Study of the spectrometric performance of SiC detectors at High Temperature

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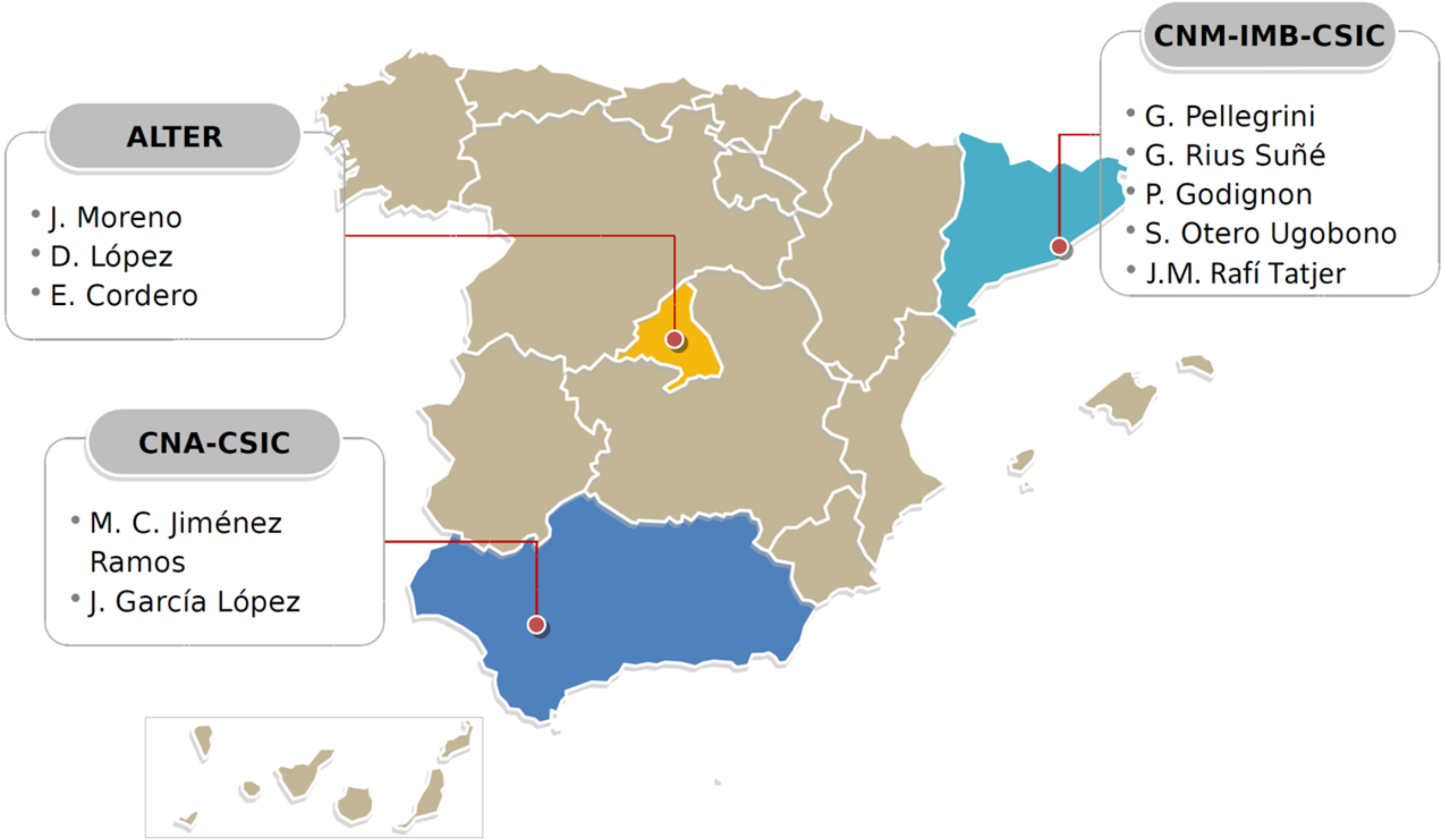
OUTLOOK

1) GRACE PROJECT.
2) NUCLEAR FUSION.
3) FAST-ION LOSS DETECTOR (FILD).
4) SiC DETECTOR MANUFACTURED AT IMB-CNM.
5) SiC MEASUREMENTS AT HIGH TEMPERATURE AT THE 3 MV TANDEM ACCELERATOR OF THE CNA.
6) RESULTS.

Institutes involved

1) GRACE PROJECT



GRACE: Graphene-enhanced RAdiation detector on Silicon Carbide for harsh Environments RTC-2017-6369-3

- CNM is developing innovative radiation detectors that can be robustly operated in harsh environments.

Device tolerant to:

- **High radiation levels** (neutron, protons, heavy ions, α- and β- particles)
- **High temperature**, at least (200 to 500 ºC)

- Spectrometric characterisation of the detectors at room temperature and at high temperature has been carried out at the CNA.

PROPERTIES OF 4H–SiC AND Si CRYSTALS

M.Moll , NIM in Physics Research A 511 (2003) 97–105

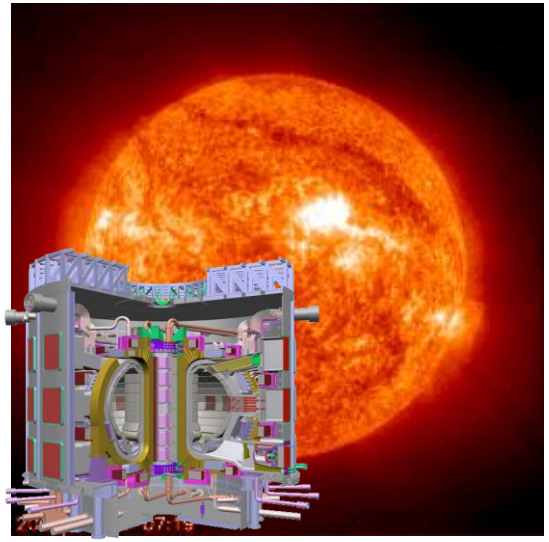
Property	4H–SiC	Si
E_g at (300K) (eV)	3.27	1.12
μ_e (cm^2 V s^{-1})	800	1500
μ_h (cm^2 V s^{-1})	115	450
e–h energy (eV)	8.4	3.6
Displacem. (eV)	25	13-20
Thermal conductivity (Wm^{-1}K^{-1})	490	130
Intrinsic carriers at (300K) (cm^{-3})	6.7×10^{-11}	1.4×10^{10}

Wide bandgap :
Reduces the leakage current, maintaining low noise levels even at high temperatures. Insensitive to visible light.

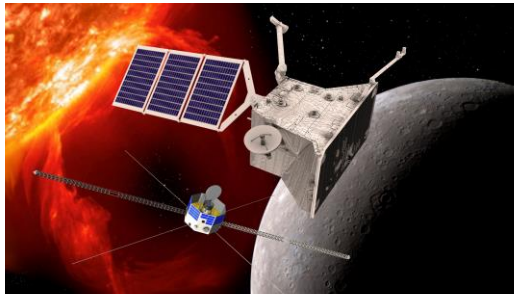
High atomic displacement threshold :
Should make the material more radiation resistant.

Lower concentration of intrinsic carriers and higher thermal conductivity:
Semiconducting behaviour at high temperatures.

GRACE PROJECT: MAIN POTENTIAL APPLICATIONS



Nuclear fusion reactors
-Plasma diagnostic



Aerospace
-Sensors and electronics

Medical
-Dosimetry in FLASH therapy and microdosimetry

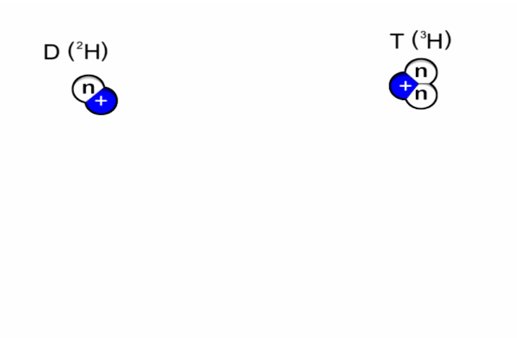
2) NUCLEAR FUSION

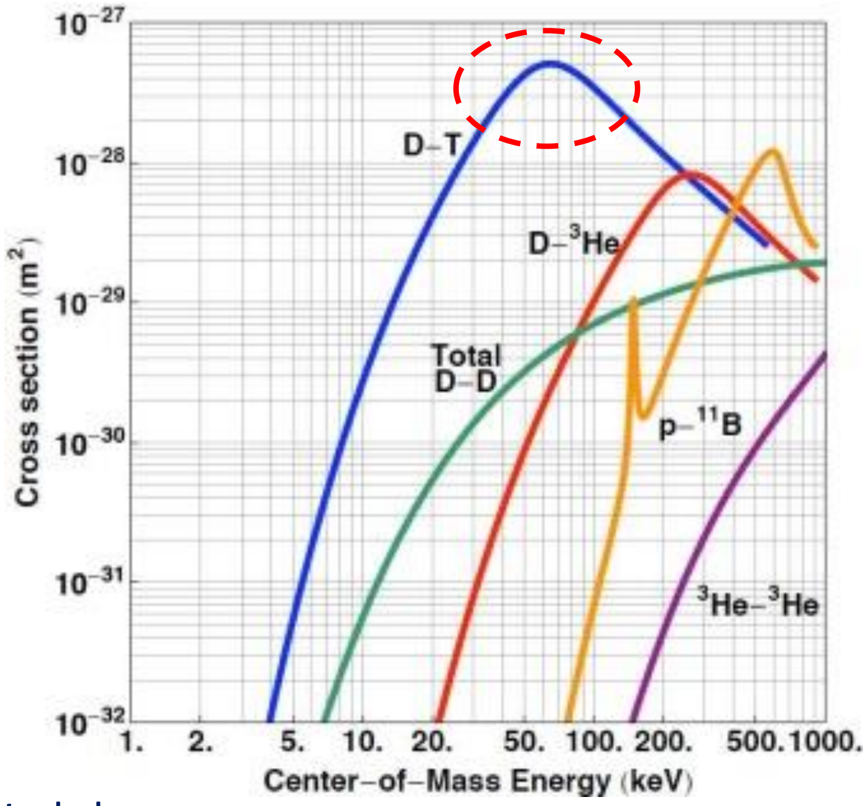
High time resolution video of a plasma from ASDEX Upgrade tokamak.
(Max-Planck-Institut für Plasmaphysik, Garching, Germany)

NUCLEAR FUSION

- Two light atoms are fused together generating a heavier atom with the aim of generating energy.
- D-T presents largest cross section for a fusion reaction

$$
\begin{aligned}
{}^2_1D + {}^3_1T &= {}^4_2\mathrm{He} + {}^1_0n + 17.6\ \mathrm{MeV} \\
{}^2_1D + {}^3_2\mathrm{He} &= {}^4_2\mathrm{He} + {}^1_1H + 18.4\ \mathrm{MeV} \\
{}^2_1D + {}^2_1D &= {}^1_0n + {}^3_2\mathrm{He} + 3.27\ \mathrm{MeV} \\
{}^2_1D + {}^2_1D &= {}^1_1H + {}^3_1T + 4.032\ \mathrm{MeV}
\end{aligned}
$$



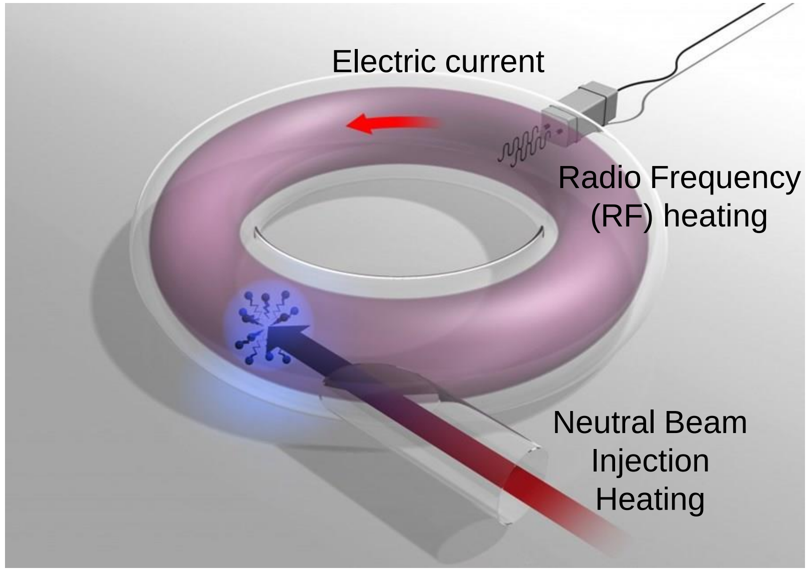


At temperatures required for fusion, all atoms are ionised, in state called “plasma”.

FAST IONS PLAY CRITICAL ROLES IN HEATING AND PLASMA STABILITY

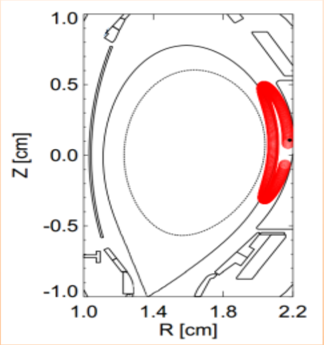
Good confinement of fast ions - fusion reactions, Neutral Beam Injection (NBI) and radio frequency (RF) - is essential for

- Fusion performance
- Device integrity

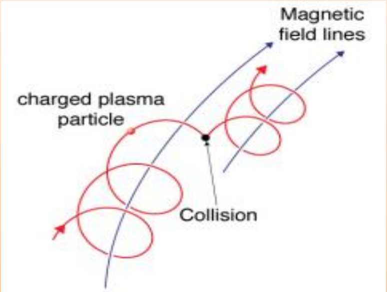


Fast-ions are subject to losses by

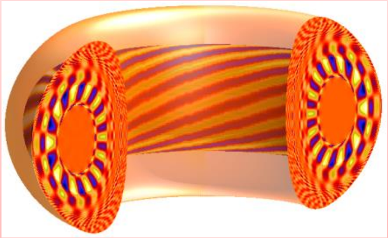
- Insufficient confinement properties of magnetic field (prompt losses)
- Coulomb collisions
- Interaction with magnetohydrodynamics fluctuations.



