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Processing Effects on Standard and Oxygenated Diodes Irradiated by Neutrons

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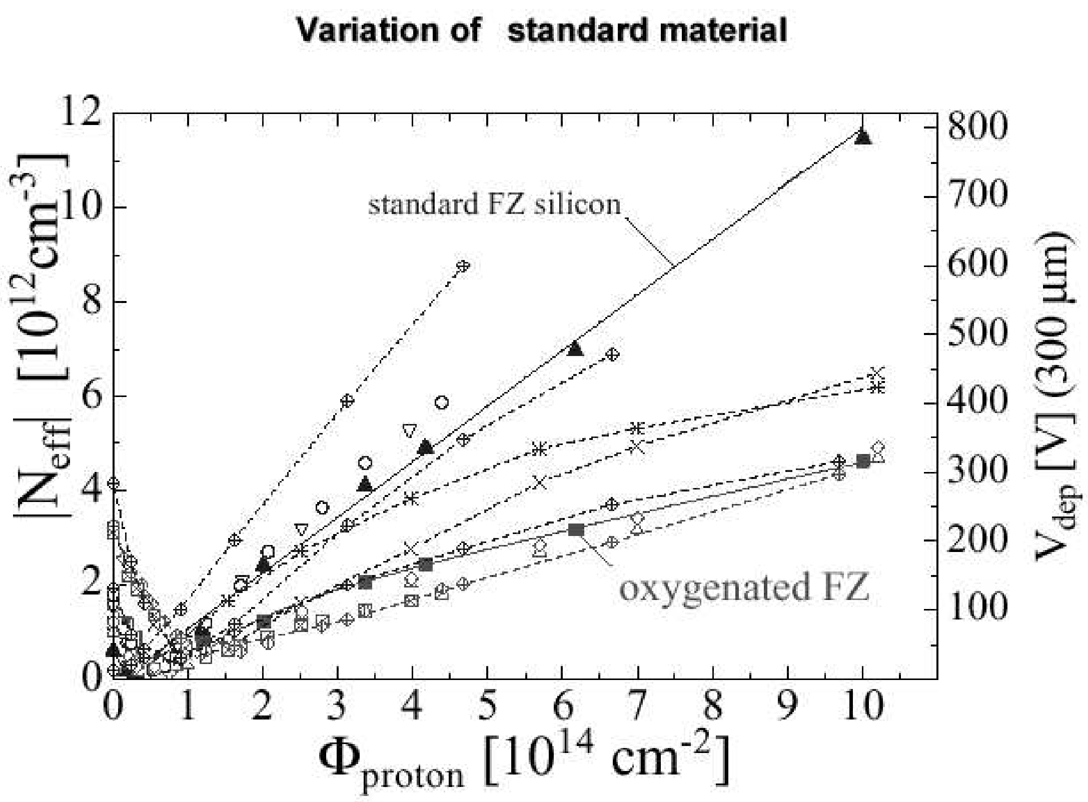
Rad-Hard Standard Samples I

The ROSE Collaboration has shown that processing can affect radiation hardness for charged hadrons even on devices manufactured on standard (i.e. not oxygenated) substrates.



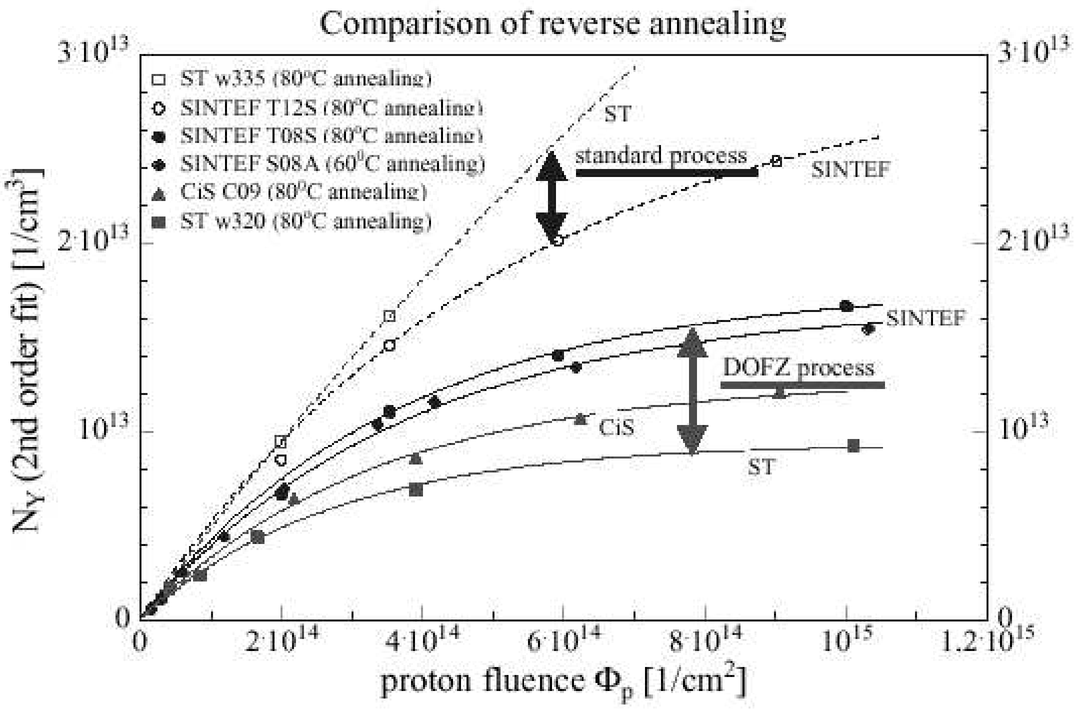
ST and Sintef devices show such a behaviour.

Oxygenation generally is strong enough to mask other effects.

Rad-Hard Standard Samples II

In the case of charged hadron irradiation oxygenation of the substrate causes a slower reverse annealing of N_{EFF}.

Even the processing of the samples can lower the saturation value of the reverse annealing of N_{EFF}



Purpose of This Work

- Previous studies performed by our group at the INFN proton irradiation facility of Legnaro (Padova) confirmed the role of processing-induced radiation-hardness for ST diodes.
- A similar work performed by the *Institut de Microelectrònica de Barcelona* has shown similar results in the case of CNM diodes.
- What is the behaviour of all these devices in the case of neutron irradiation? Is it possible to find any processing-related effect?

