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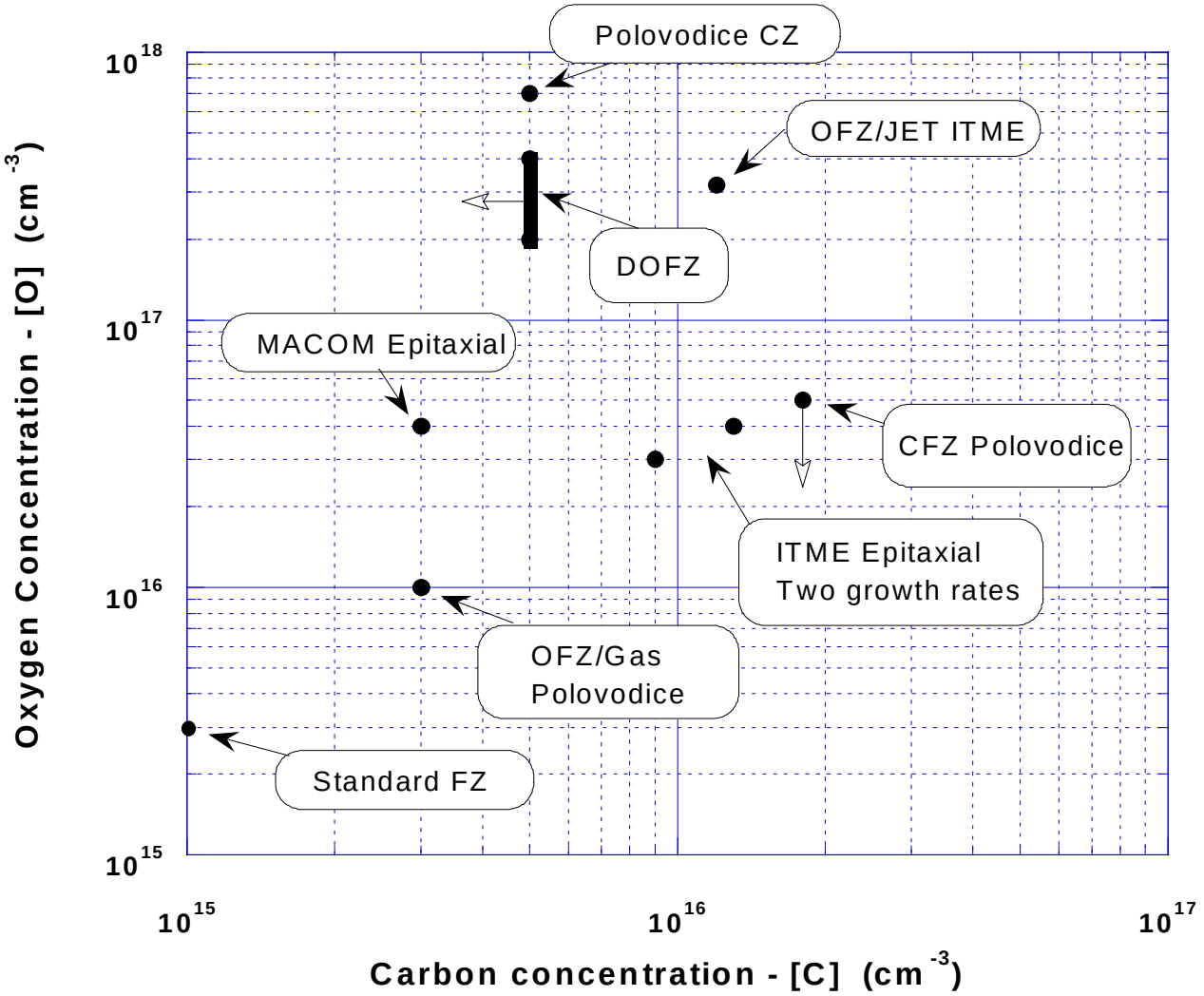
Polovodice CZ
OFZ/JET ITME
DOFZ
MACOM Epitaxial
CFZ Polovodice
ITME Epitaxial
Two growth rates
OFZ/Gas
Polovodice
Standard FZ
10^{18}
10^{17}
10^{16}
10^{15}
10^{15}
10^{16}
10^{17}
Oxygen Concentration - [O] (cm^{-3})
Carbon concentration - [C] (cm^{-3})

Fig. 1

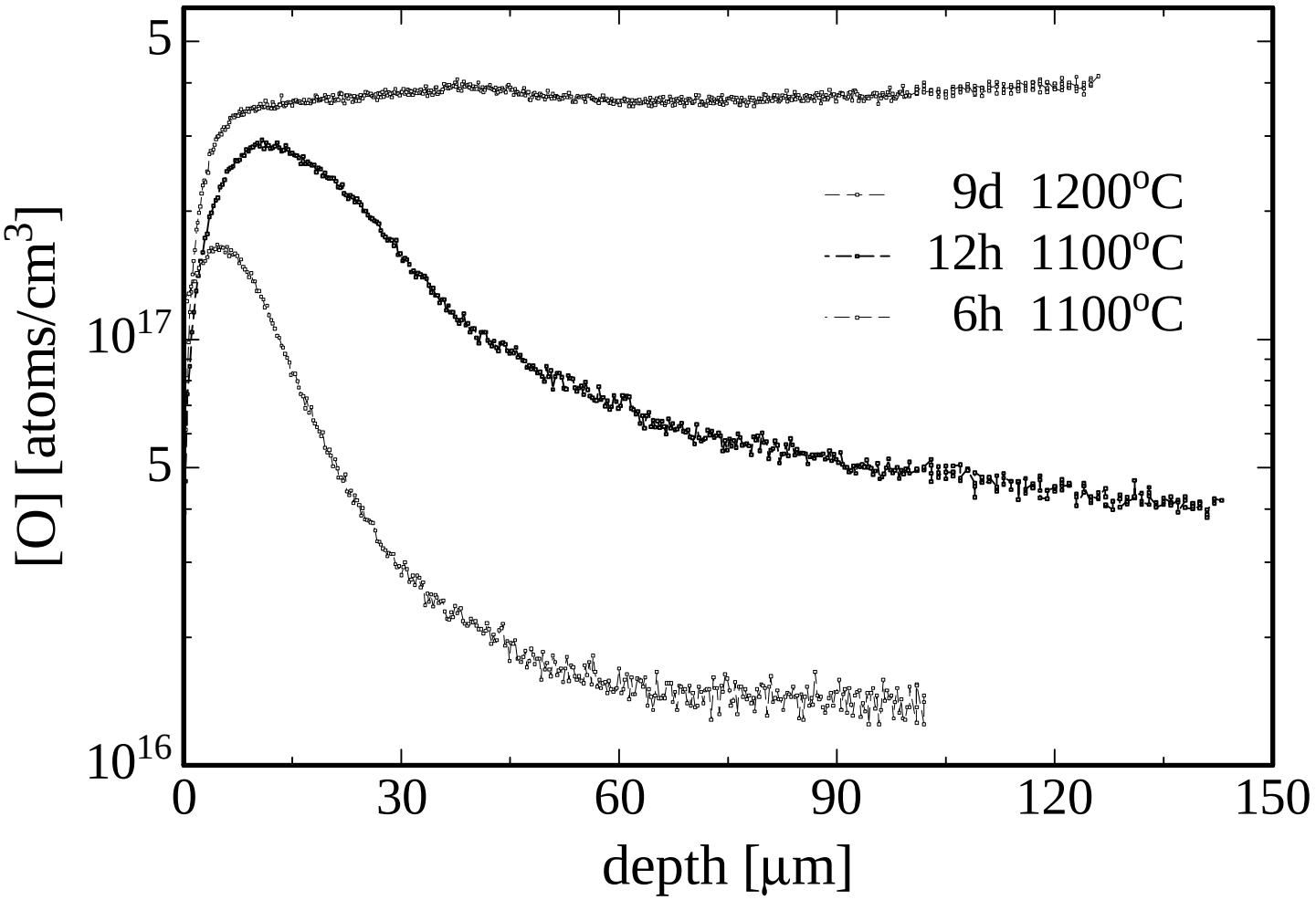
5
10^{17}
5
10^{16}
[O] [atoms/cm^3]
0
30
60
90
120
150
depth [μm]
9d 1200°C
12h 1100°C
6h 1100°C