First orbit ion loss

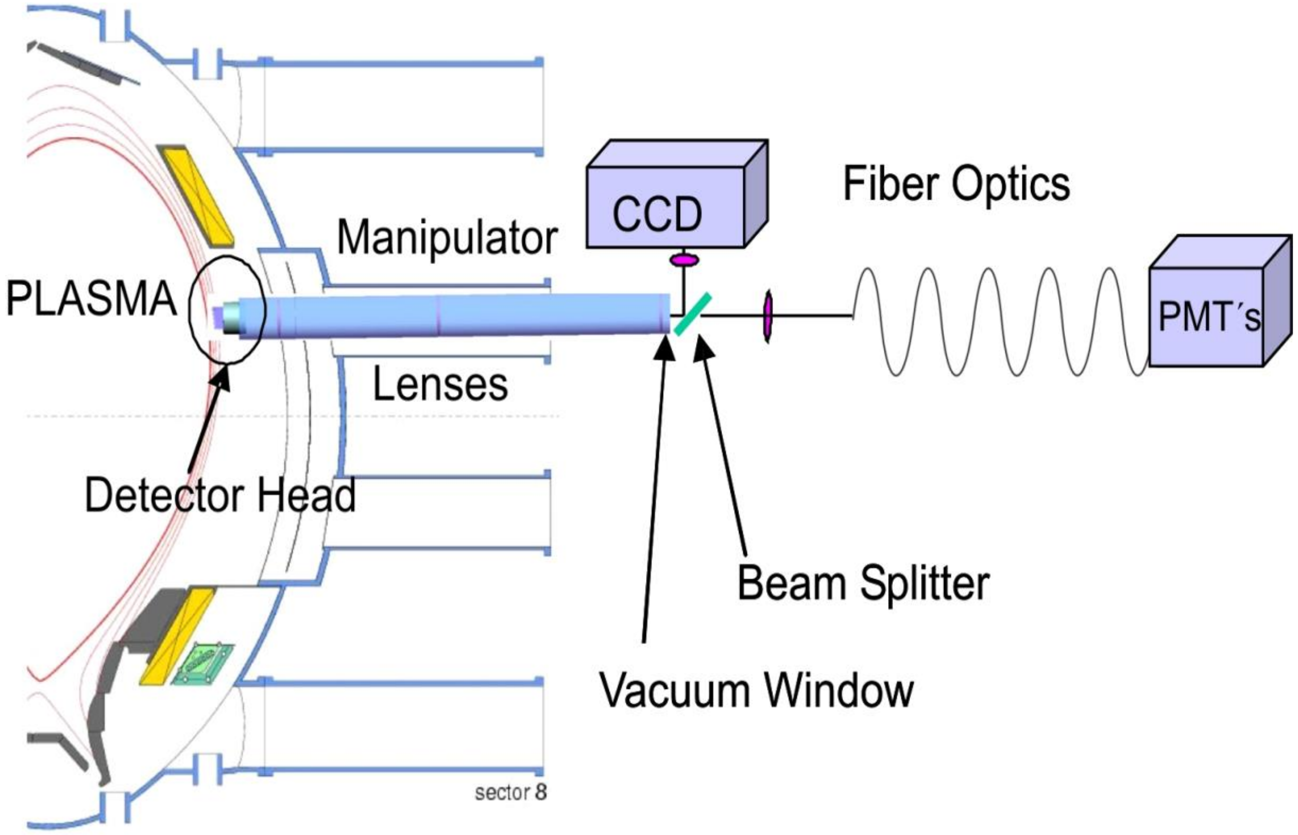


Coulomb Collisions



Interaction with MHD instabilities

3) FAST-ION LOSS DETECTOR (FILD)



Mauricio Rodríguez-Ramos Ph.D*: "Absolute calibration and application of the scintillator-based detector for fast ion losses in nuclear fusion devices" 2017.*
CNA & ASDEX Upgrade.

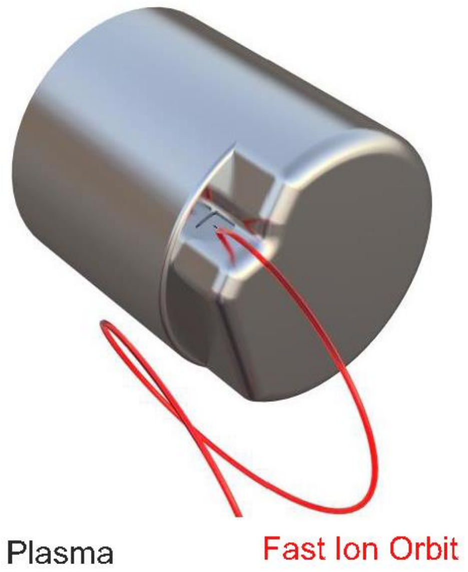
FIELD* PROVIDES FULL INFORMATION ON VELOCITY-SPACE OF ESCAPING IONS

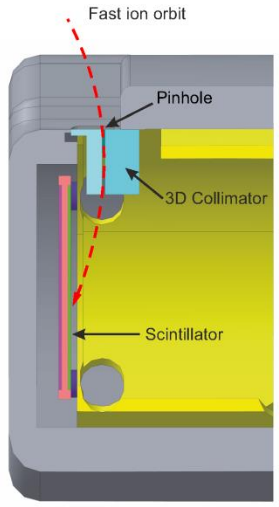
- Design based on a similar TFTR detector *J. Zweben et al*, NF'89

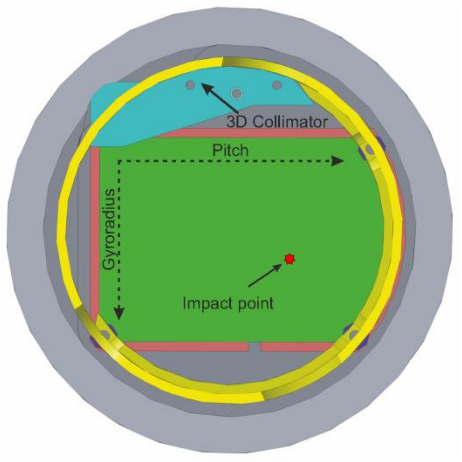
- The strike points of the ions on the scintillator plate depend on their gyroradius and pitch-angle (~magnetic spectrometer)

- Active component: thin film novel scintillator material $SrGa_2S_4:Eu^{2+}$ (TGGreen) with short decay time (490 ns) and high efficiency.

M. Garcia Munoz et al. JINST'11





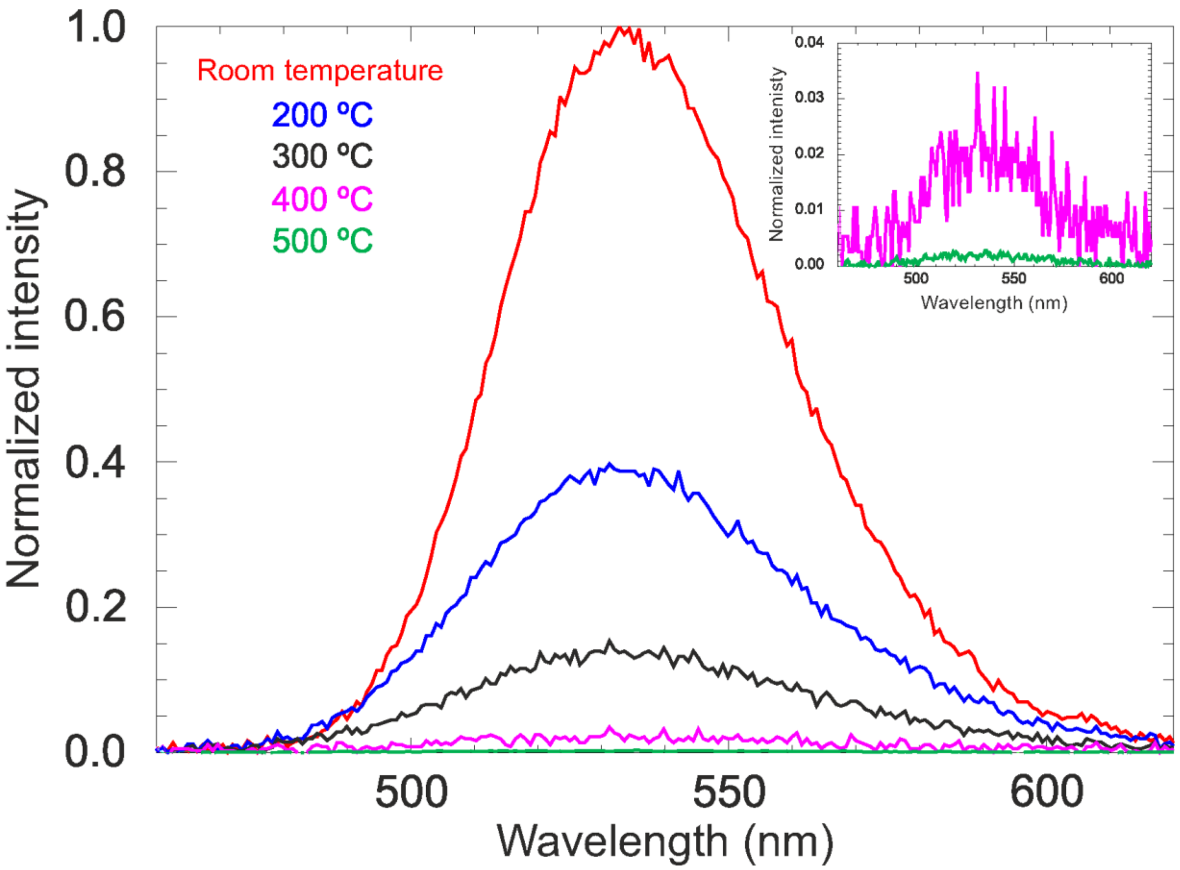


*M.Garcia-Munoz et al, RSI'09

THE ABSOLUTE PHOTON YIELD DECREASES WITH OPERATION TEMPERATURE.

- During tokamak operation, heat load at first wall could make FILD operate a T>RT.

M Rodriguez-Ramos *et al* 2017 *NIM B* **403** , 7–12.

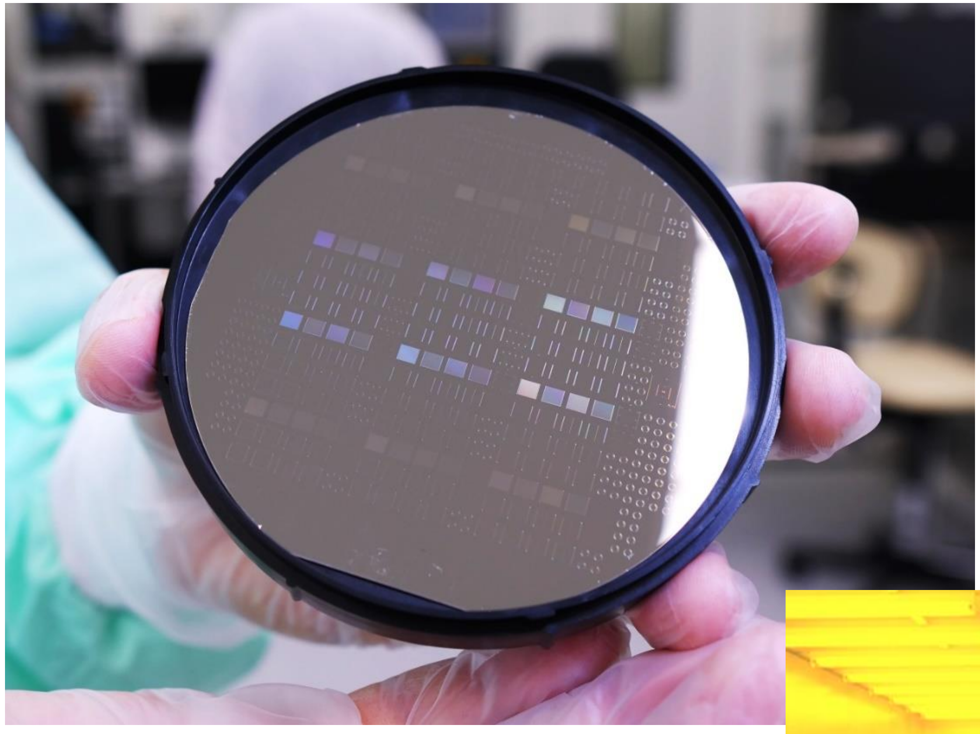


$$\kappa = \frac{\varepsilon_T}{\varepsilon_{RT}}$$

Ion	$\kappa_{200ºC}$ (%)	$\kappa_{300ºC}$ (%)	$\kappa_{400ºC}$ (%)	$\kappa_{500ºC}$ (%)
H^+	47±12	10±3	1.3±0.3	0.10±0.03
D^+	41±10	10±3	1.8±0.4	0.20±0.05
He^{++}	30±7	10±3	1.7±0.4	0.20±0.05

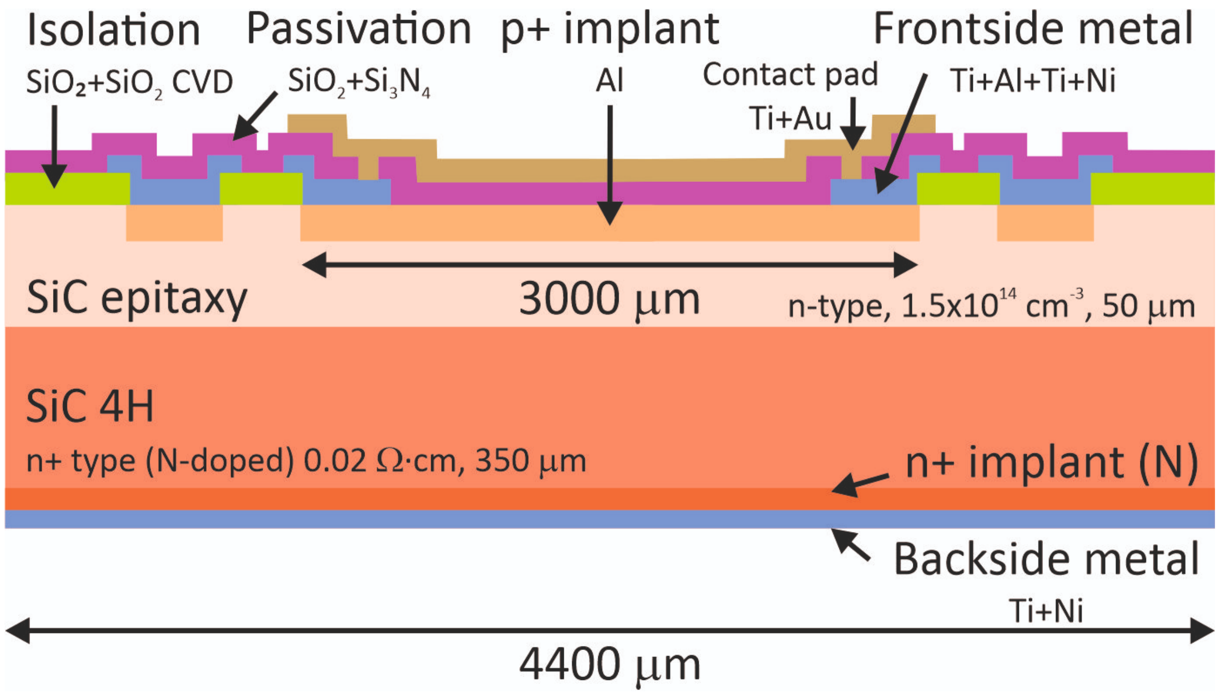
Quenching of material for T > 400º C !!!

