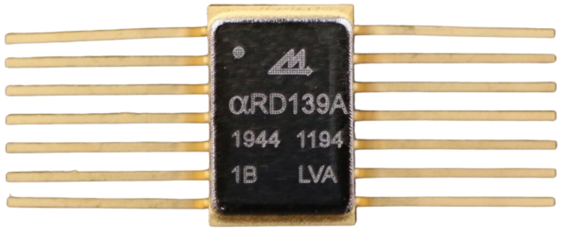


Qualification of αRD139A and αRD1567 ICs

- The αRD1567 is a low-power, 5V CMOS dual transceiver designed to meet the requirements of MIL-STD-1553/1760 specifications. The transmitter section of each channel takes complementary CMOS/TTL digital input data and converts it to bi-phase Manchester encoded 1553 signals suitable for driving the bus isolation transformer.

Developed using own funds of the company

- The quad comparator 139 has a long and successful history of development and application in various technology fields, including defense and aerospace programs. The αRD139A series consists of four independent precision voltage comparators with an offset voltage specification as low as 2 mV max for all four comparators. They are designed to operate from a single power supply over a wide range of voltages.



Developed in the frame of PECS project

Questions & Answers

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