Fig. 2

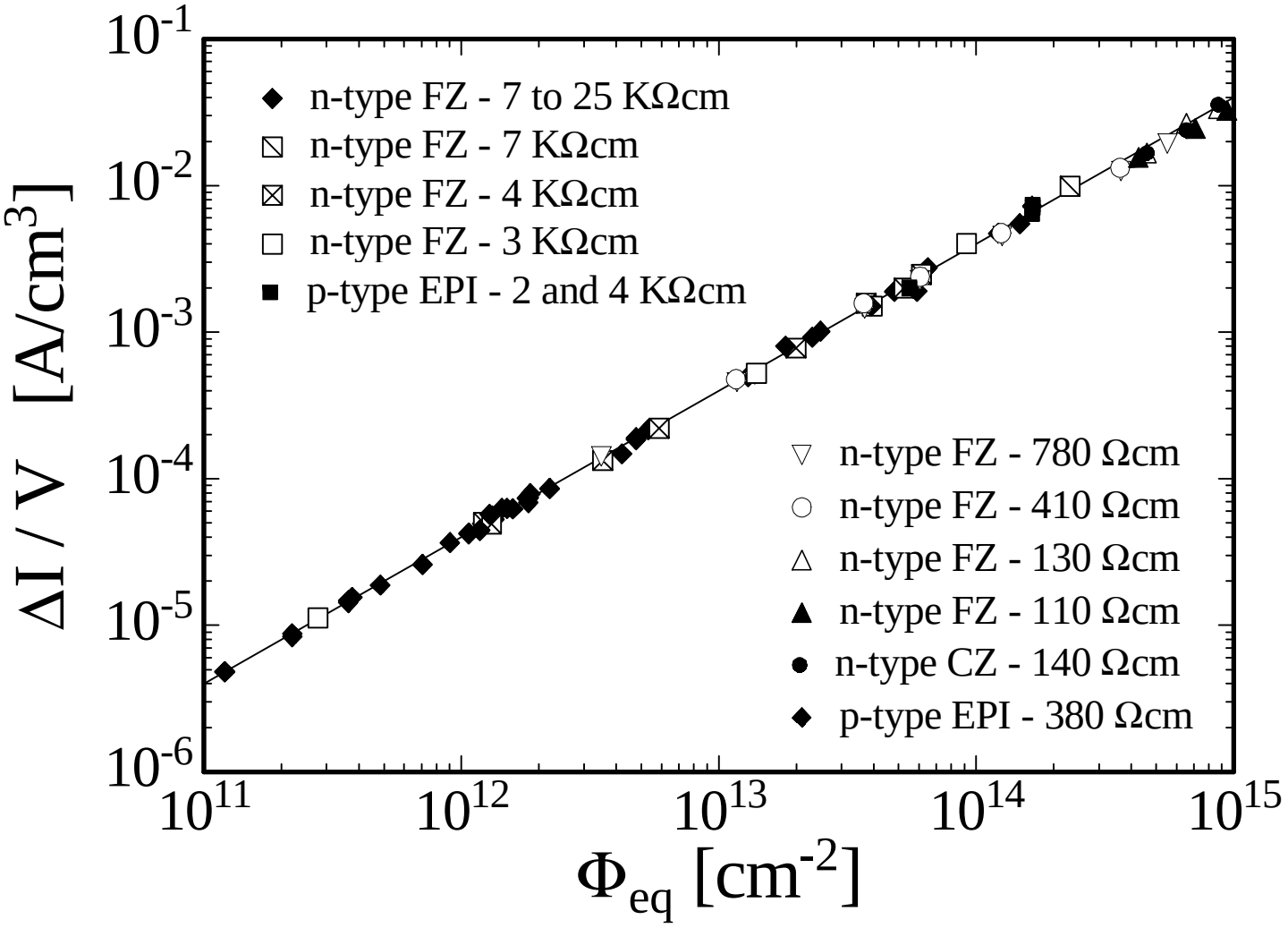
n-type FZ - 7 to 25 KΩcm
n-type FZ - 7 KΩcm
n-type FZ - 4 KΩcm
n-type FZ - 3 KΩcm
p-type EPI - 2 and 4 KΩcm
n-type FZ - 780 Ωcm
n-type FZ - 410 Ωcm
n-type FZ - 130 Ωcm
n-type FZ - 110 Ωcm
n-type CZ - 140 Ωcm
p-type EPI - 380 Ωcm
ΔI / V [A/cm3]
Φeq [cm-2]
10-1
10-2
10-3
10-4
10-5
10-6
10^11
10^12
10^13
10^14
10^15