4) SiC DETECTOR MANUFACTURED AT IMB-CNM

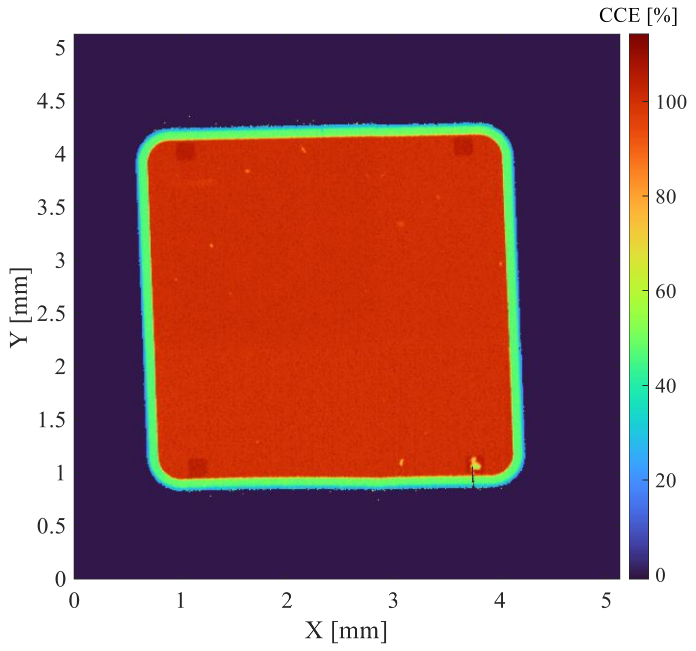


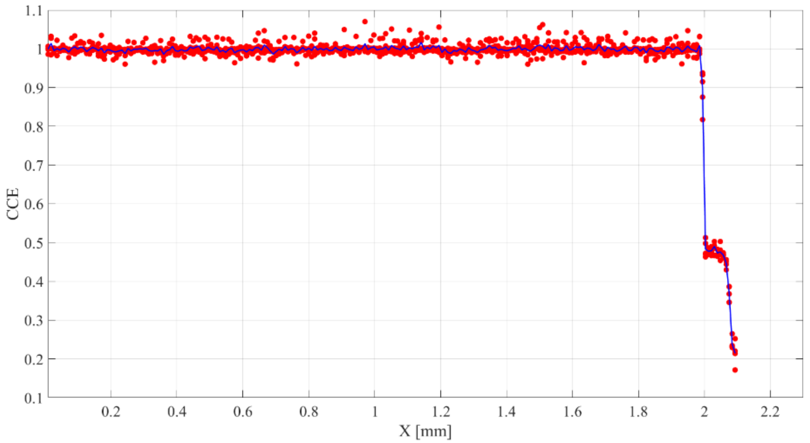
SiC DETECTOR MANUFACTURED AT IMB-CNM

Single diode with extra metal layer. Run 13575.



CCE homogeneity study on twin diode.

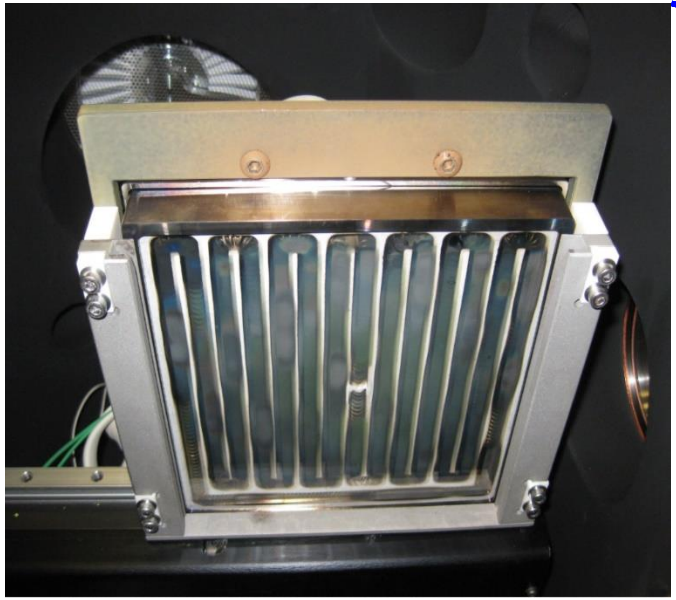




Homogeneity IBIC measurements on the microprobe line at CNA with He^{2+} @ 3.5 MeV. The mean standard deviation is ~1%.

5) SiC MEASUREMENTS AT HIGH TEMPERATURE AT THE 3 MV TANDEM OF THE CNA

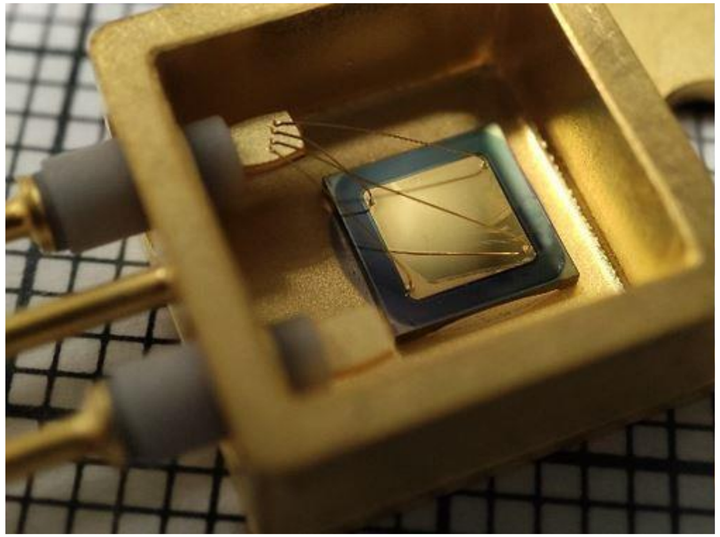
SiC MEASUREMENTS SETUP

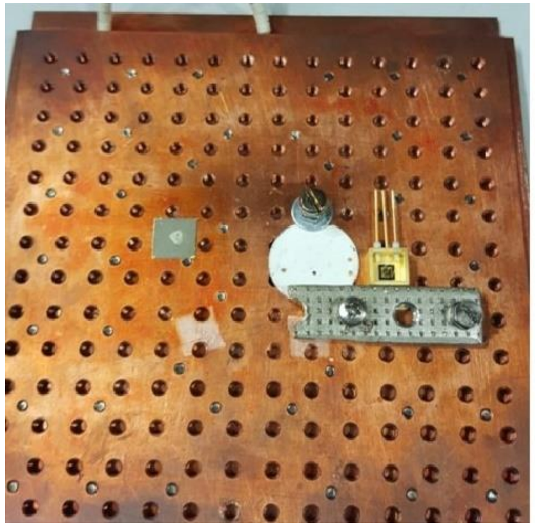


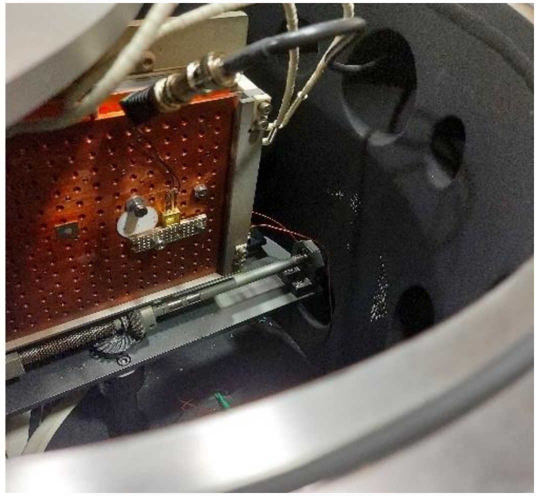
Furnace accommodated inside the chamber (RT-500 ºC)

Vacuum chamber for high temperature measurements.

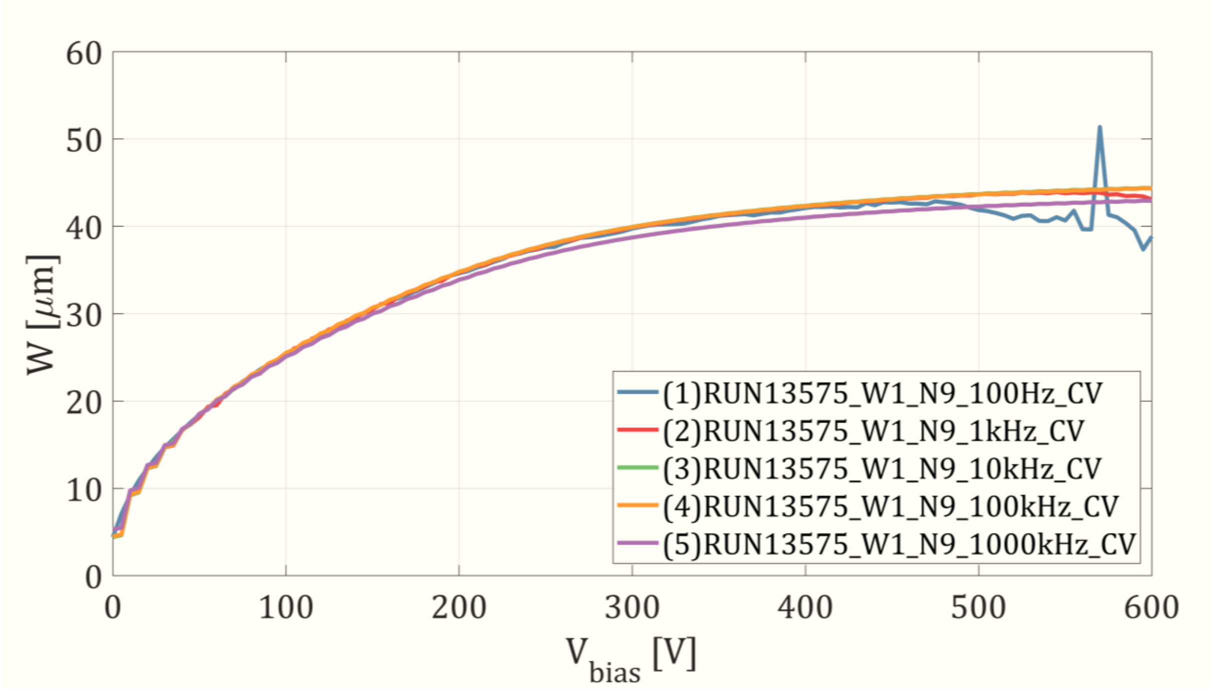
- TO257 package
- Ag Sintering
- Gold bondings