Samples:

- Micron standard and oxygenated MGR diodes

- Manufactured by Micron Semiconductor, England, on Wacker silicon
- We found in earlier works that they are suitable to be used as reference devices

- ST standard and oxygenated GR diodes

- Manufactured by ST Microelectronics, Italy, on Wacker silicon
- As already reported by RD48, processing causes radiation hardness even in standard devices; V_{DEP} increase is similar to what is found in the case of oxygenated samples

- CNM standard and oxygenated GR diodes

- Manufactured by CNM, Spain, on Topsil silicon
- As reported by CNM the standard devices are radiation hard almost as oxygenated ones

Neutron Sources

- At the INFN Laboratories of Legnaro neutron irradiation can be performed thanks to a deuteron-on-beryllium source. Maximum energy ~ 11 MeV; average energy 3 MeV.

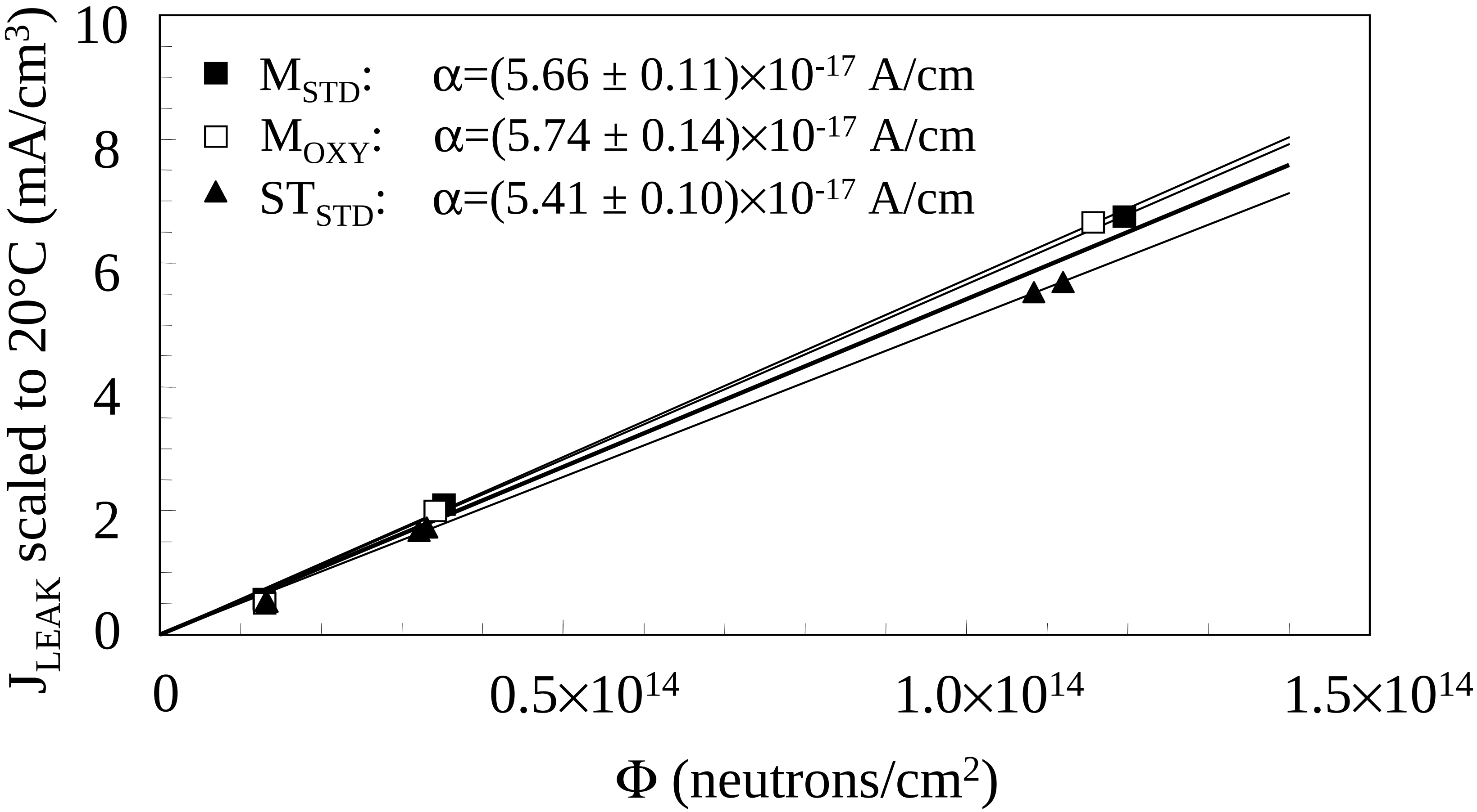
- We chose to use also the Triga Mark III reactor of the Jožef Stefan Institute in Ljubljana.
  Maximum energy ~ 10 MeV; average energy 1 MeV.
  This facility was used by the ROSE collaboration and can be considered as a *reference* neutron source.

Annealing

All samples have been annealed at 80°C for 4 minutes.