Fig. 3a

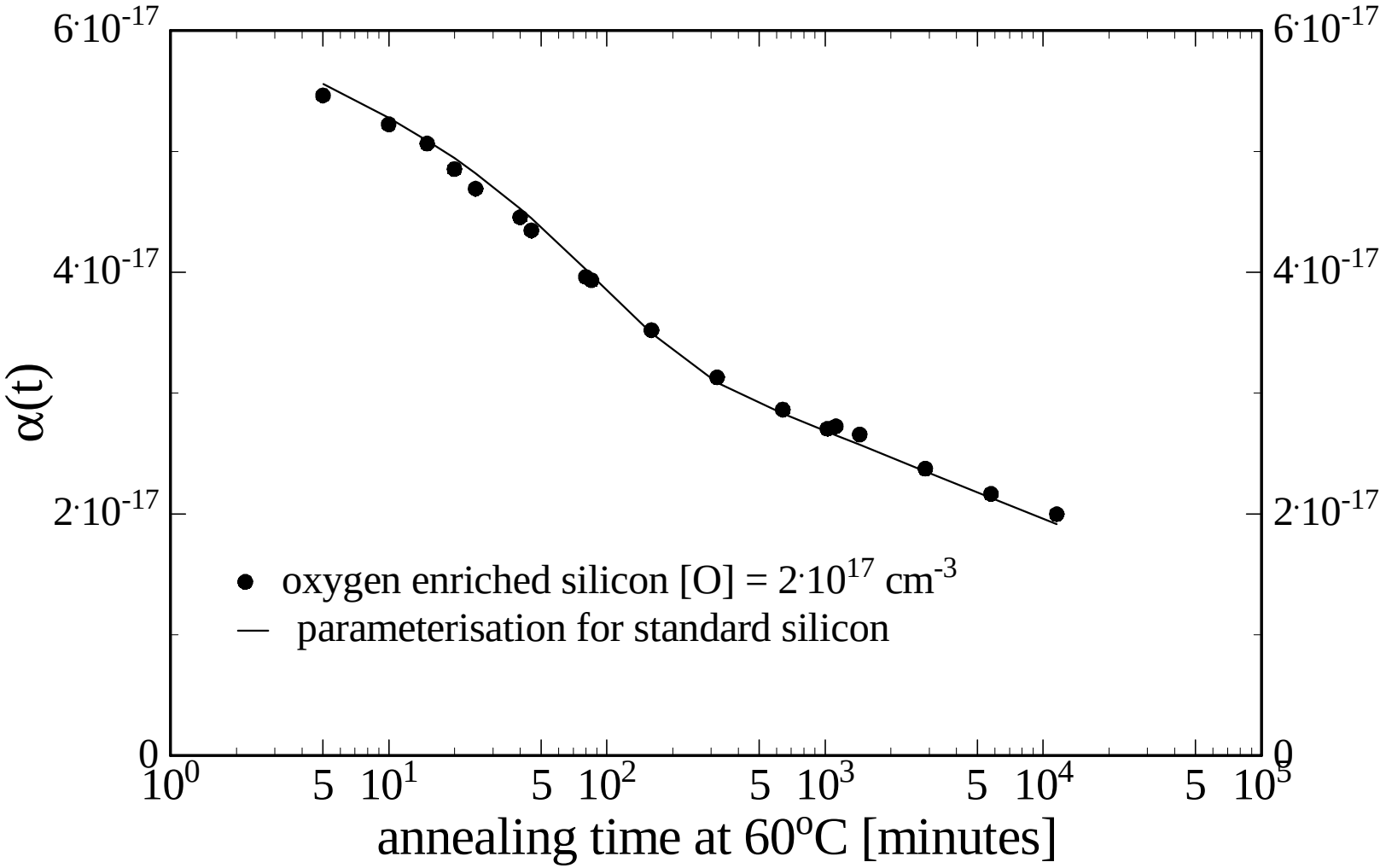
6·10-17
4·10-17
2·10-17
0
α(t)
oxygen enriched silicon [O] = 2·10^17 cm^-3
parameterisation for standard silicon
10^0
5 10^1
5 10^2
5 10^3
5 10^4
5 10^5
annealing time at 60°C [minutes]

Fig 3b

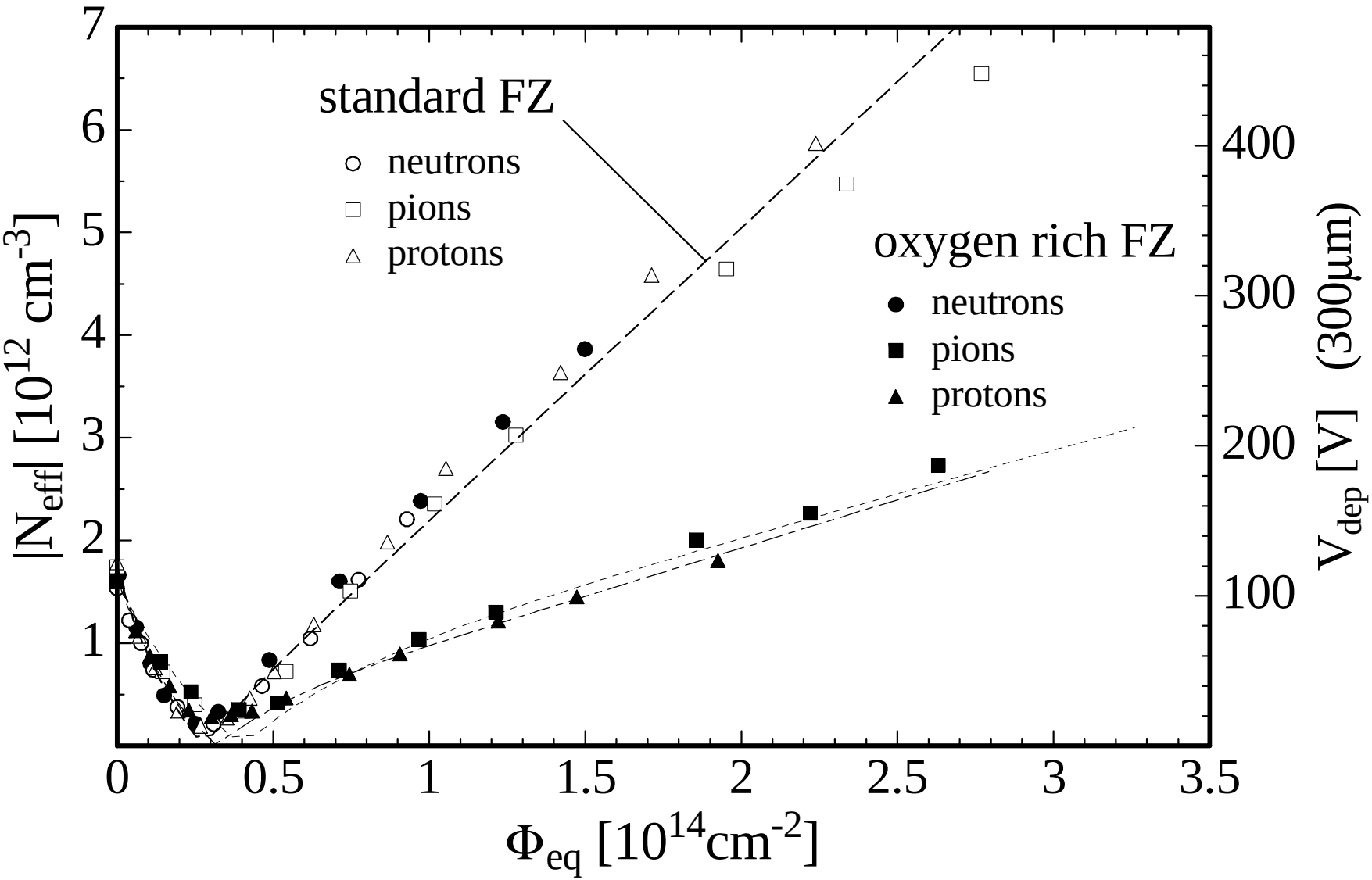
standard FZ
neutrons
pions
protons
oxygen rich FZ
neutrons
pions
protons
|N_eff| [10^12 cm^-3]
V_dep [V] (300µm)
Φ_eq [10^14cm^-2]
0
0.5
1
1.5
2
2.5
3
3.5
1
2
3
4
5
6
7
100
200
300
400