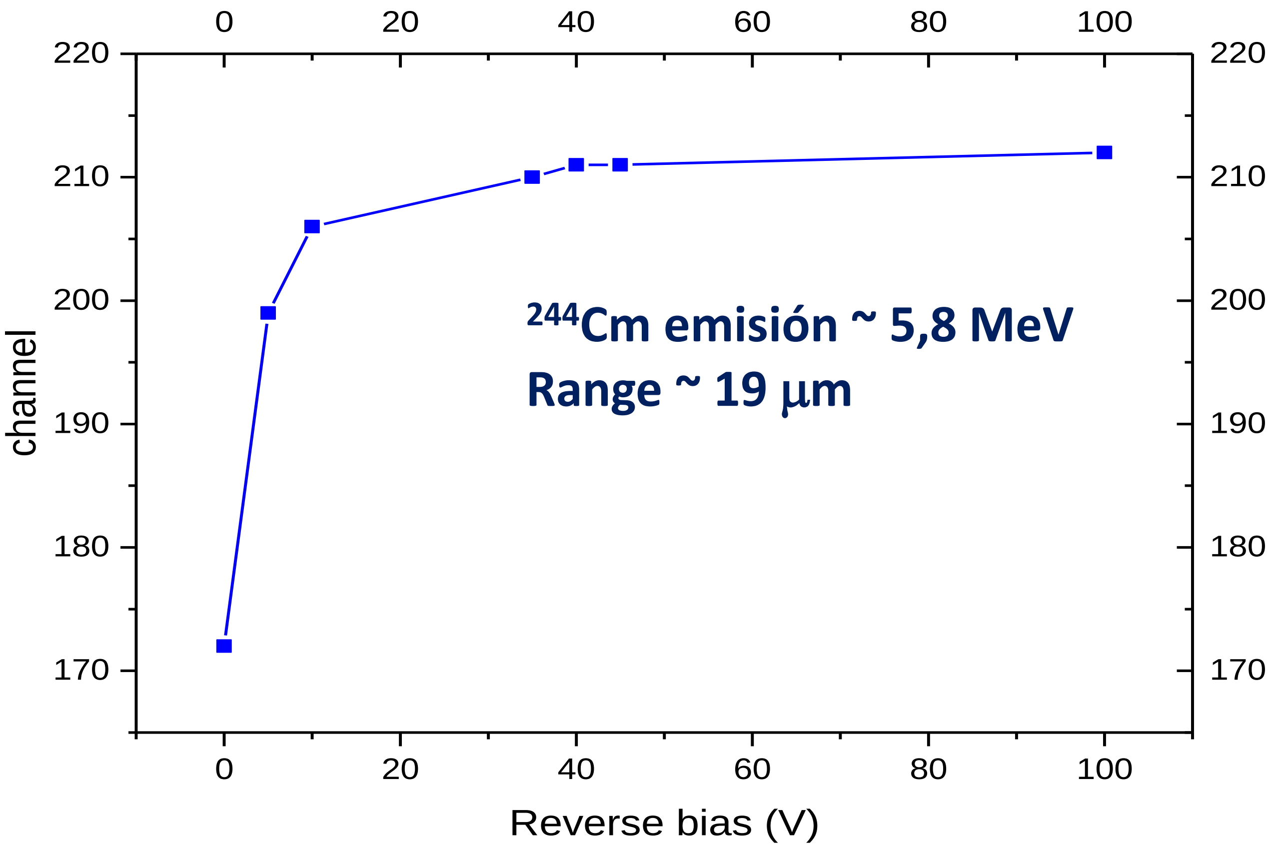






ALPHA SOURCE MEASUREMENT AT RT FOR SETTING THE OPERATION VOLTAGE

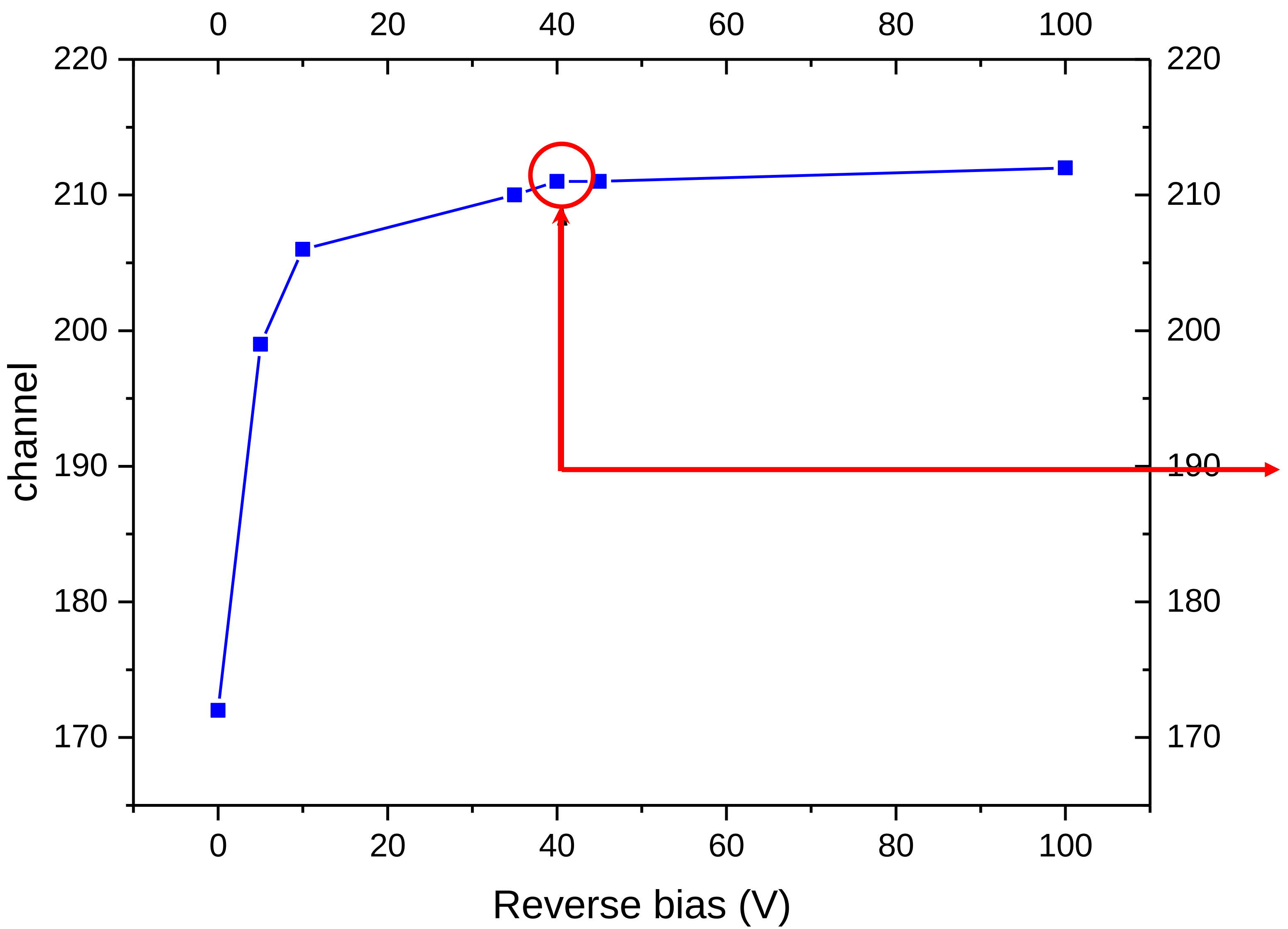




^{244}Cm emisión ~ 5,8 MeV

Range ~ 19 μm

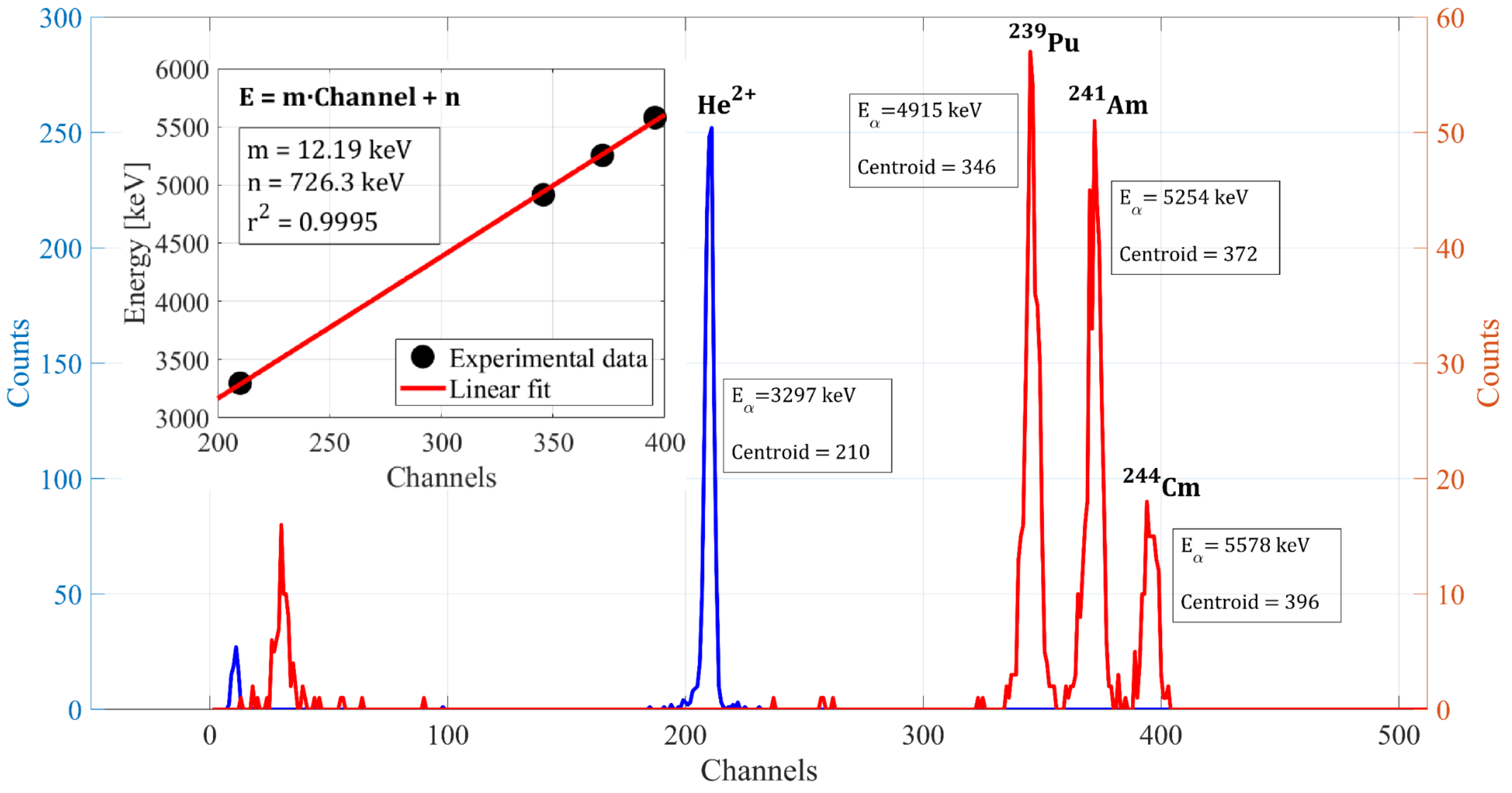
ALPHA SOURCE MEASUREMENT AT RT FOR SETTING THE OPERATION VOLTAGE

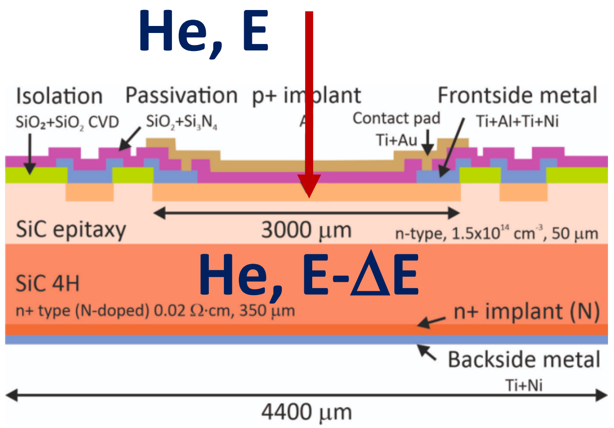


At 40 V the deplexion zone is thick enough to completely stop the 5.8 MeV alpha particles and the CCE signal saturate.

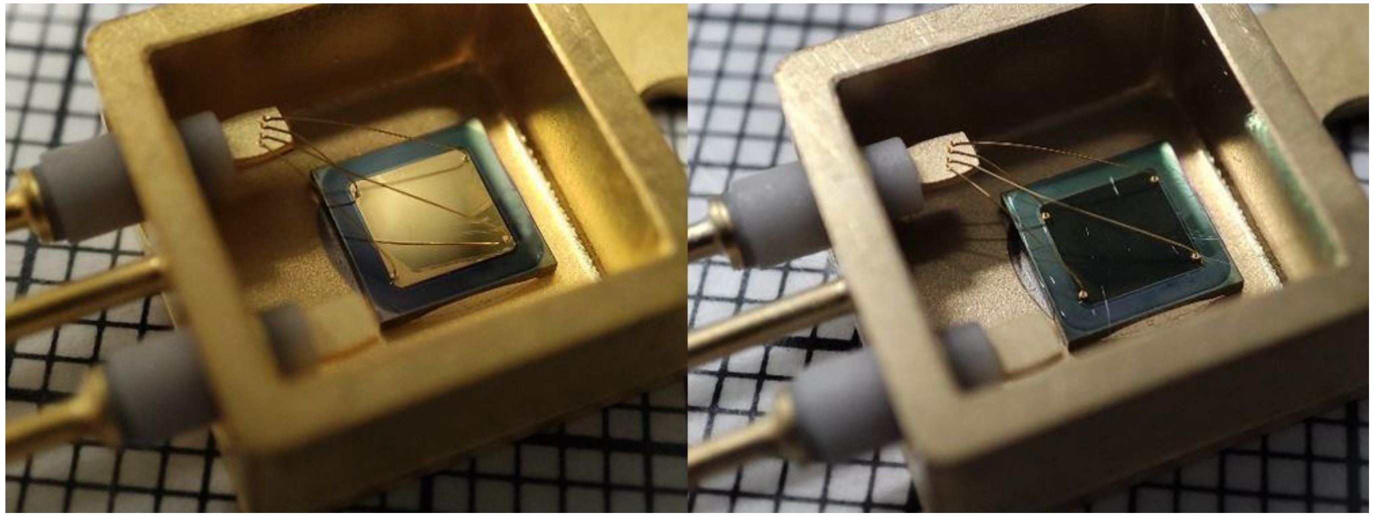
Both electronic noise and reverse current increase at higher voltages during high temperature measurements, so it was decided to perform the experiments at 40 V.