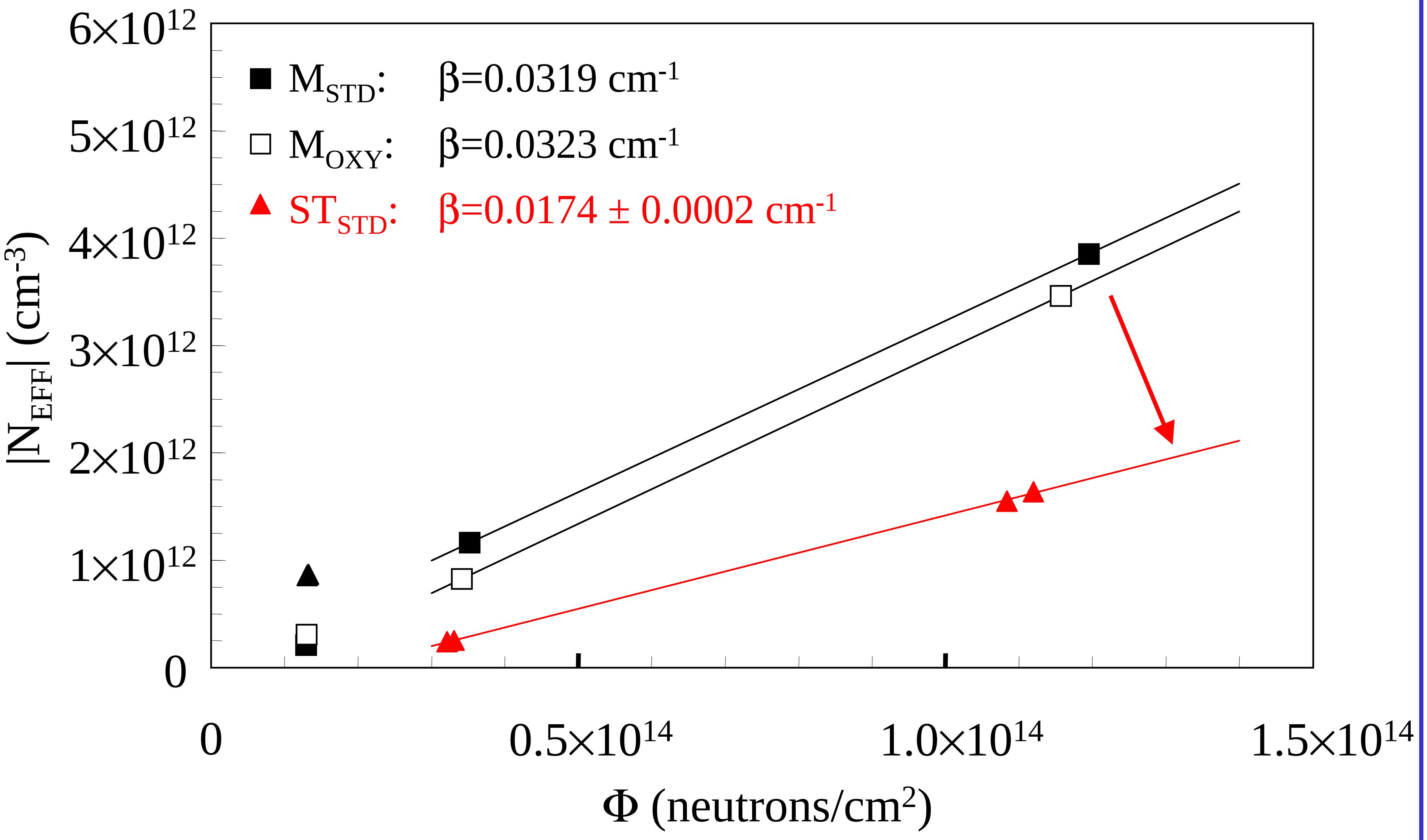
$\alpha(80°C,4min)=4.56\times10^{-17}$ A/cm for 1MeV neutrons.