Fig. 4a

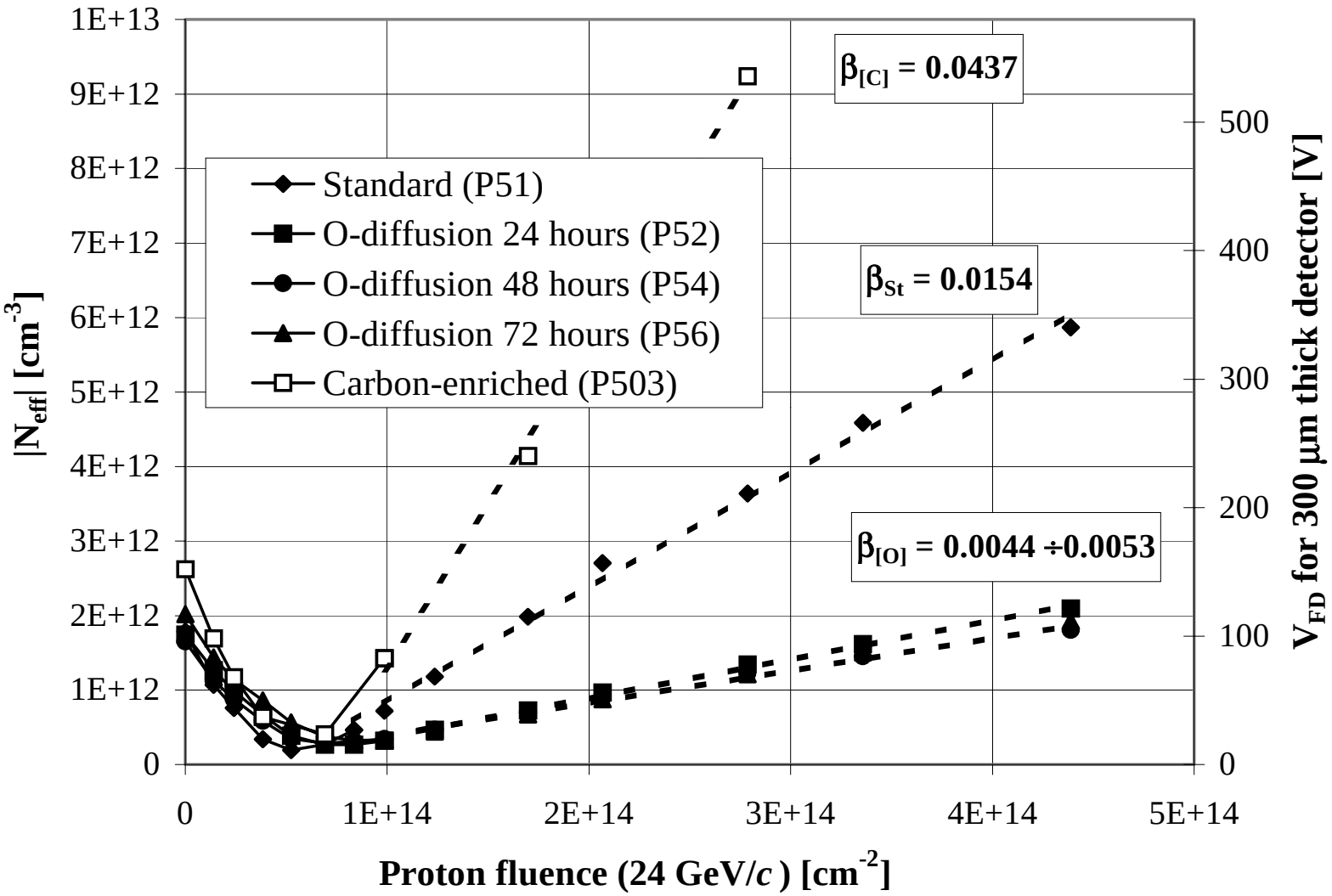
1E+13
9E+12
8E+12
7E+12
6E+12
5E+12
4E+12
3E+12
2E+12
1E+12
0
0
1E+14
2E+14
3E+14
4E+14
5E+14
500
400
300
200
100
0
Standard (P51)
O-diffusion 24 hours (P52)
O-diffusion 48 hours (P54)
O-diffusion 72 hours (P56)
Carbon-enriched (P503)
β[C] = 0.0437
βSt = 0.0154
β[O] = 0.0044 ÷0.0053
|Neff| [cm-3]
VFD for 300 μm thick detector [V]
Proton fluence (24 GeV/c) [cm-2]