MULTICHANNEL CALIBRATION AT RT

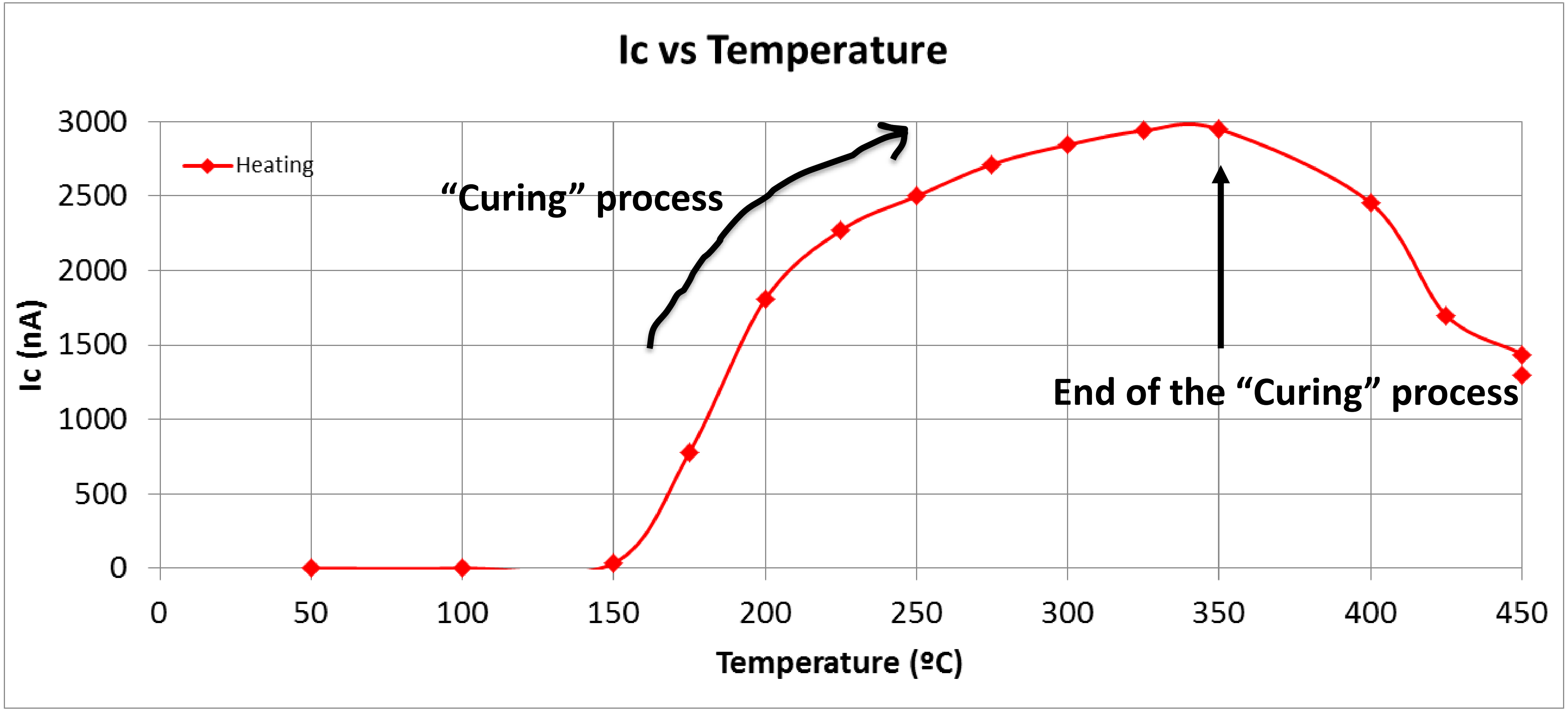




6) RESULTS

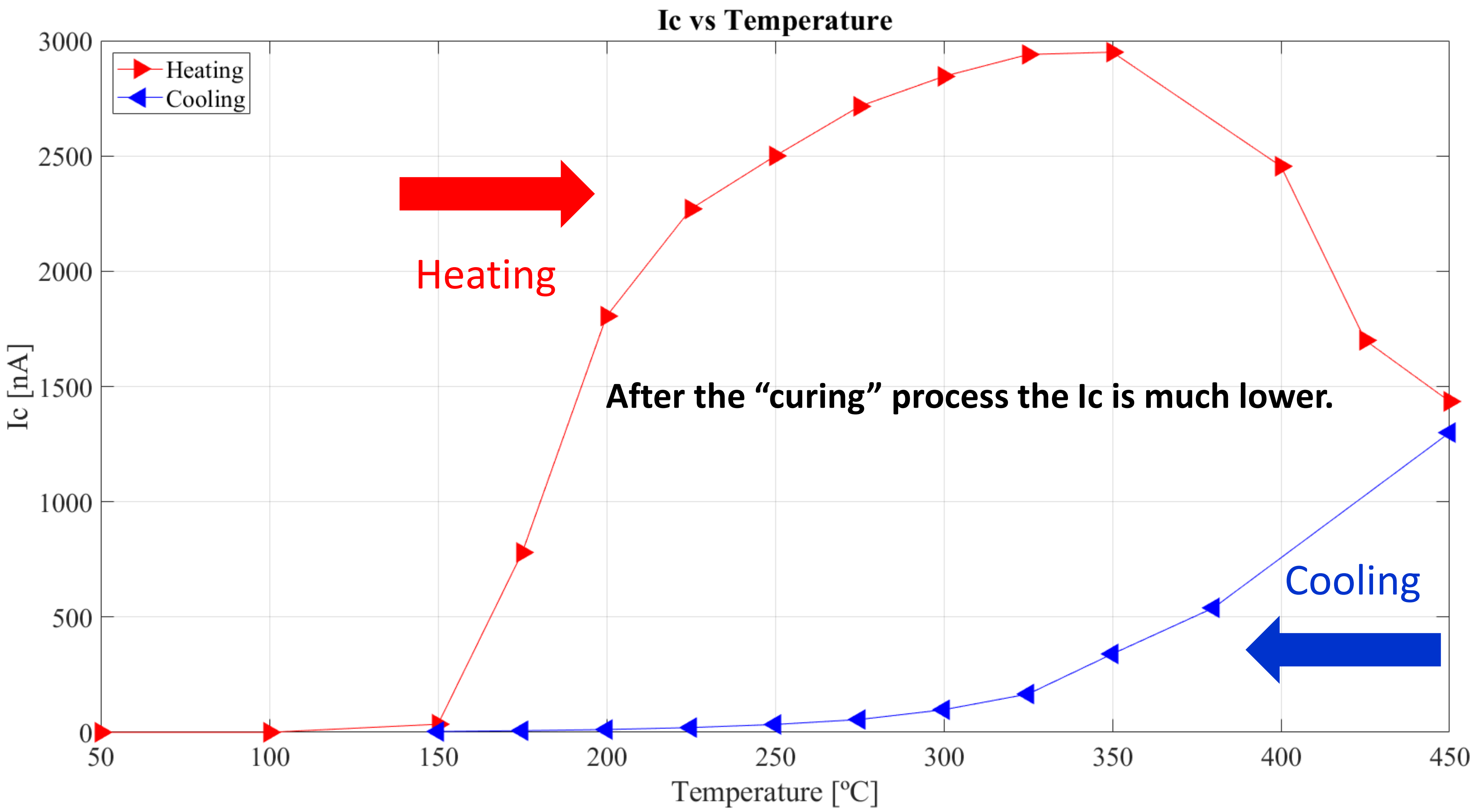


REVERSE CURRENT VS Tª

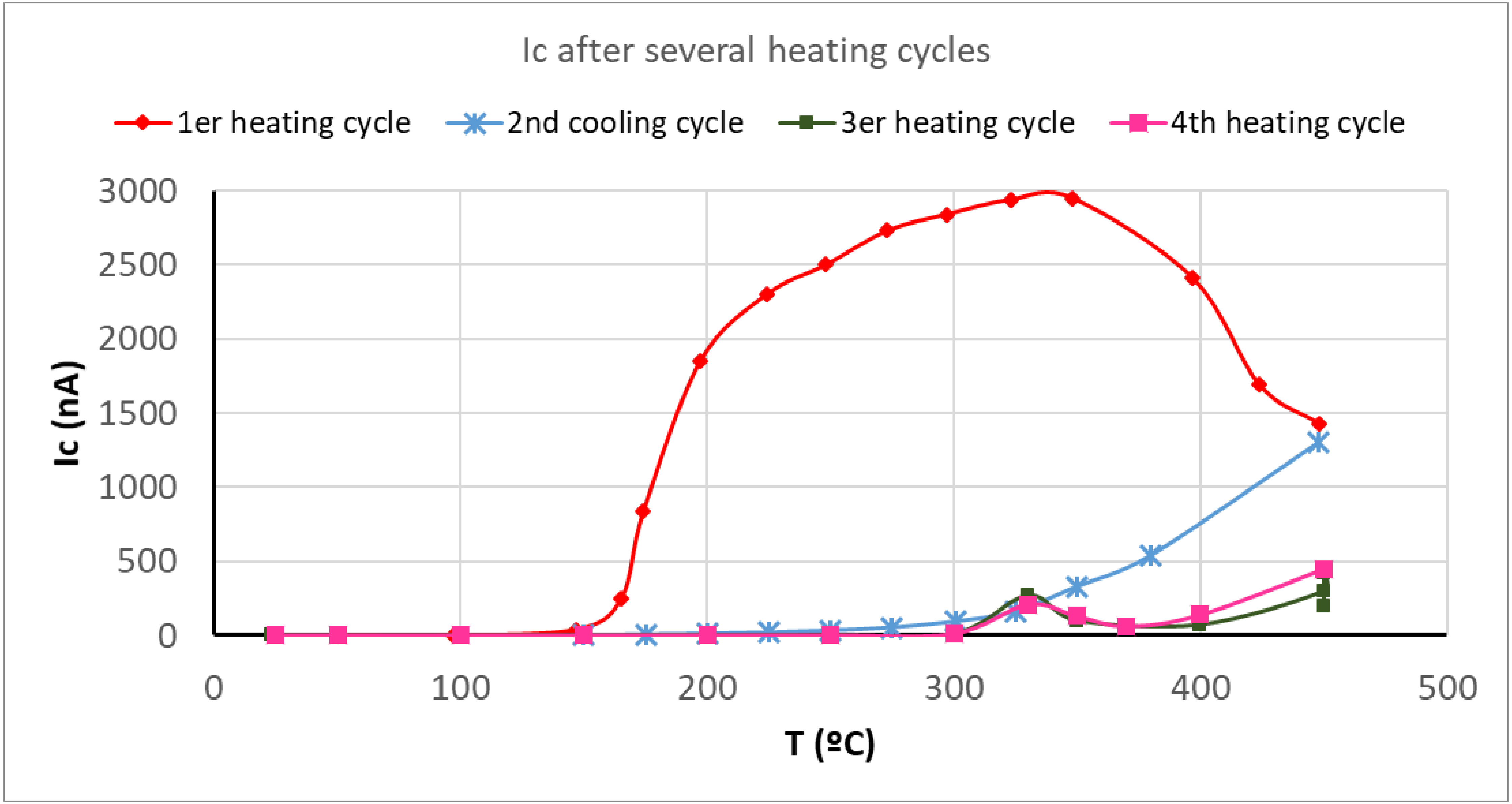


First heating cycle: Ic reaches a maximum and then decreases

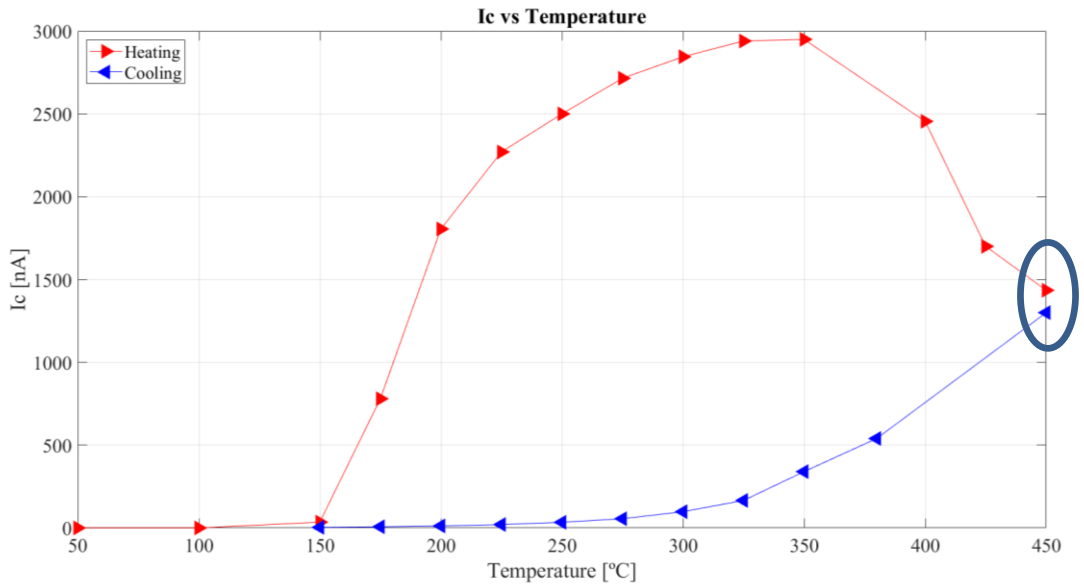
REVERSE CURRENT VS Tª

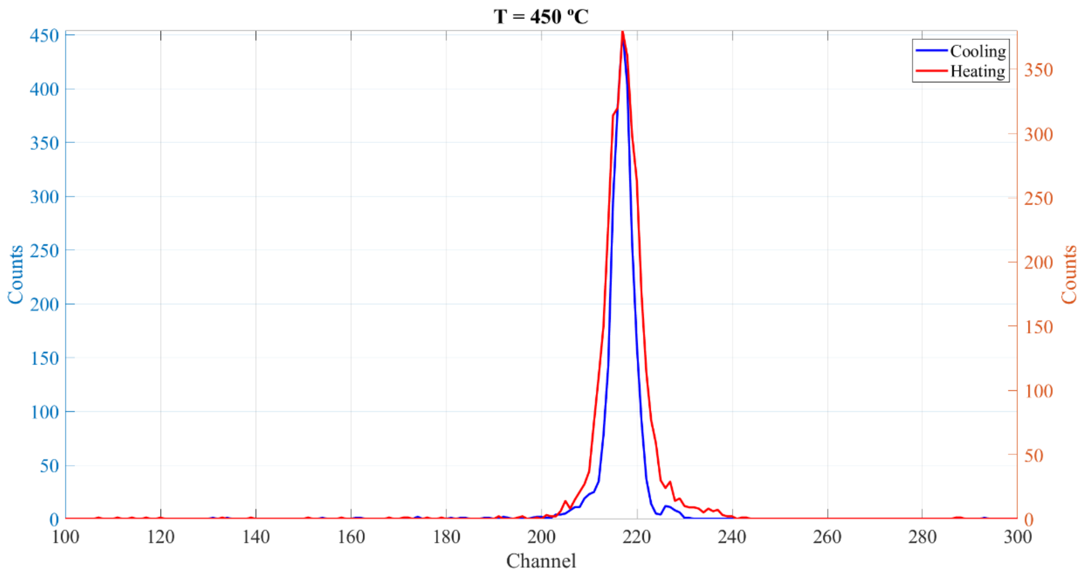


REVERSE CURRENT VS Tª

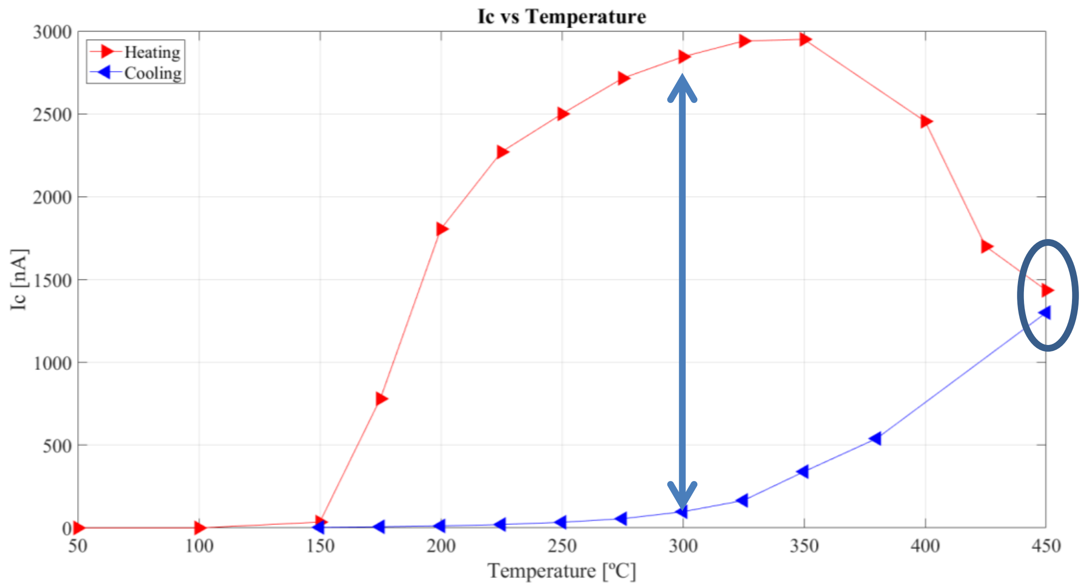