^{9}Be(d,n)^{10}B - α Value

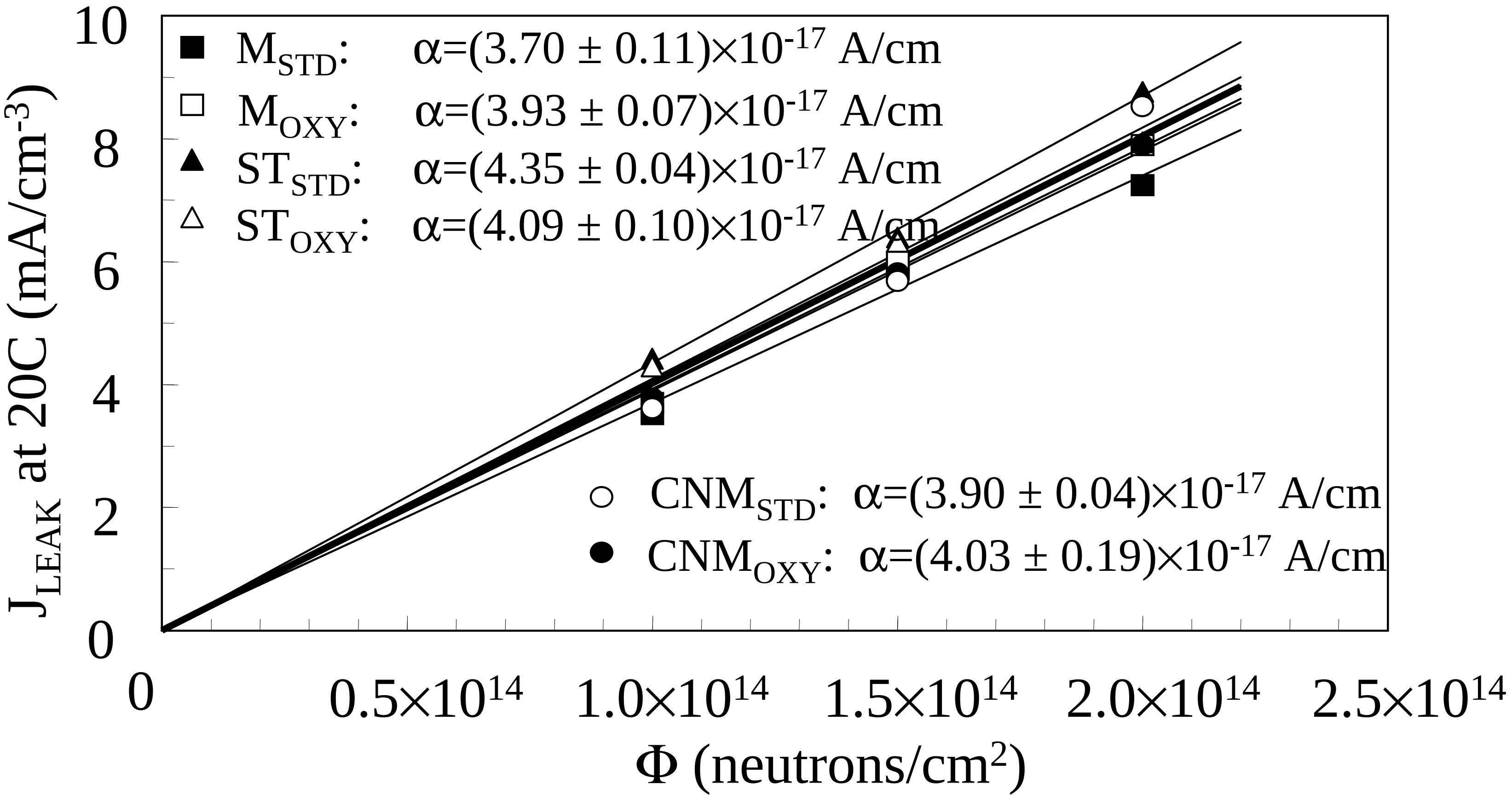


All data: α=(5.41 ± 0.10)×10^{-17} A/cm
k=1.19

$^{9}Be(d,n)^{10}B$ - β Value



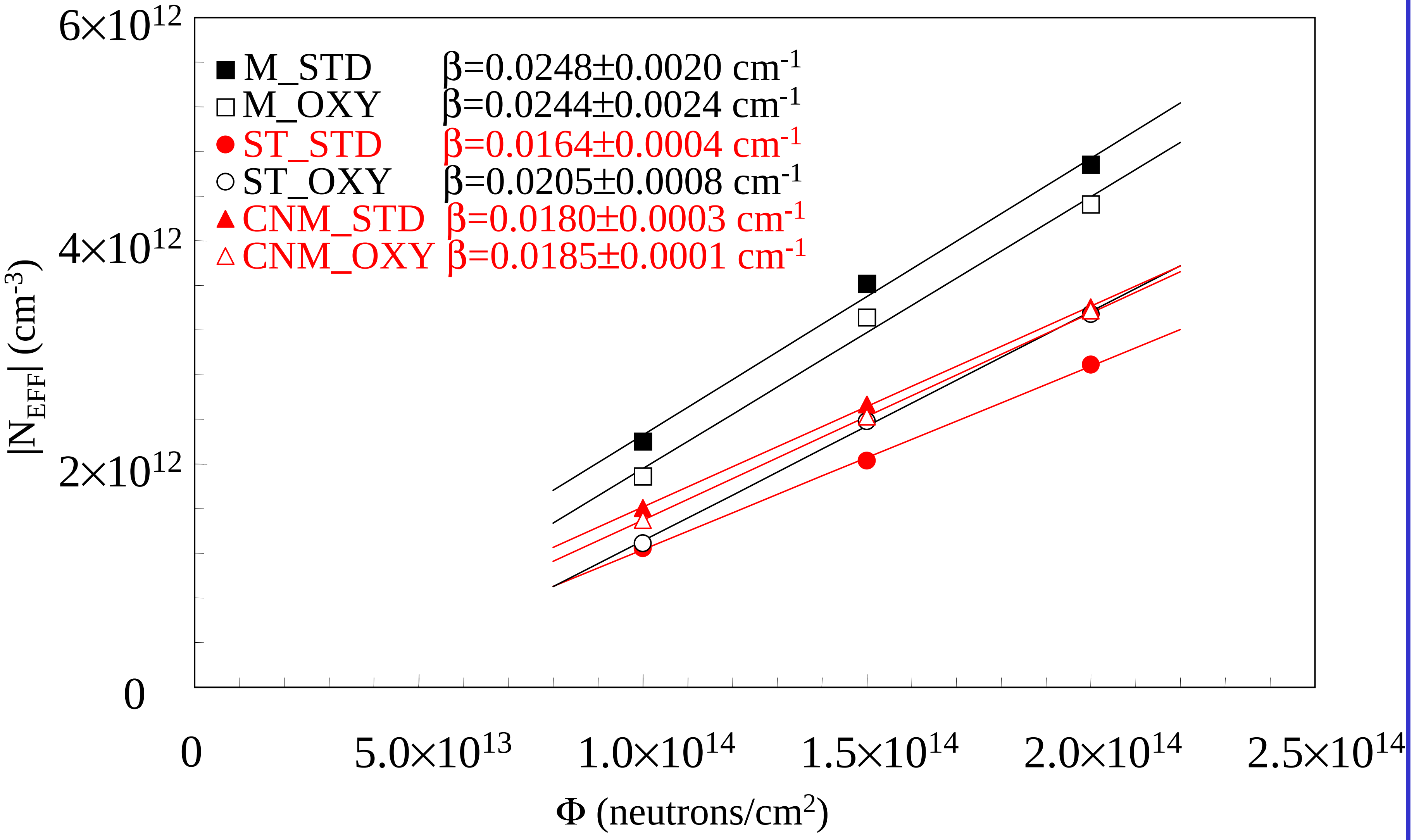
Nuclear Reactor - α Value



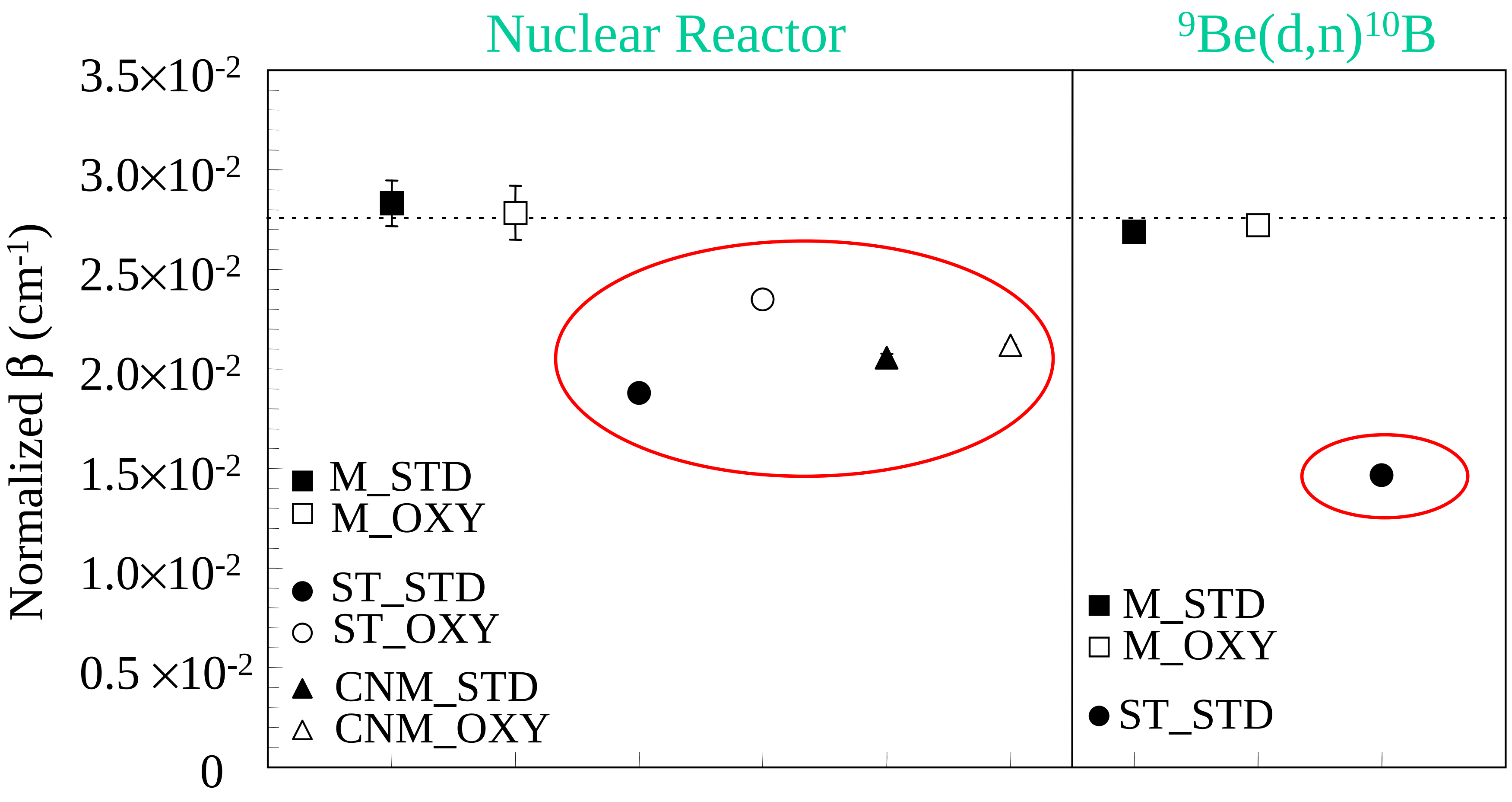
All data: α=(3.99 ± 0.05)×10^{-17} A/cm

k=0.875