Fig. 4b

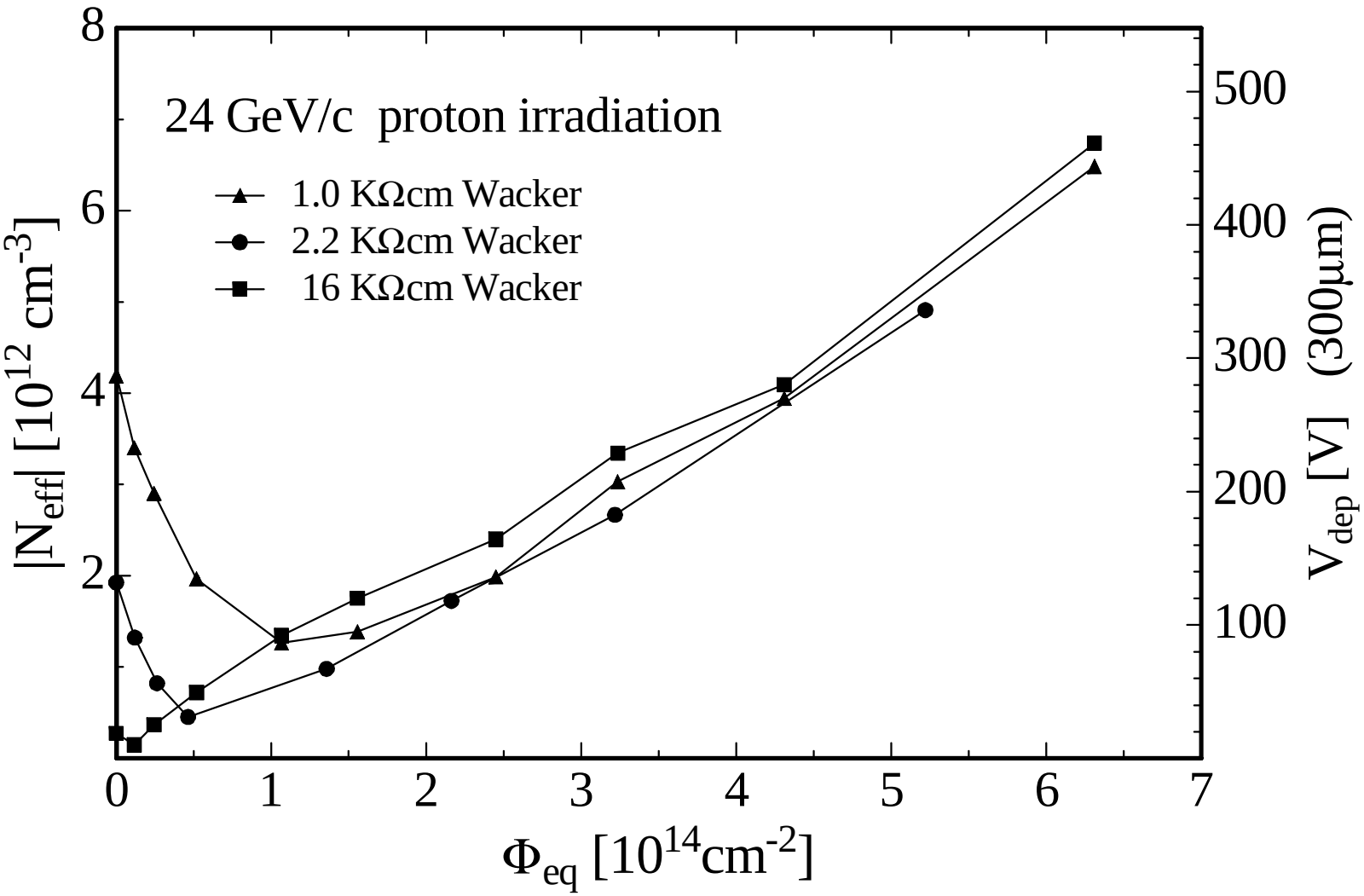
24 GeV/c proton irradiation
1.0 KΩcm Wacker
2.2 KΩcm Wacker
16 KΩcm Wacker
|N_eff| [10^12 cm^-3]
V_dep [V] (300μm)
Φ_eq [10^14 cm^-2]
0
1
2
3
4
5
6
7
2
4
6
8
100
200
300
400
500

Fig. 5a

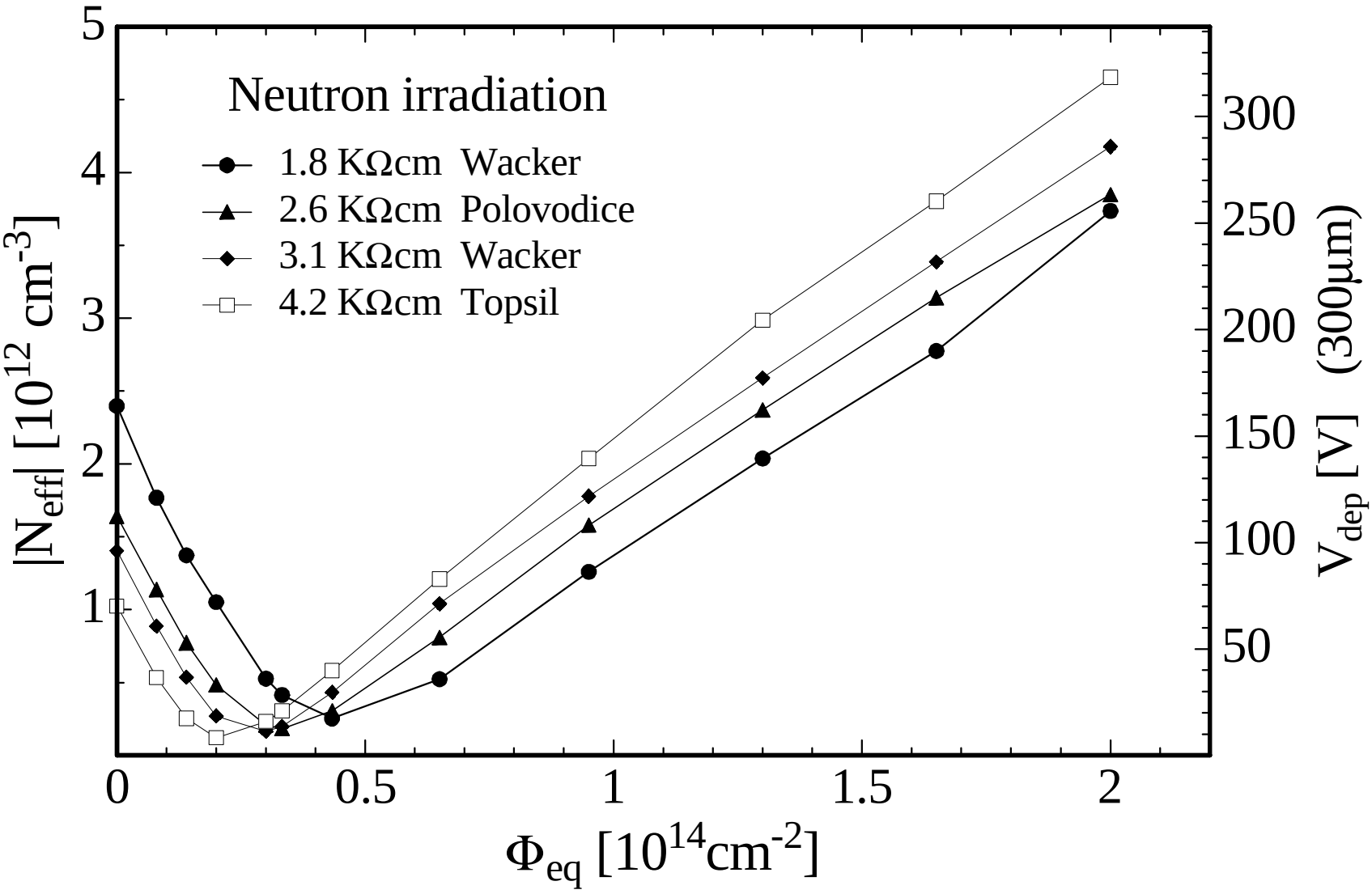
Neutron irradiation
1.8 KΩcm Wacker
2.6 KΩcm Polovodice
3.1 KΩcm Wacker
4.2 KΩcm Topsil
|Neff| [10^12 cm^-3]
Vdep [V] (300μm)
Φeq [10^14cm^-2]
0
0.5
1
1.5
2
1
2
3
4
5
50
100
150
200
250
300