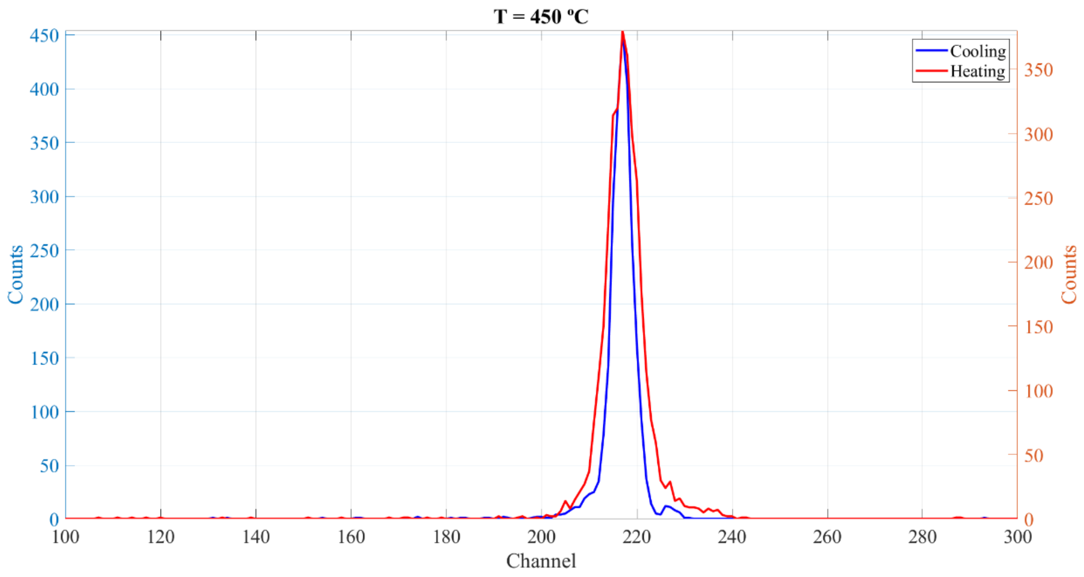
REVERSE CURRENT → RESOLUTION

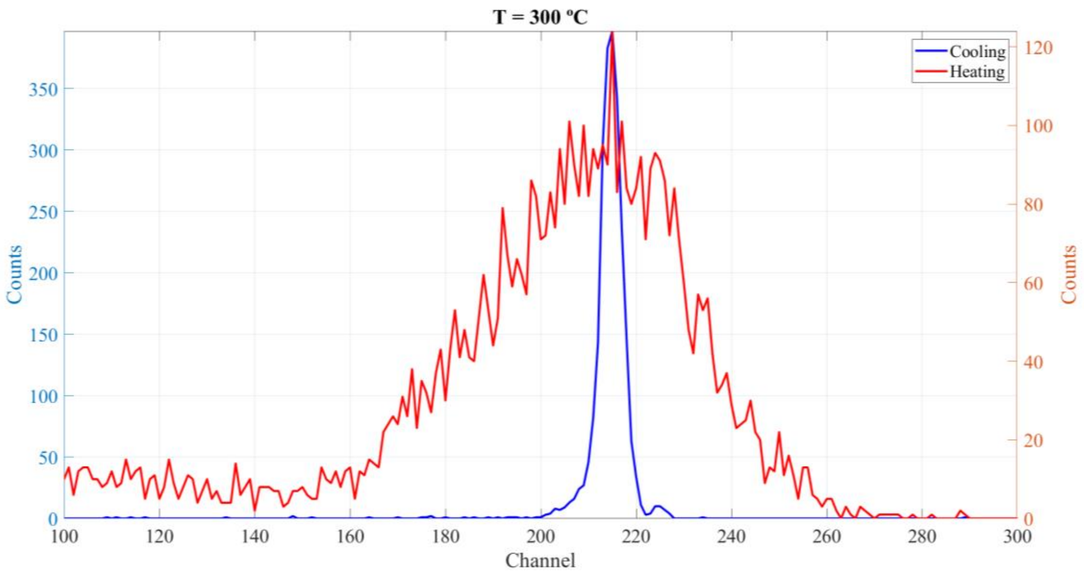




REVERSE CURRENT → RESOLUTION







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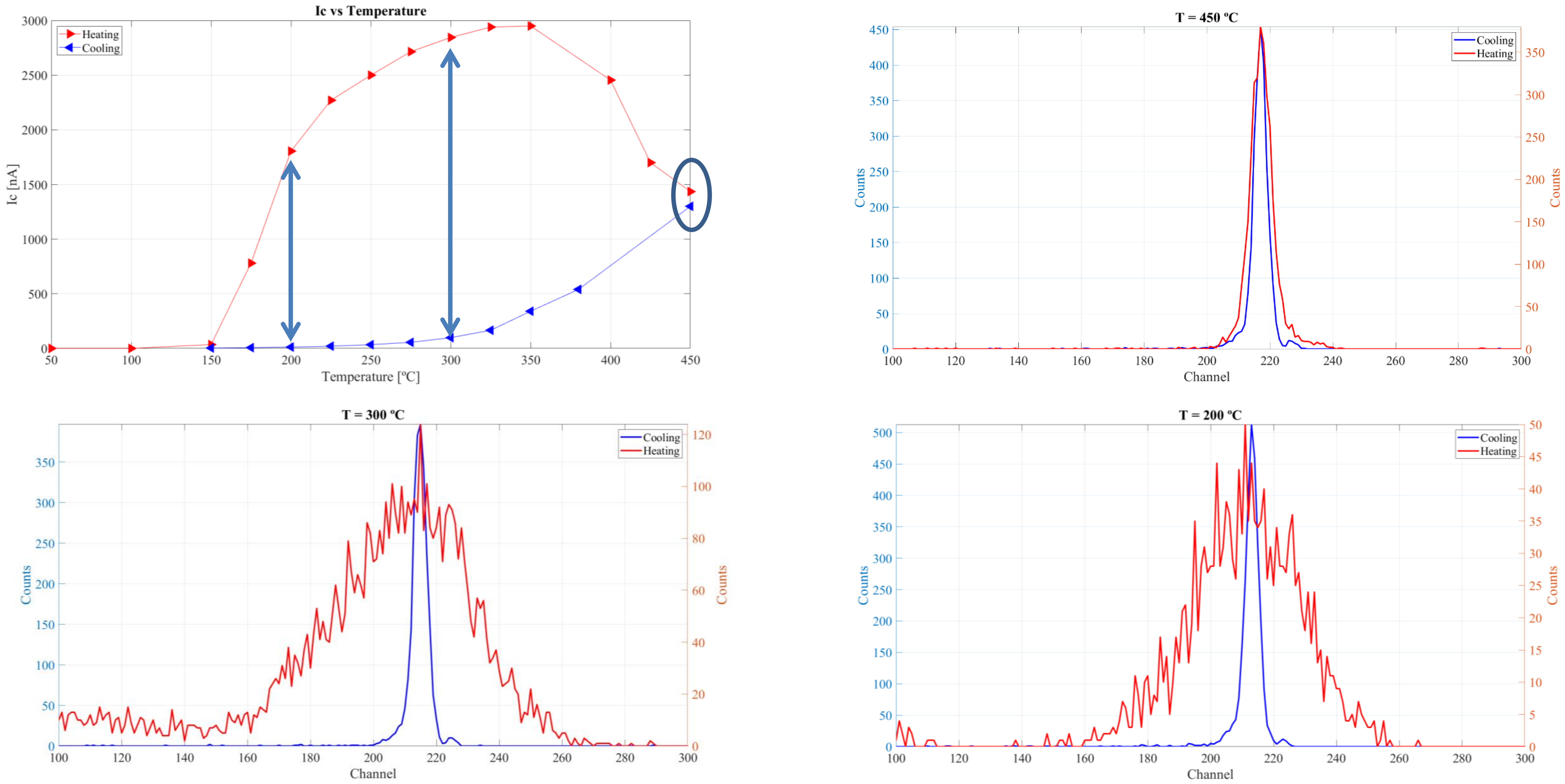

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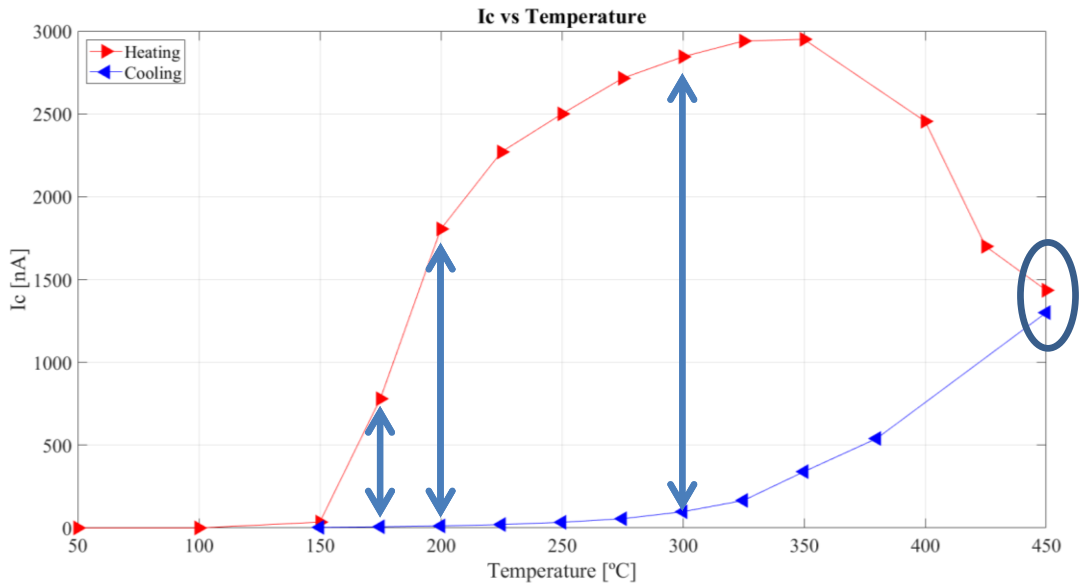
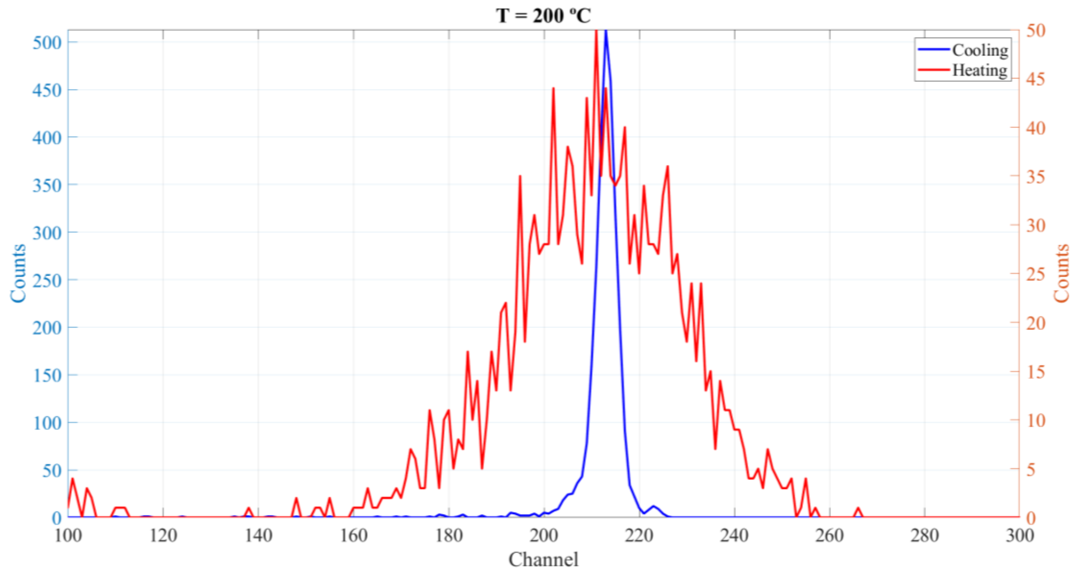
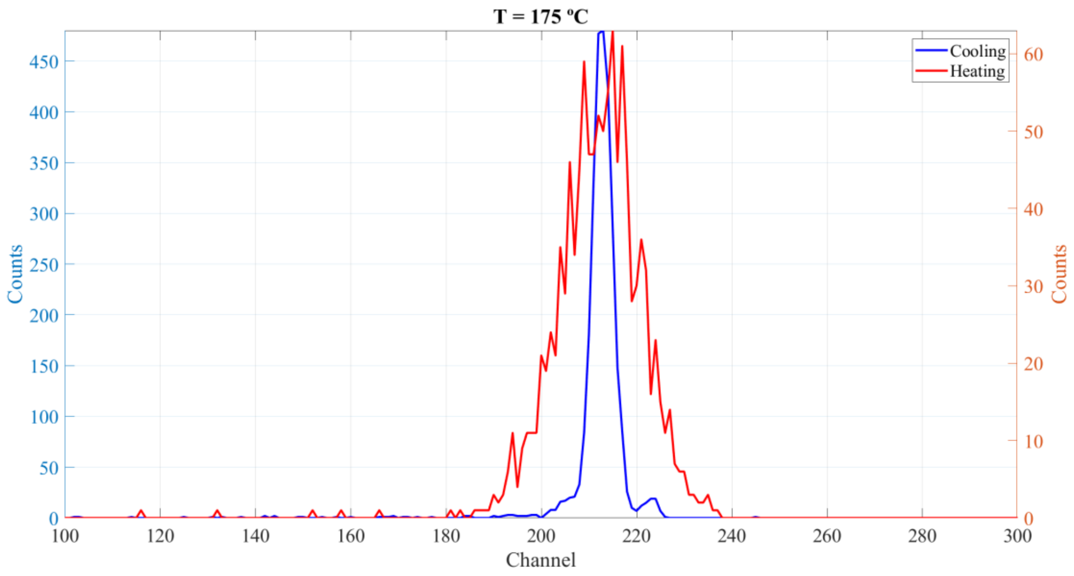
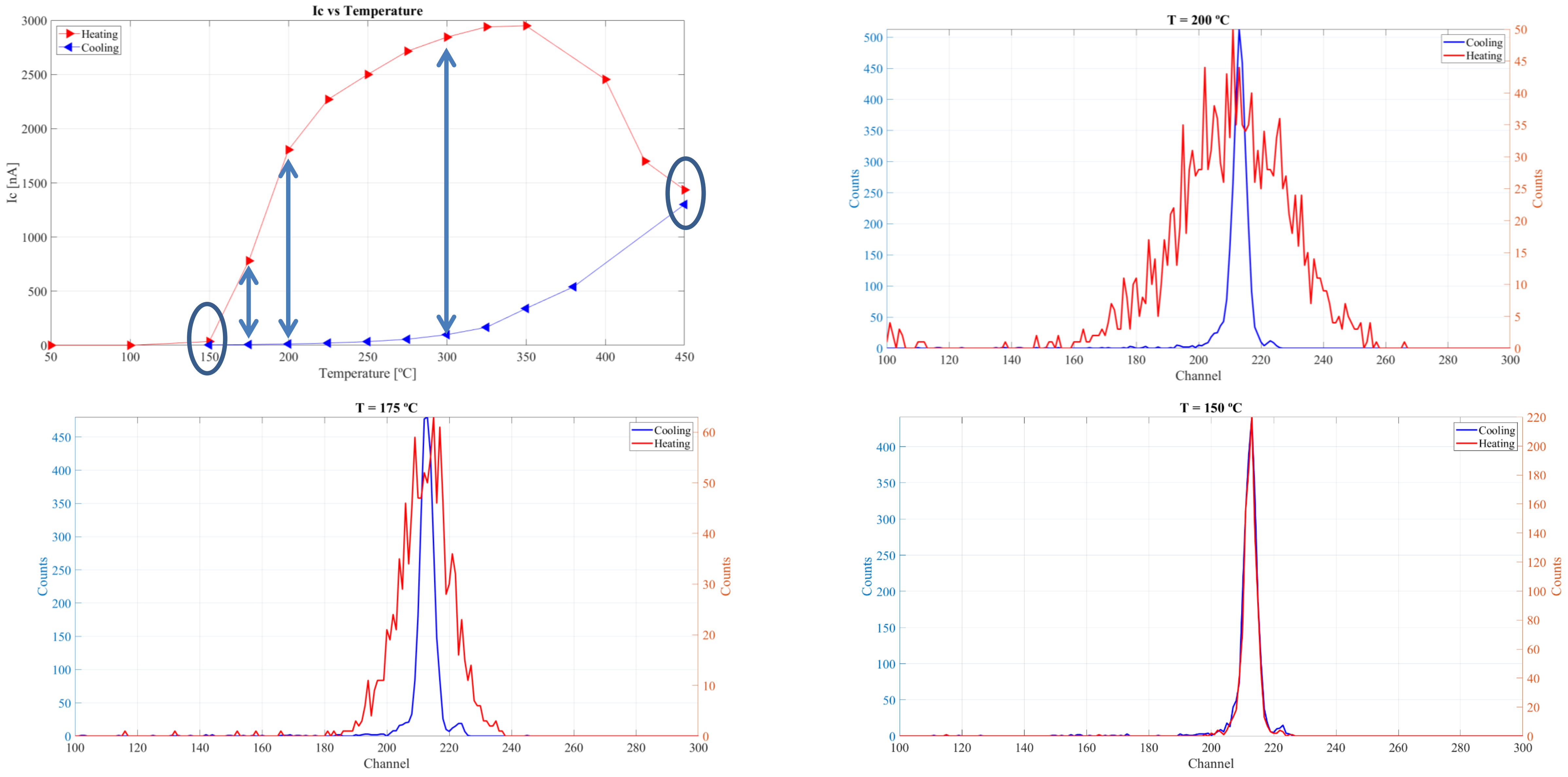