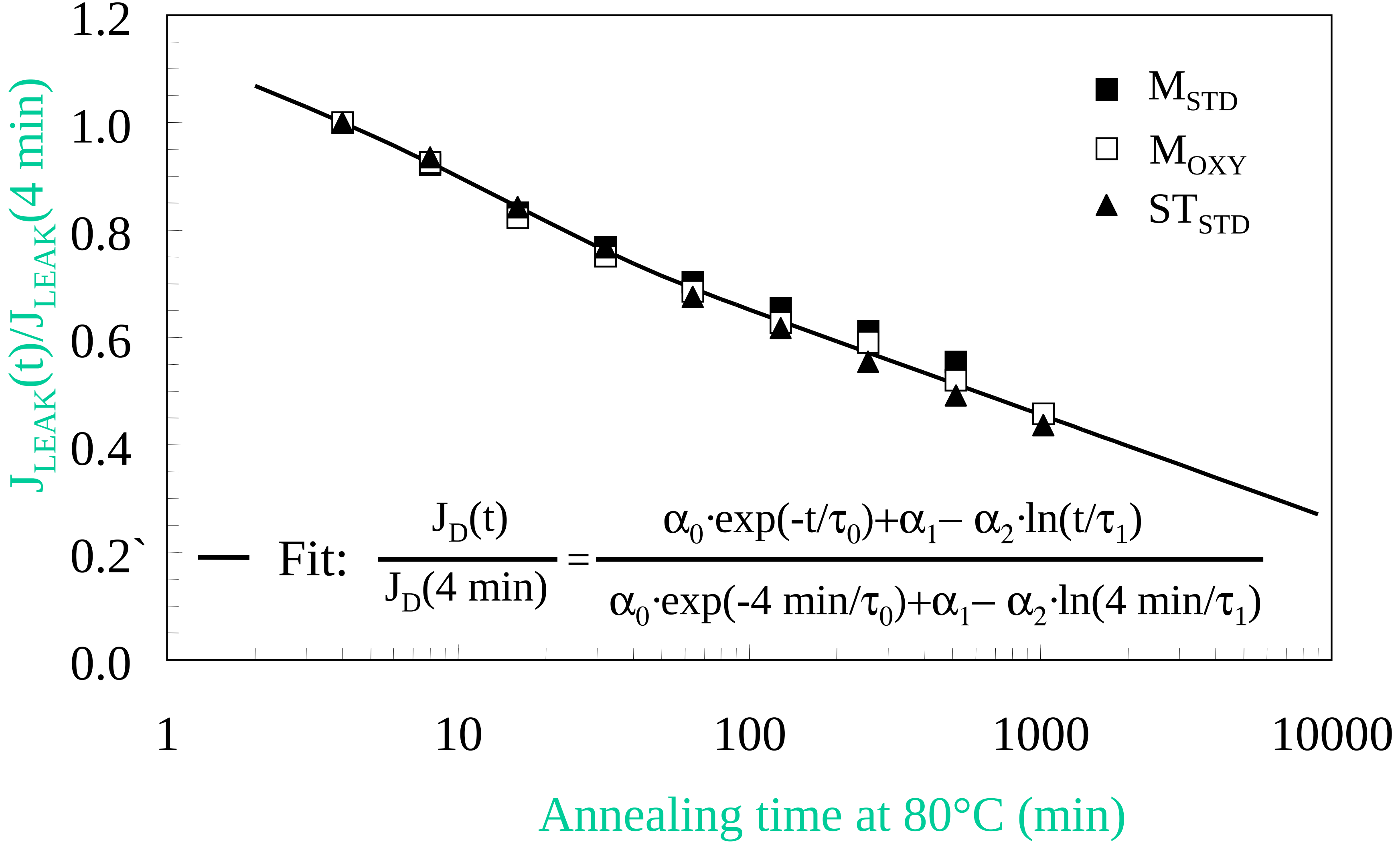
Nuclear Reactor - β Value



Normalized β Value - Summary

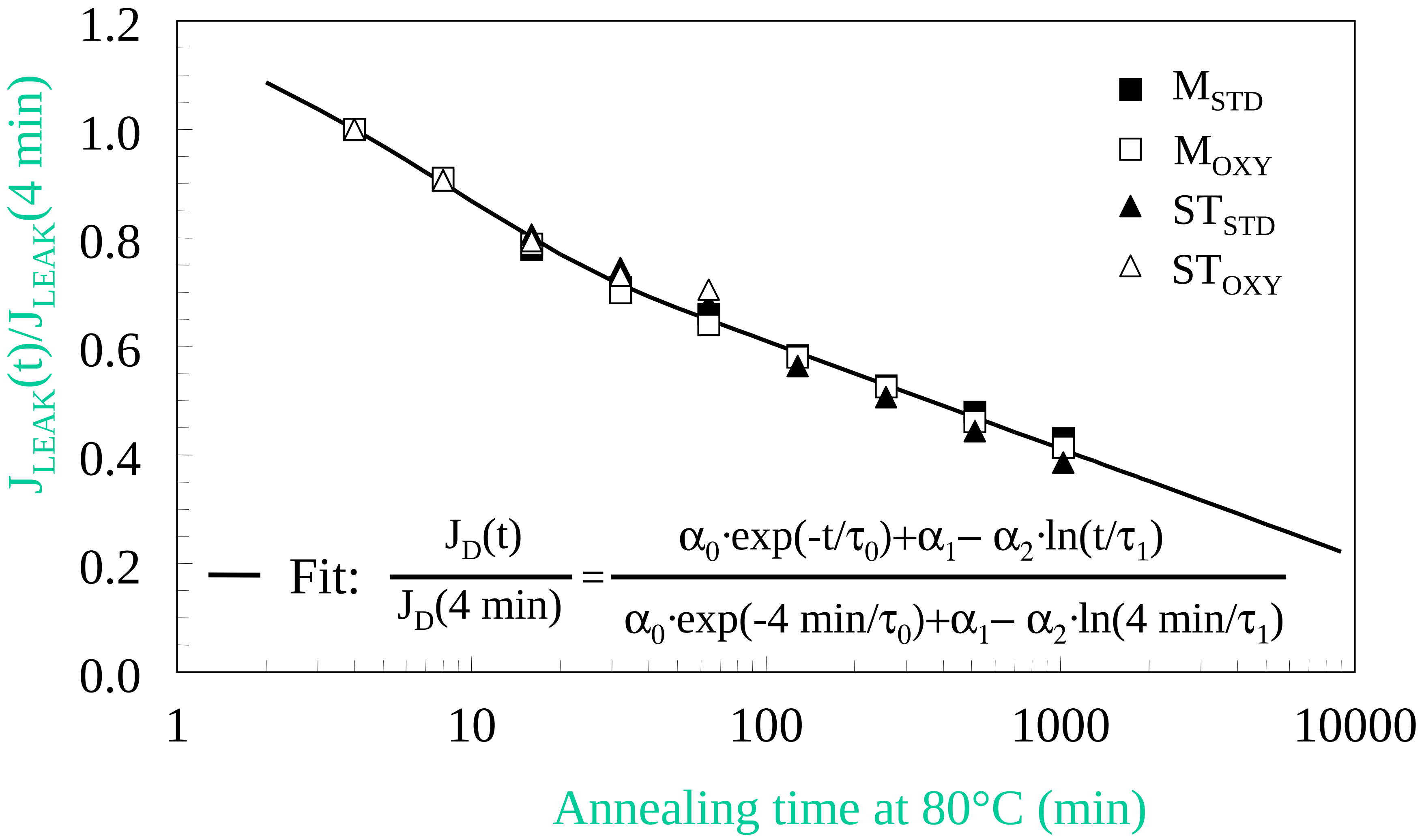


J_{LEAK} Annealing: $^{9}B(d,n)^{10}B$



$$\frac{J_D(t)}{J_D(4\ min)} = \frac{\alpha_0 \cdot \exp(-t/\tau_0) + \alpha_1 - \alpha_2 \cdot \ln(t/\tau_1)}{\alpha_0 \cdot \exp(-4\ min/\tau_0) + \alpha_1 - \alpha_2 \cdot \ln(4\ min/\tau_1)}$$

J_{LEAK} Annealing: Nuclear Reactor



$$\frac{J_D(t)}{J_D(4\ min)} = \frac{\alpha_0 \cdot \exp(-t/\tau_0) + \alpha_1 - \alpha_2 \cdot \ln(t/\tau_1)}{\alpha_0 \cdot \exp(-4\ min/\tau_0) + \alpha_1 - \alpha_2 \cdot \ln(4\ min/\tau_1)}$$