Fig. 5b

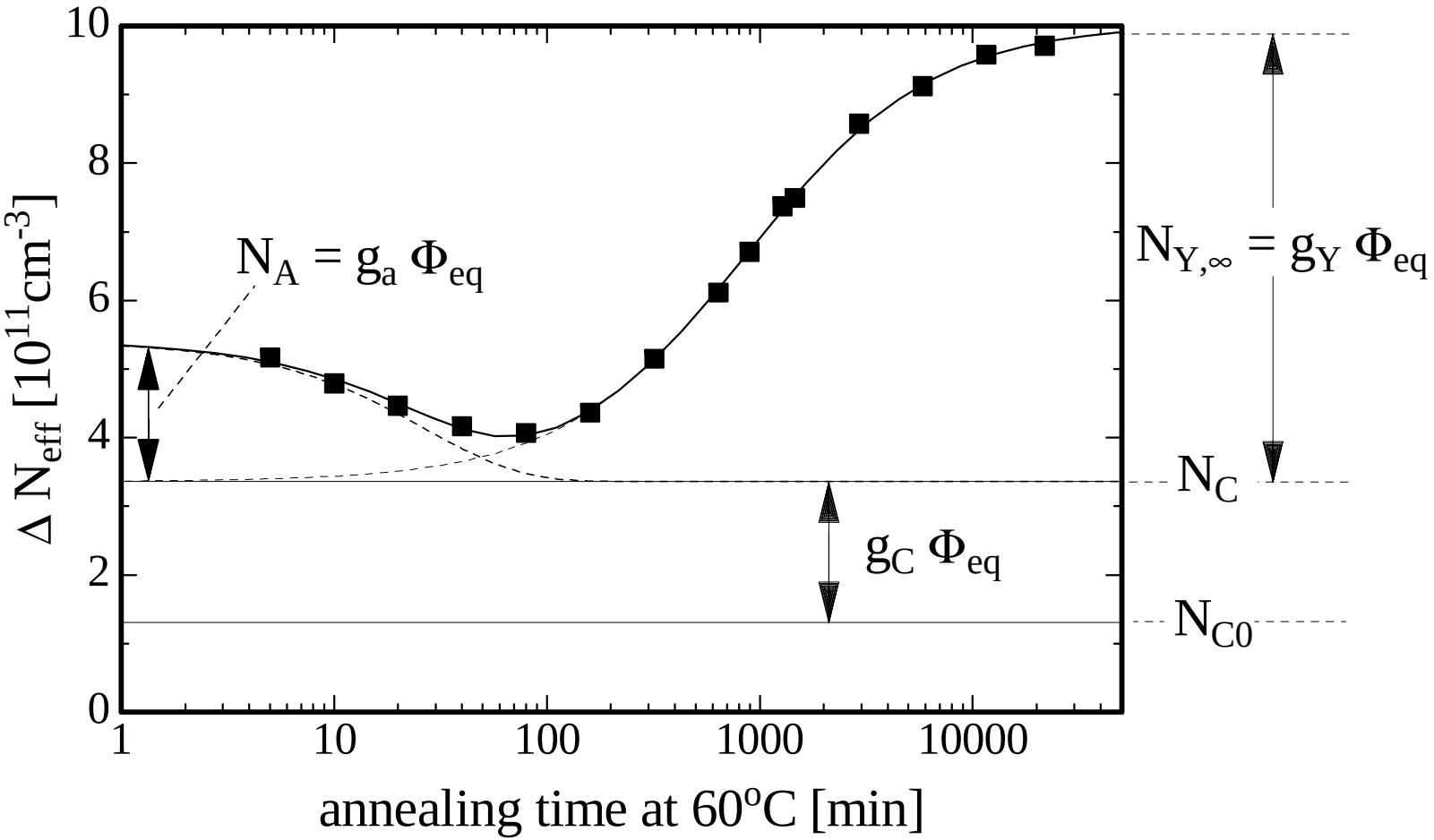
10
8
6
4
2
0
1
10
100
1000
10000
Δ N_eff [10^11 cm^-3]
annealing time at 60°C [min]
N_A = g_a Φ_eq
N_Y,∞ = g_Y Φ_eq
N_C
g_C Φ_eq
N_C0