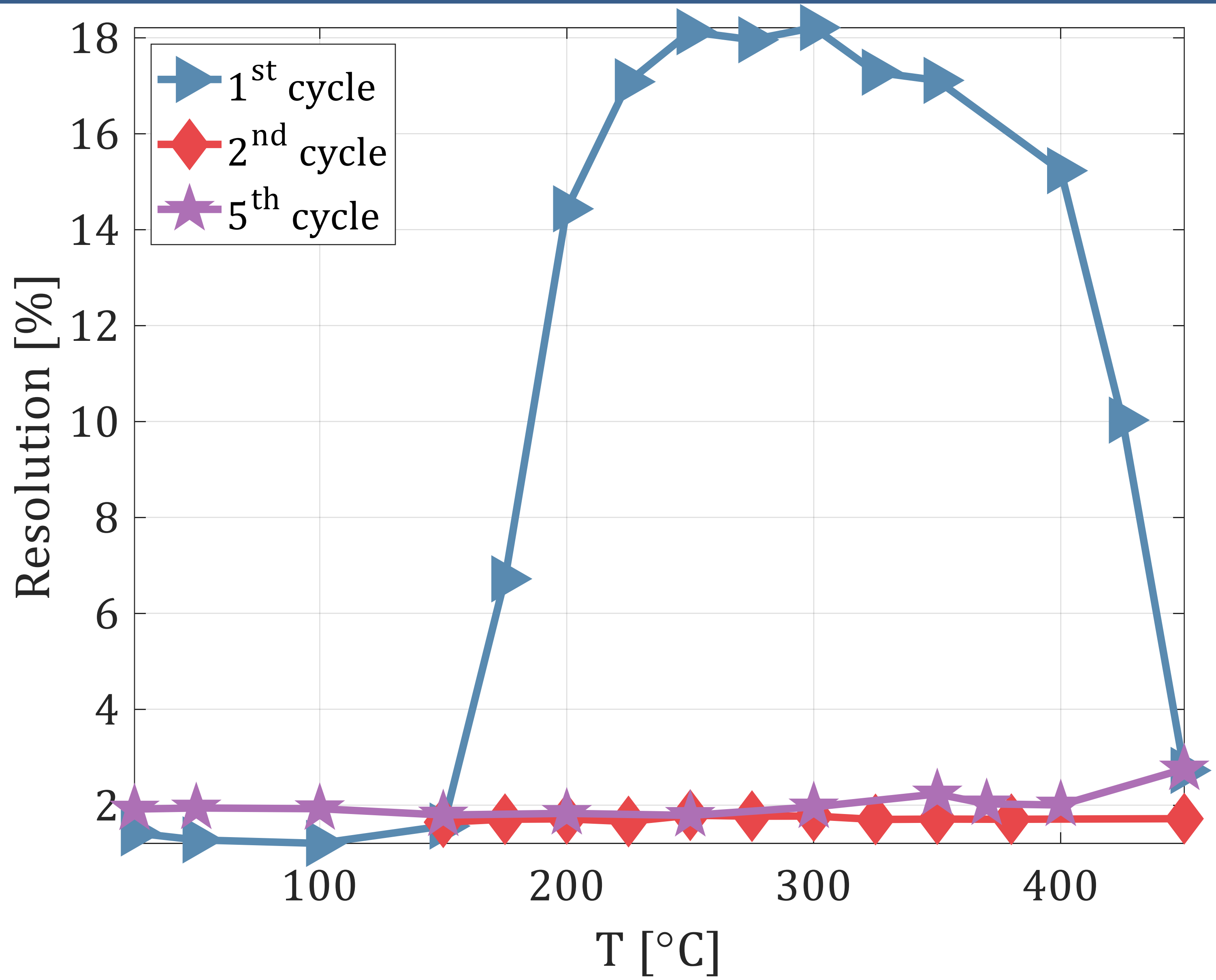
REVERSE CURRENT → RESOLUTION



RESOLUTION AFTER "CURING"PROCESS

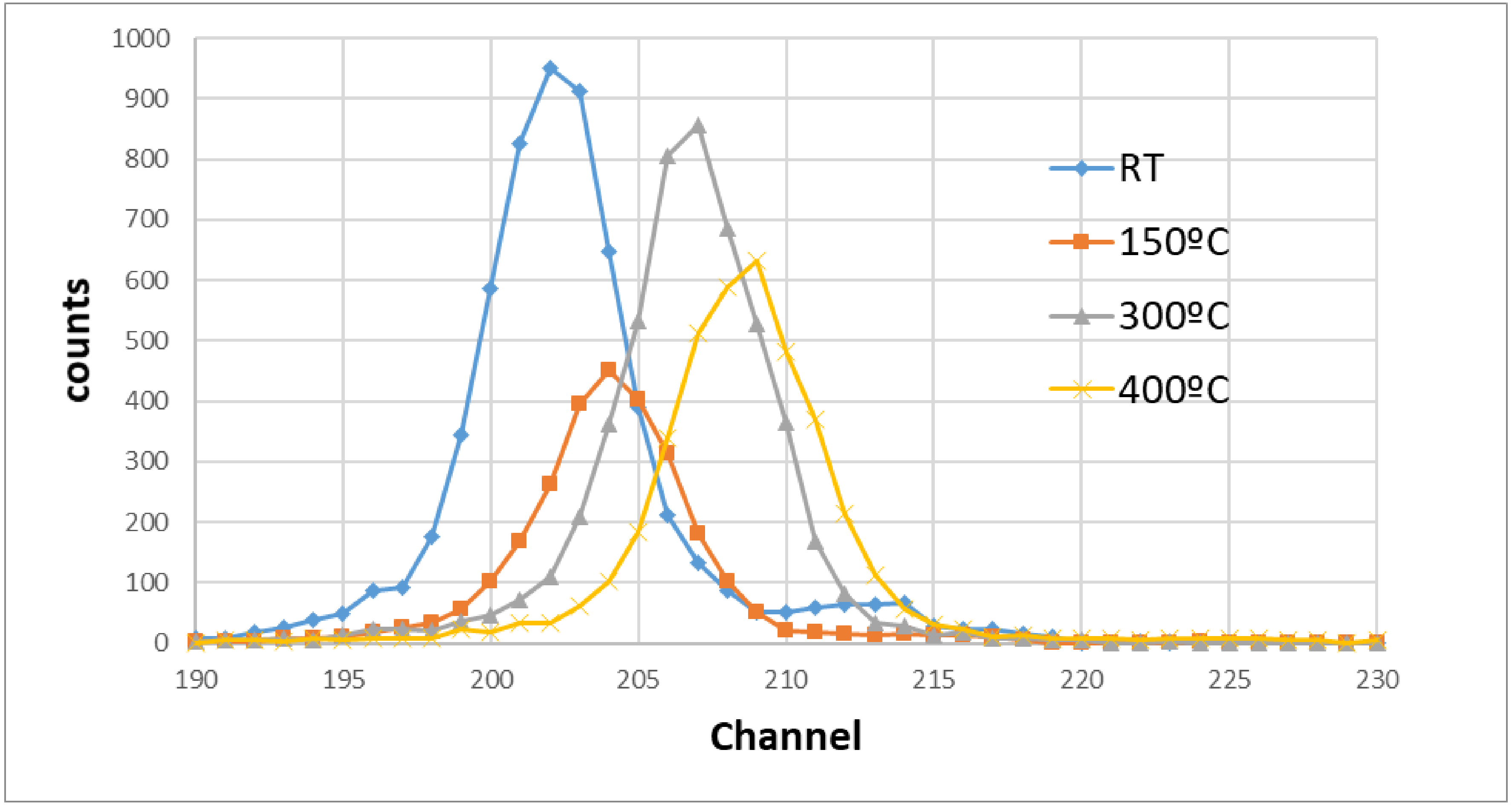
5 heating cycles were performed

Once the detector is "cured", the resolution does not change with temperature, it remains constant at around 2% for several heating cycles!!!



THE INCREASE OF CHARGE COLLECTED VS T IS EXPECTED

Measurements from RT to 450ºC



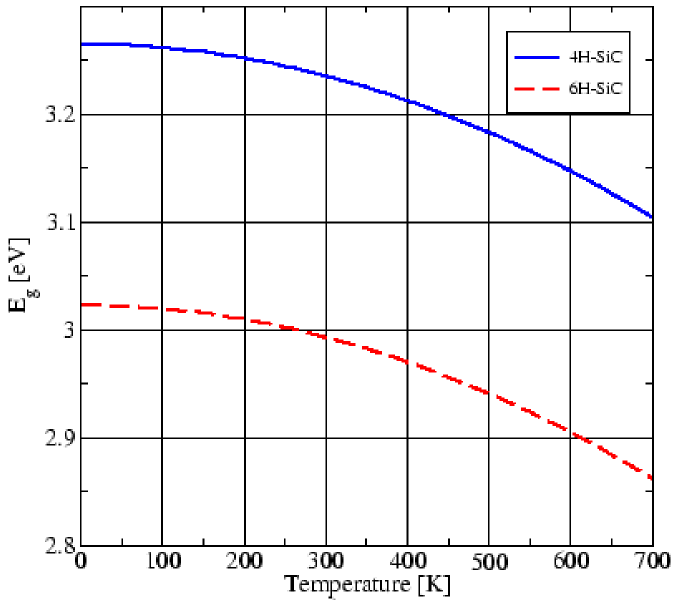
THE INCREASE OF CHARGE COLLECTED VS T IS EXPECTED

Measurements from RT to 450ºC → **Change in the BandGap energy**

Properties of Advanced Semiconductor Materials: GaN, AIN, InN, BN, SiC, SiGe. John Wiley & Sons. (2001).

$$E_g(T) = 3.265 - 6.5 \times 10^{-4} \frac{T^2}{T + 1300} \; (eV)$$

https://www.iue.tuwien.ac.at/phd/ayalew/node61.html



THE INCREASE OF CHARGE COLLECTED VS T IS EXPECTED

Measurements from RT to 450ºC → **Change in the BandGap energy** → **Change in the pair creation energy**

Properties of Advanced Semiconductor Materials: GaN, AIN, InN, BN, SiC, SiGe. John Wiley & Sons. (2001).

$$E_g(T) = 3.265 - 6.5 \times 10^{-4} \frac{T^2}{T + 1300} \ (eV)$$

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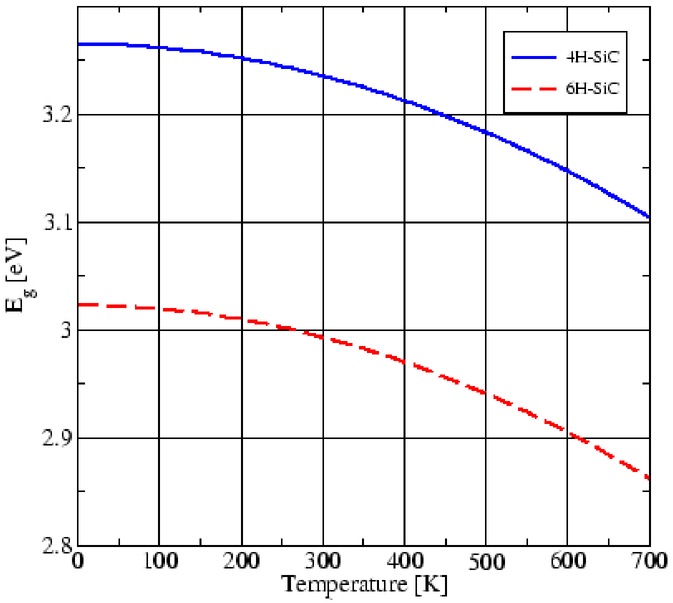

THE INCREASE OF CHARGE COLLECTED VS T IS EXPECTED

Measurements from RT to 450ºC → **Change in the BandGap energy** → **Change in the pair creation energy** → **Change in measured energy**

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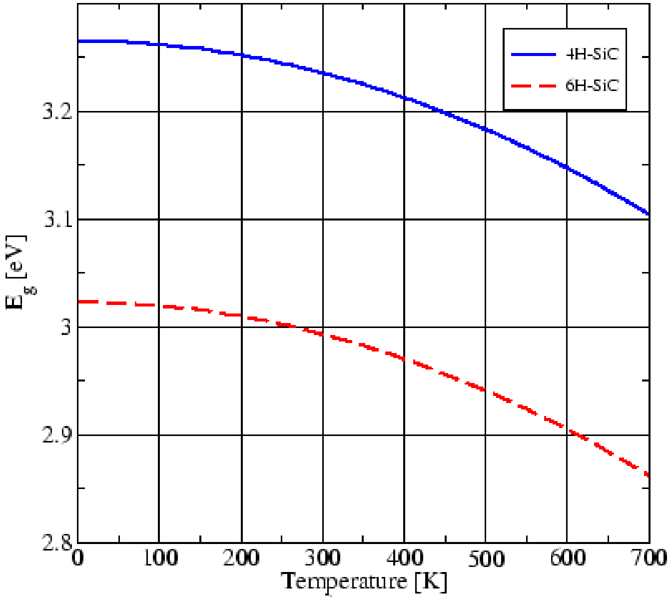
$$E_g(T) = 3.265 - 6.5 \times 10^{-4} \frac{T^2}{T + 1300} \; (eV)$$