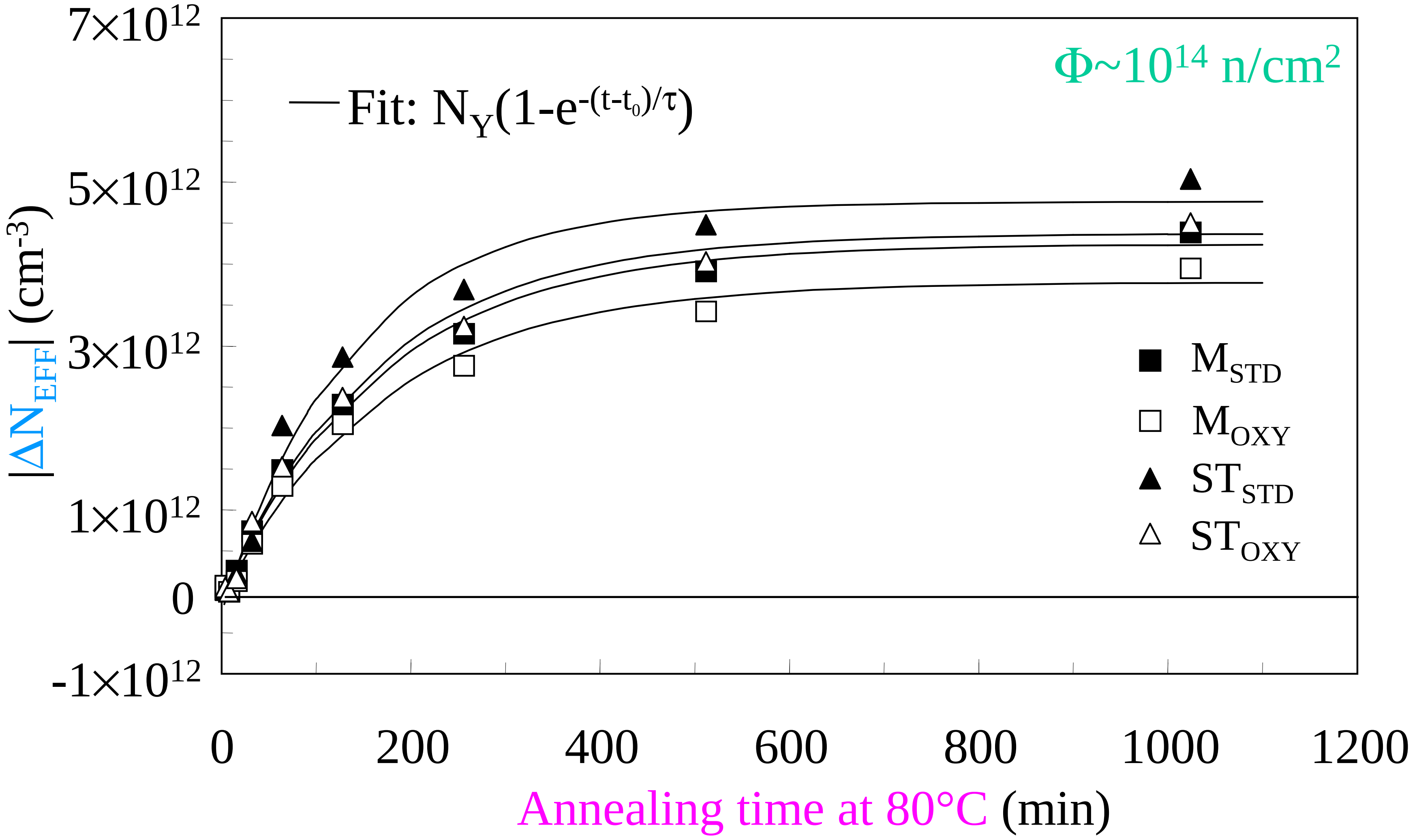
J_{LEAK} Annealing: Summary

$$\frac{J_{LEAK}(t)}{J_{LEAK}(4\,\mathrm{min})} = \frac{\alpha_0 \times \exp(-t/\tau_0) + \alpha_1 - \alpha_2 \times \ln(t/\tau_1)}{\alpha_0 \times \exp(-4\,\mathrm{min}/\tau_0) + \alpha_1 - \alpha_2 \times \ln(4\,\mathrm{min}/\tau_1)}$$

Neutron Source	α_0	τ_0 (min)	α_1	α_2	τ_1 (min)
Reactor	1.98 ± 0.22	9.4 ± 1.5	11.7 ± 0.9	1.00 ± 0.08	1
^{9}Be(d,n)^{10}B	1.15 ± 0.22	16.5 ± 4.0	12.3 ± 1.2	1.00 ± 0.10	1

- Data from different samples are fitted together
- τ_1 is fixed to 1 min
- α_0 is larger for diodes irradiated at the detector, while all other parameters are compatible within errors

ΔN_{EFF} Annealing: Nuclear Reactor



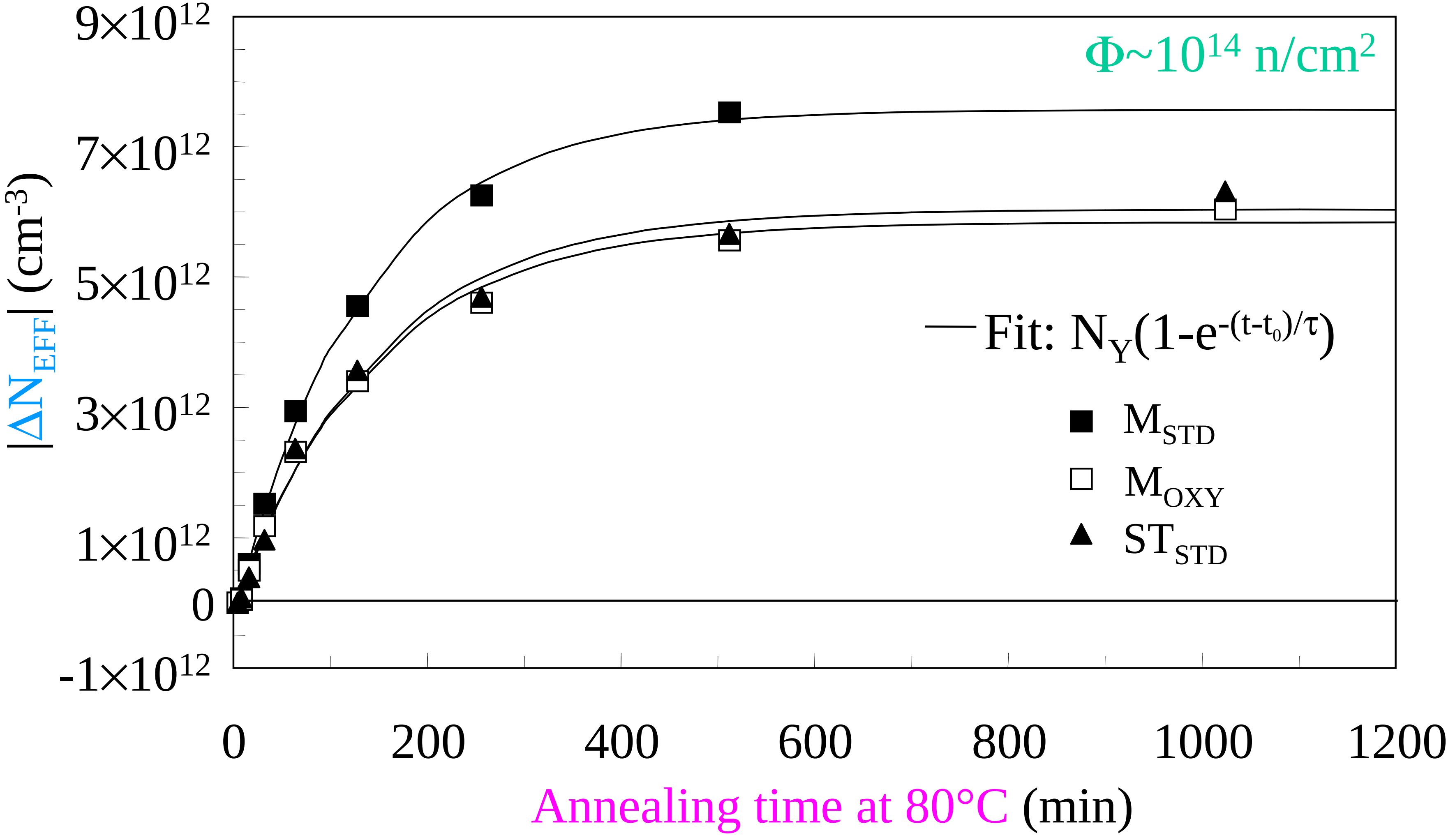
ΔN_{EFF} Annealing: Nuclear Reactor

$$\Delta N_{EFF}(t) = N_Y \times \exp\left(-\frac{t-t_0}{\tau}\right)$$

Sample	N_Y (10^{12} cm^{-3})	τ (min)	t_0 (min)
M_{STD}	4.24 ± 0.14	167 ± 20	3.1 ± 4.6
M_{OXY}	3.78 ± 0.15	169 ± 25	5.1 ± 5.5
ST_{STD}	4.76 ± 0.13	136 ± 25	7.3 ± 5.4
ST_{OXY}	4.34 ± 0.16	162 ± 22	3.9 ± 5.0