Fig. 6

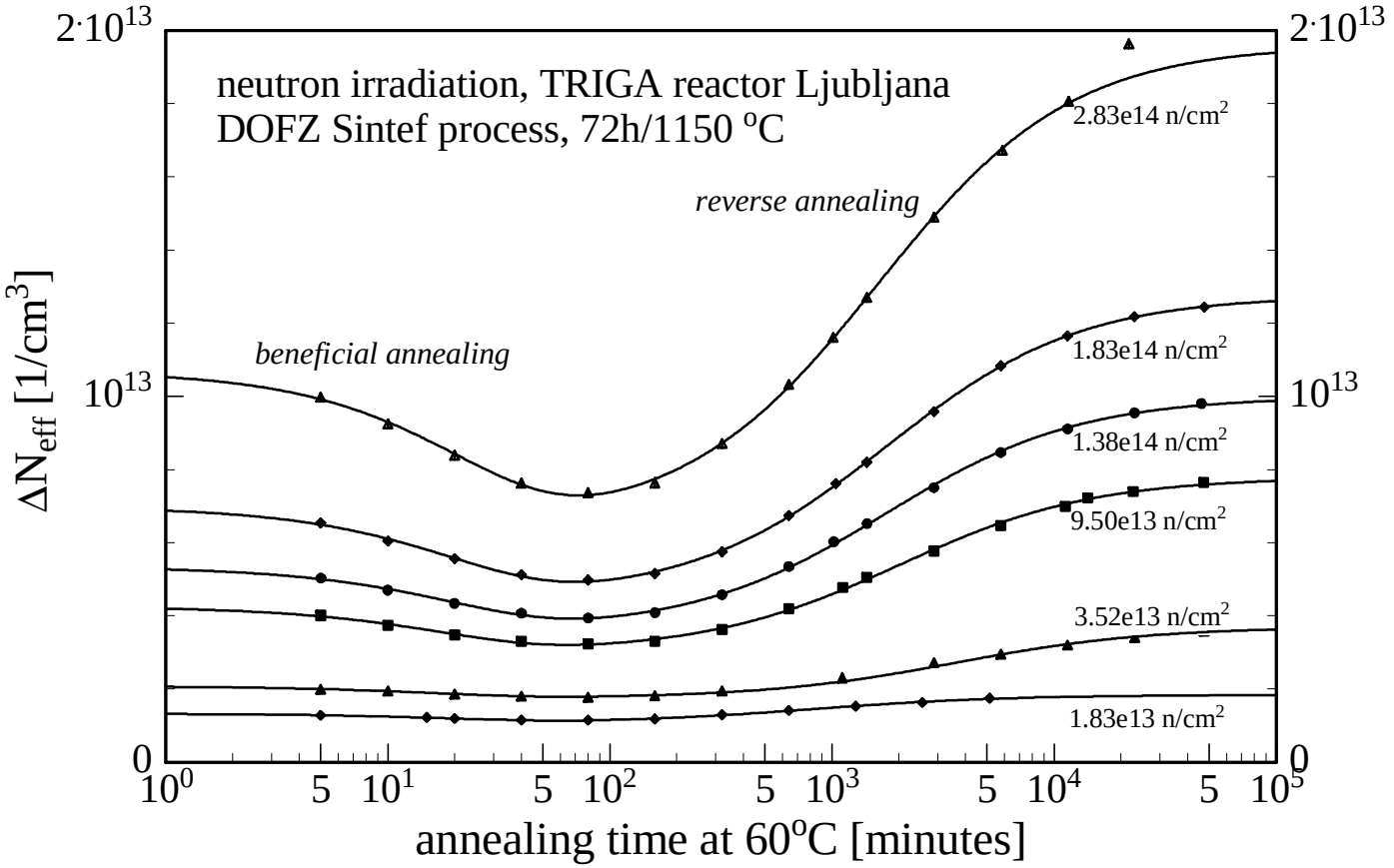
neutron irradiation, TRIGA reactor Ljubljana
DOFZ Sintef process, 72h/1150 °C
reverse annealing
beneficial annealing
2.83e14 n/cm2
1.83e14 n/cm2
1.38e14 n/cm2
9.50e13 n/cm2
3.52e13 n/cm2
1.83e13 n/cm2
ΔNeff [1/cm3]
annealing time at 60°C [minutes]
2·10^13
10^13
0
10^0
5 10^1
5 10^2
5 10^3
5 10^4
5 10^5

Fig. 7

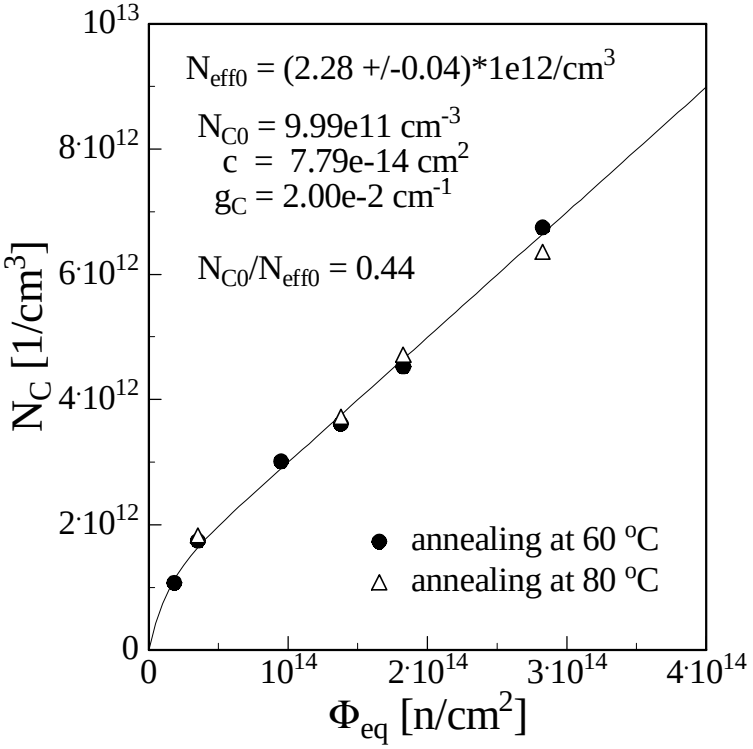
N_{eff0} = (2.28 +/-0.04)*1e12/cm^3
N_{C0} = 9.99e11 cm^{-3}
c = 7.79e-14 cm^2
g_C = 2.00e-2 cm^{-1}
N_{C0}/N_{eff0} = 0.44
annealing at 60 °C
annealing at 80 °C
N_C [1/cm^3]
Φ_{eq} [n/cm^2]
0
2·10^{12}
4·10^{12}
6·10^{12}
8·10^{12}
10^{13}
10^{14}
2·10^{14}
3·10^{14}
4·10^{14}

Fig. 8a

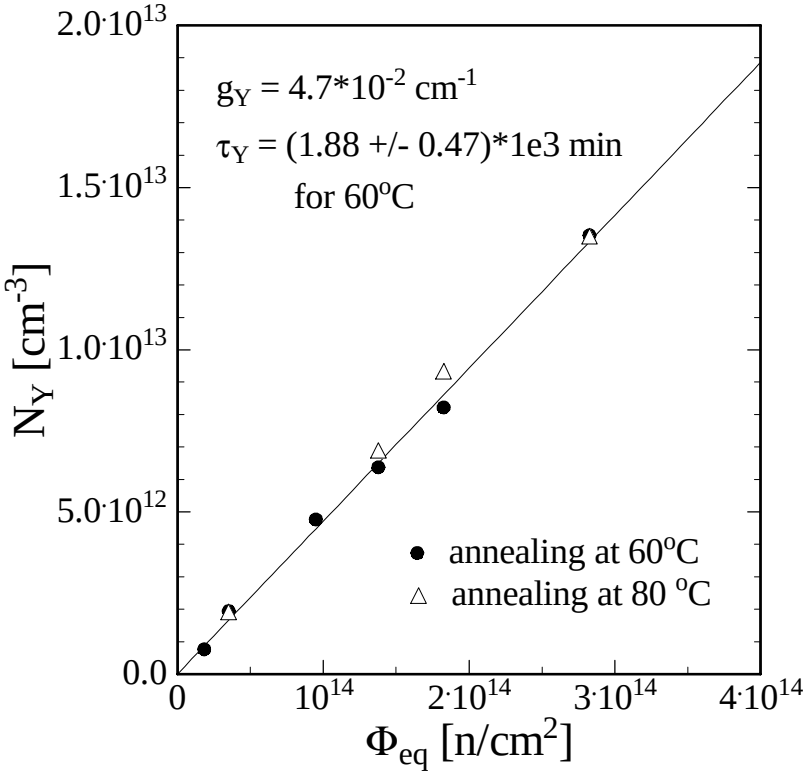
g_Y = 4.7*10^{-2} cm^{-1}
τ_Y = (1.88 +/- 0.47)*1e3 min
for 60°C
annealing at 60°C
annealing at 80 °C
N_Y [cm^{-3}]
Φ_{eq} [n/cm^2]
0.0
5.0·10^{12}
1.0·10^{13}
1.5·10^{13}
2.0·10^{13}
10^{14}
2·10^{14}
3·10^{14}
4·10^{14}