$$\varepsilon_{4H-SiC}(T) = \varepsilon_{4H-SiC}(RT) \frac{E(RT)}{E(T)}$$

https://www.iue.tuwien.ac.at/phd/ayalew/node61.html

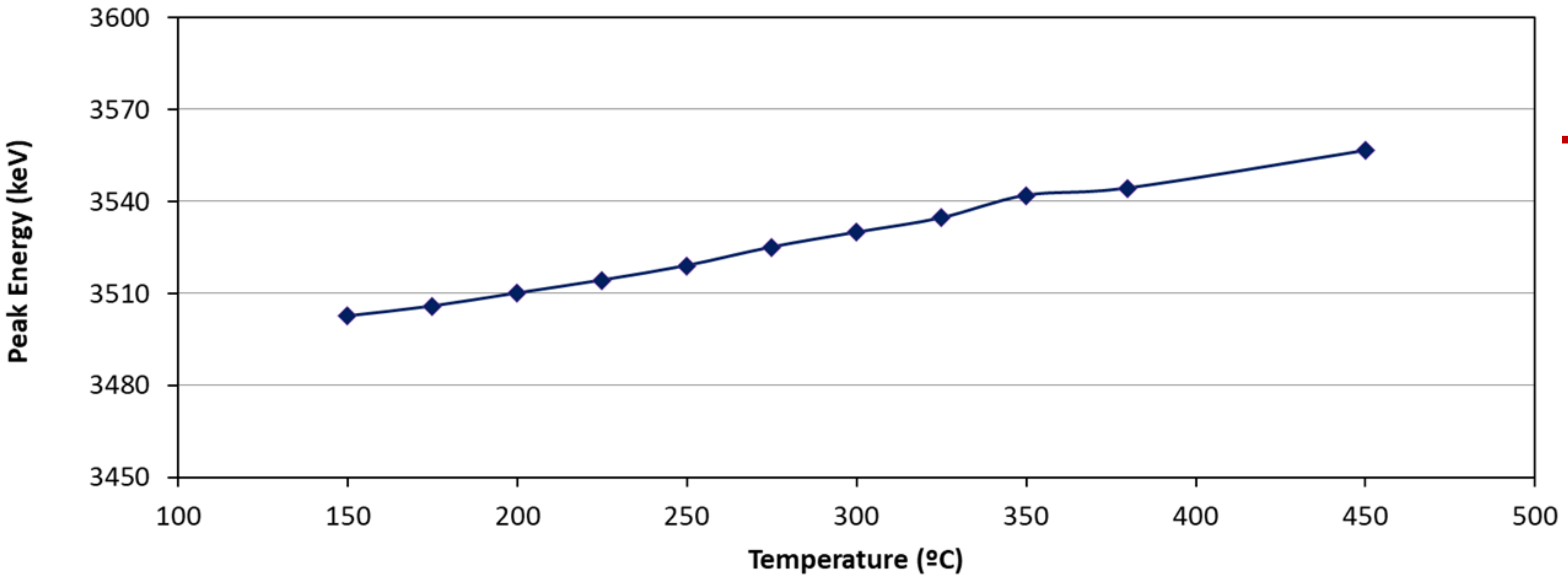


THE INCREASE OF CHARGE COLLECTED VS T IS EXPECTED

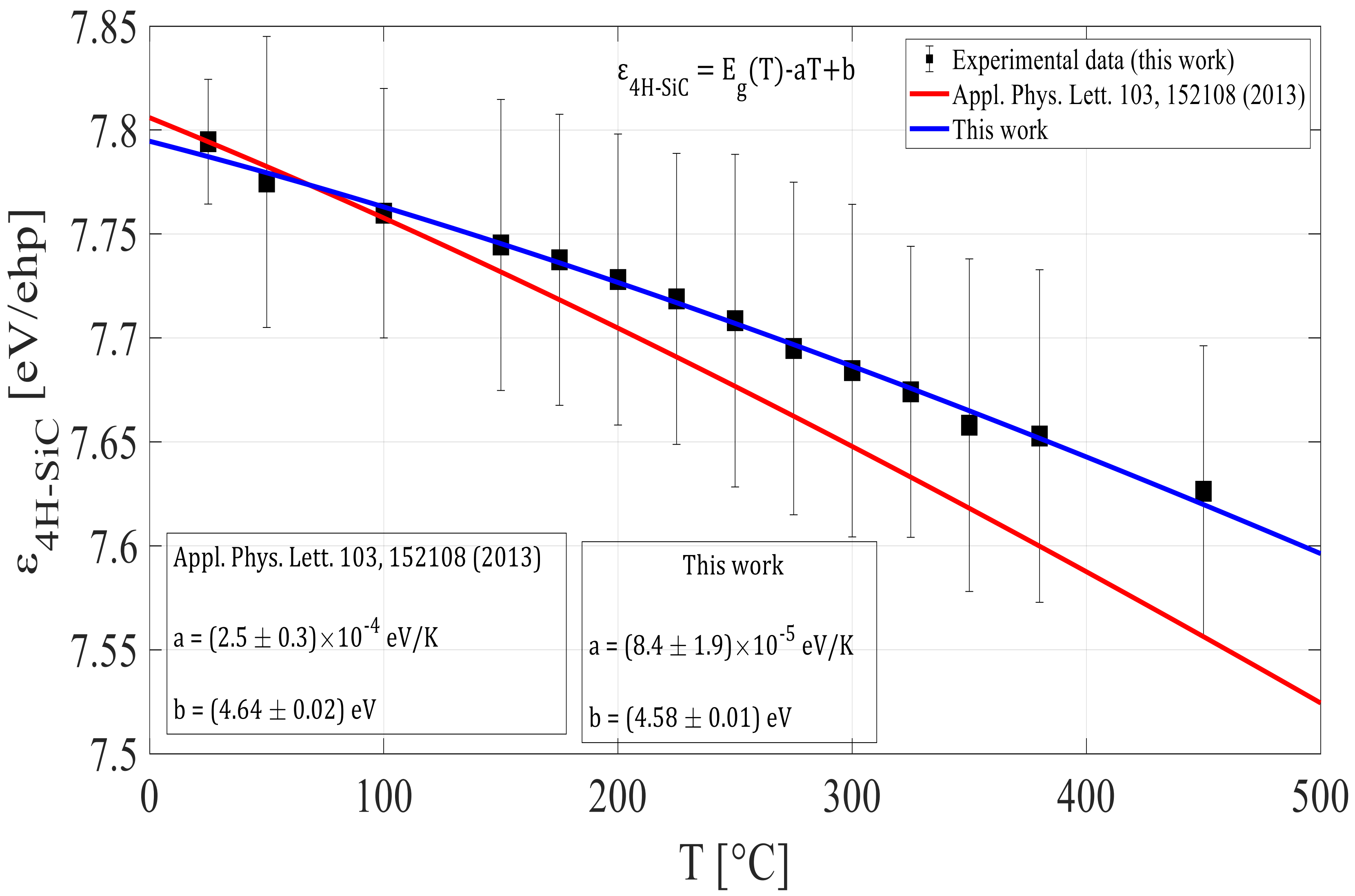
Measurements from RT to 450ºC → **Change in the BandGap energy** → **Change in the pair creation energy** → **Change in measured energy**

$$E_g(T) = 3.265 - 6.5 \times 10^{-4} \frac{T^2}{T + 1300}\ (eV)$$

$$\varepsilon_{4H-SiC}(T) = \varepsilon_{4H-SiC}(RT) \frac{E(RT)}{E(T)}$$

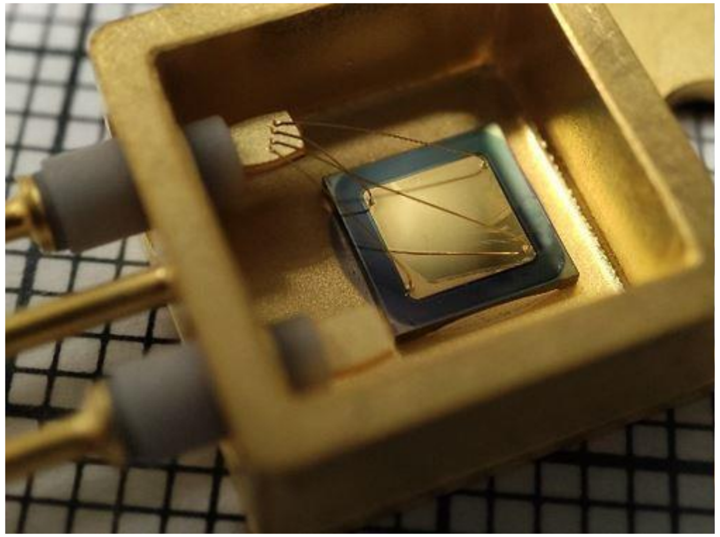


PAIR CREATION ENERGY VS T



CONCLUSIONS

- SiC detectors have been developed at IMB with very good spectrometric response until 450ºC .
- This opens possibilities to use these detectors to monitor the fast ions losses in fusion plasmas.
- The radiation hardness of these devices at high temperature is under study.



THANK YOU FOR YOUR ATTENTION

Acknowledgements to :

***Project RETOS-EMPRESA:** **RTC-2017-6369-3**

PROJECT LEADER (US-1380791)
"US/JUNTA/FEDER, UE"

VI PPIT - US

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CNA Centro Nacional de Aceleradores

UNIVERSIDAD DE SEVILLA

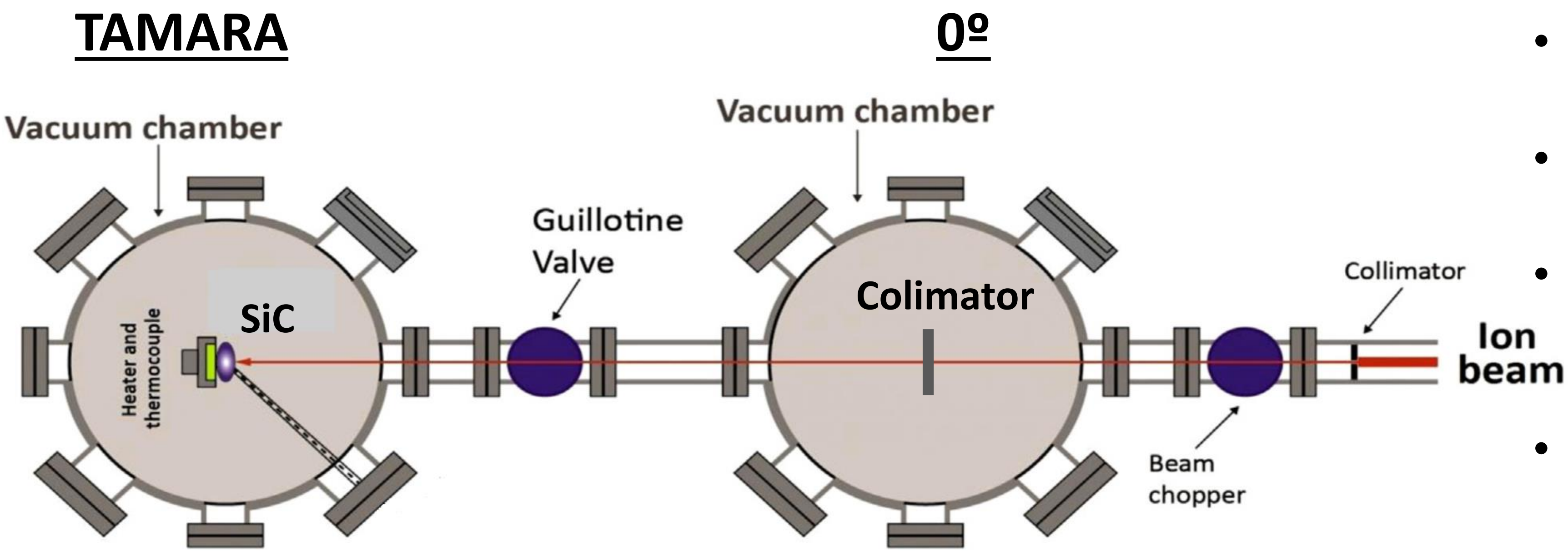
CSIC Consejo Superior de Investigaciones Científicas

Infraestructuras Científicas y Técnicas Singulares

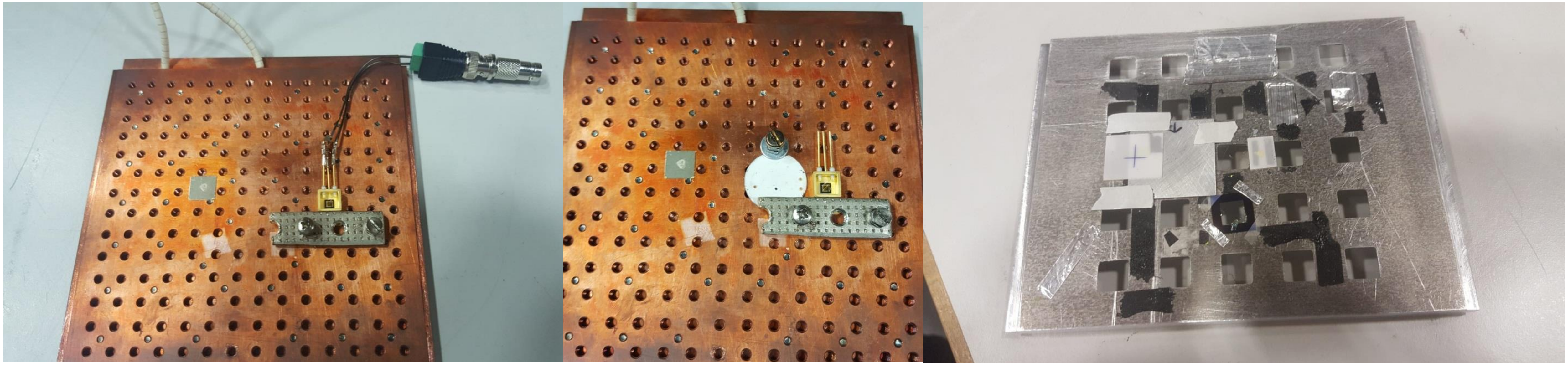
Junta de Andalucía

BACKUP

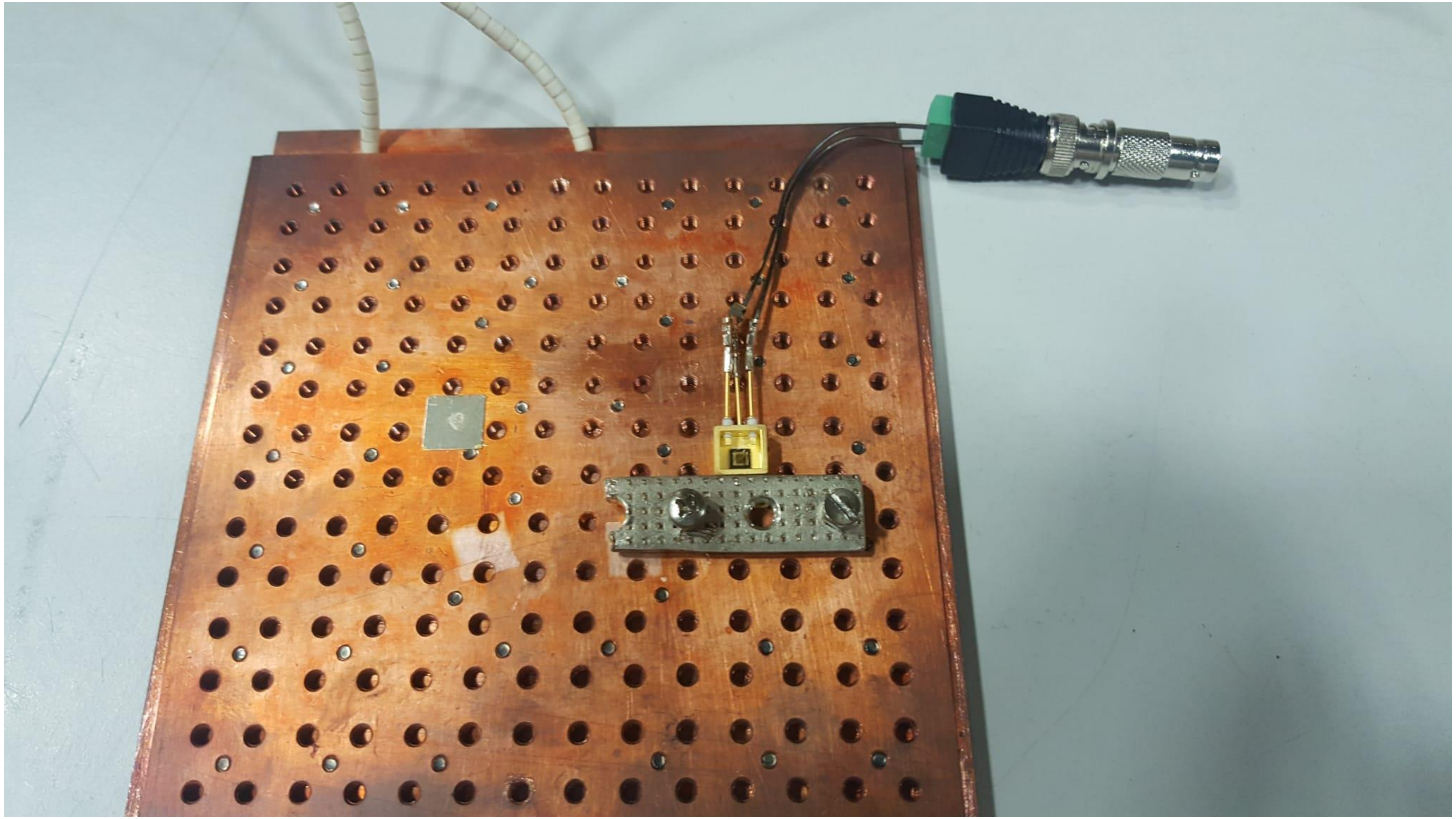
SETUP



- **IBIC spectra using 3.5 MeV alphas**
- **Collimated beam (80 μm)**
- **Low count rate (~ 100 Hz) to avoid detector damage**
- **Beam fixed: detector moves using stepping motors**



OUTLOOK



SiC MEASUREMENTS AT HIGH TEMPERATUREAT THE 3 MV TANDEM OF THE CNA