- N_Y is slightly smaller for oxygenated samples
- τ values are compatible within errors

ΔN_{EFF} Annealing: $^{9}Be(d,n)^{10}B$



ΔN_{EFF} Annealing: $^{9}Be(d,n)^{10}B$

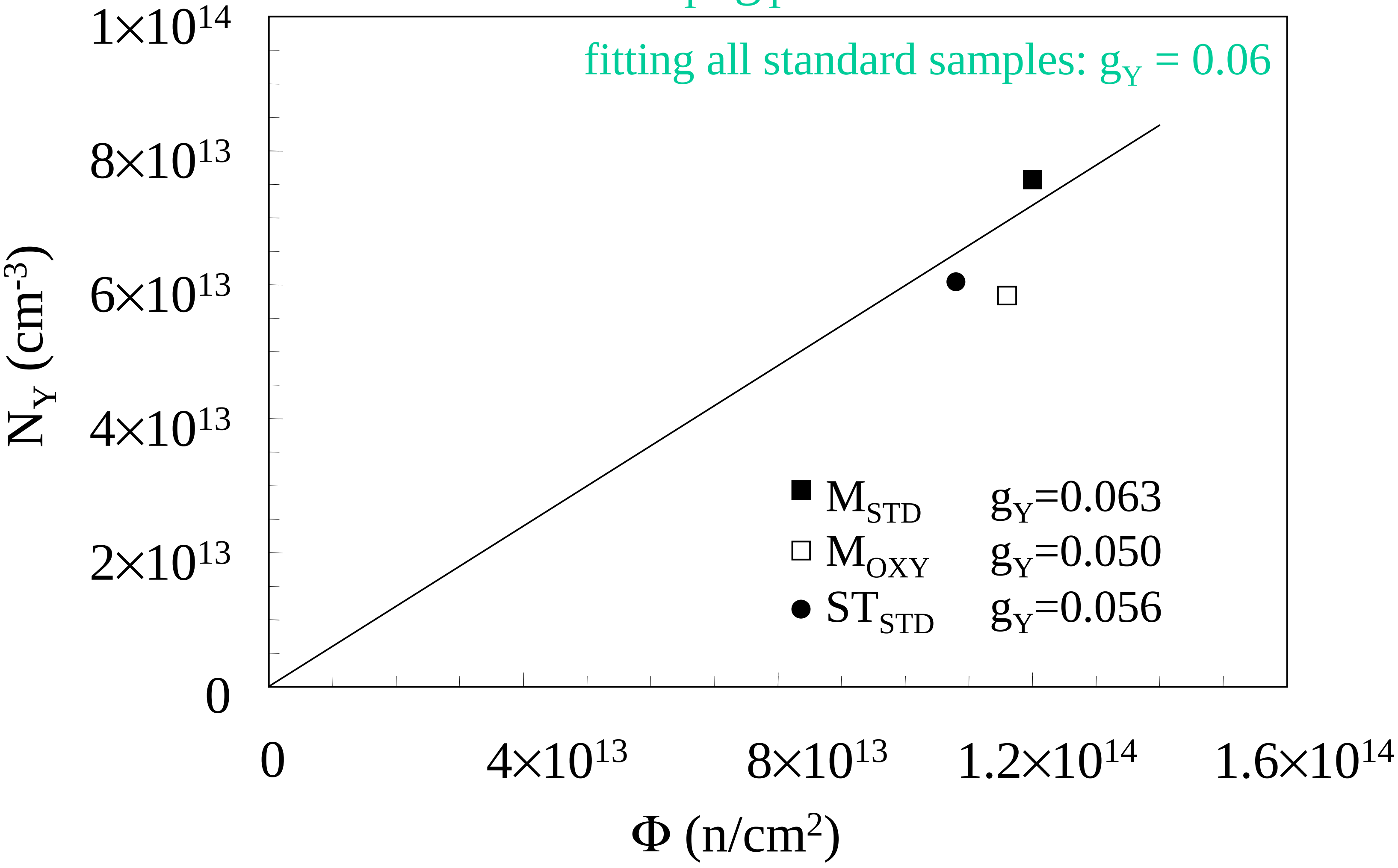
$$\Delta N_{EFF}(t) = N_Y \times \exp\left(-\frac{t-t_0}{\tau}\right)$$

Sample	N_Y (10^{12} cm^{-3})	τ (min)	t_0 (min)
M_{STD}	7.57 ± 0.19	132 ± 10	4.5 ± 2.1
M_{OXY}	5.84 ± 0.14	144 ± 21	2.3 ± 3.2
ST_{STD}	6.04 ± 0.23	144 ± 13	4.5 ± 5.0

- Each diode has received a (slightly) different fluence, thus a direct comparison of N_Y values is not straightforward
- τ values are compatible

ΔN_{EFF} Annealing: $^{9}Be(d,n)^{10}B$

$N_Y = g_Y \times \Phi$



Conclusions: Radiation Damage

- Micron standard and oxygenated diodes behave as expected: no dependence from oxygenation and/or processing

- ST standard diodes are clearly radiation hard not only for charged hadrons but even in the case of neutrons
  $\beta(\ ST_{STD}\ ) = (\ 0.6 \div 0.7\ ) \times \beta(\ Micron\ )$

- CNM standard and oxygenated samples, known to be radiation hard when irradiated with high energy protons, show a smaller β than Micron diodes, confirming that processing can play a role even in the case of neutron irradiation
  $\beta(\ CNM\ ) = (\ 0.7\ ) \times \beta(\ Micron\ )$

Conclusions: Damage Annealing

- The saturation value of the reverse annealing is slightly smaller in the case of oxygenated devices

- The time characteristics of the reverse annealing are affected neither by oxygenation nor by processing

- Processing can influence the defect generation but not their evolution

Open Questions

- What are the microscopic mechanisms of the processing-related effects?

- Are these effects relative to the crystal manufacturing or to the crystal processing?

- How can these characteristics influence the damage creation, even in the case of neutron irradiation (clusters of defects)?

- Why they don’t change the defect annealing?