Fig 8b

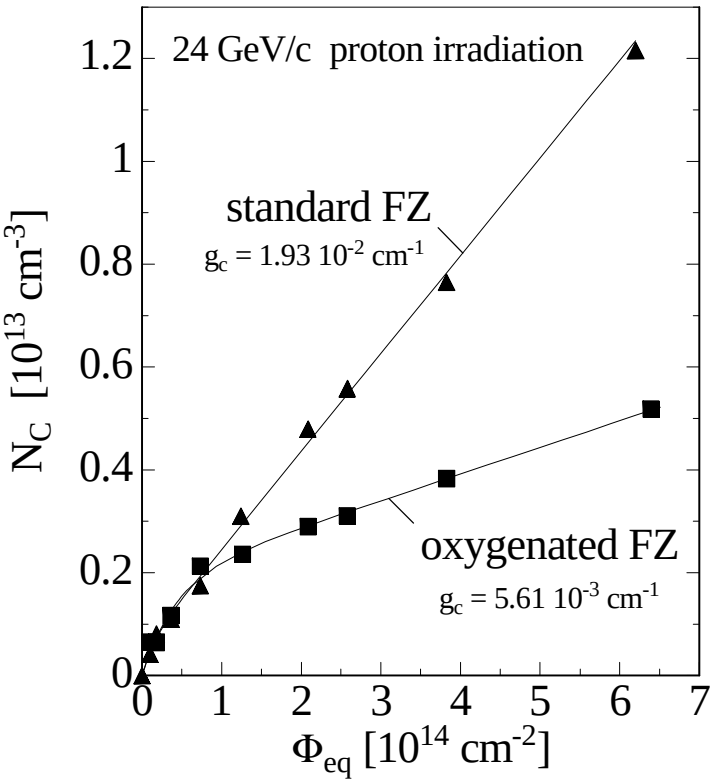
24 GeV/c proton irradiation
standard FZ
g_c = 1.93 10^{-2} cm^{-1}
oxygenated FZ
g_c = 5.61 10^{-3} cm^{-1}
N_C [10^{13} cm^{-3}]
Φ_{eq} [10^{14} cm^{-2}]
0
0.2
0.4
0.6
0.8
1
1.2
0
1
2
3
4
5
6
7

Fig. 9a

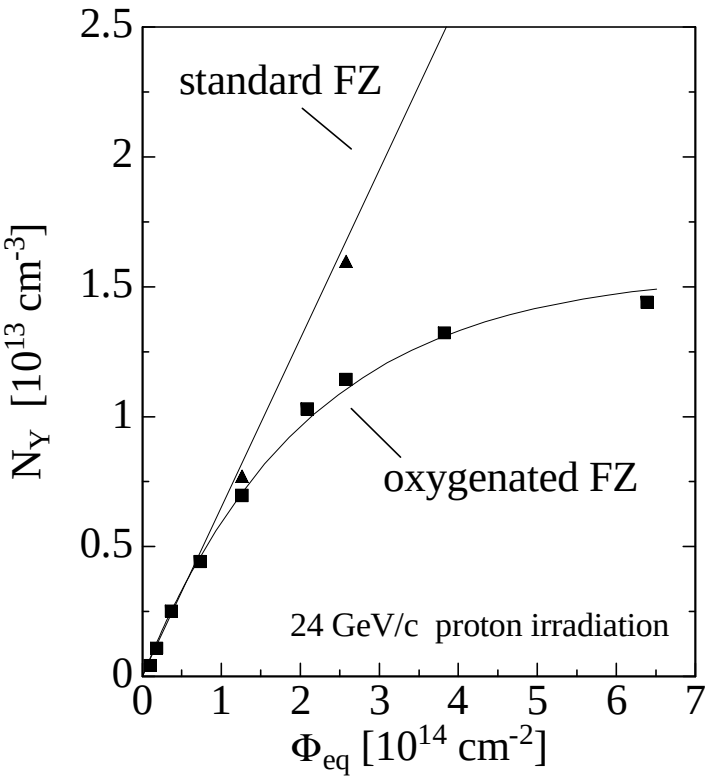
standard FZ
oxygenated FZ
24 GeV/c proton irradiation
N_Y [10^{13} cm^{-3}]
Φ_{eq} [10^{14} cm^{-2}]
0
0.5
1
1.5
2
2.5
0
1
2
3
4
5
6
7

Fig 9b

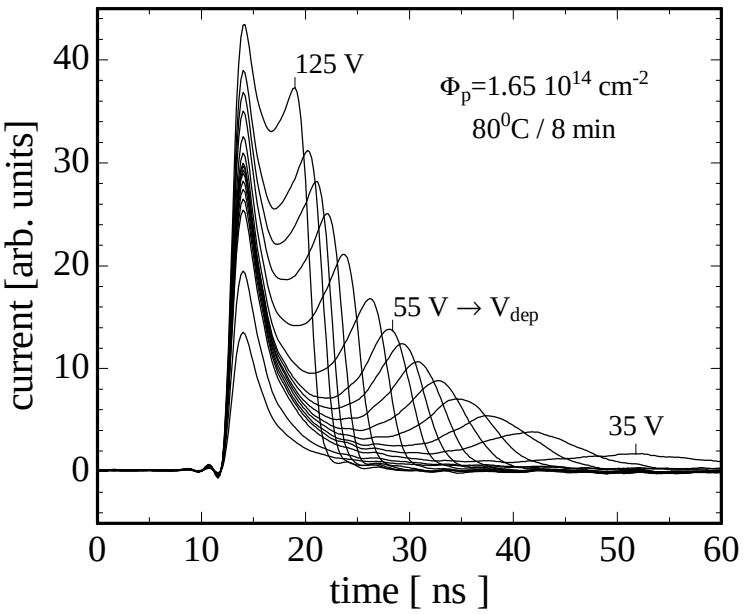

Fig. 10a

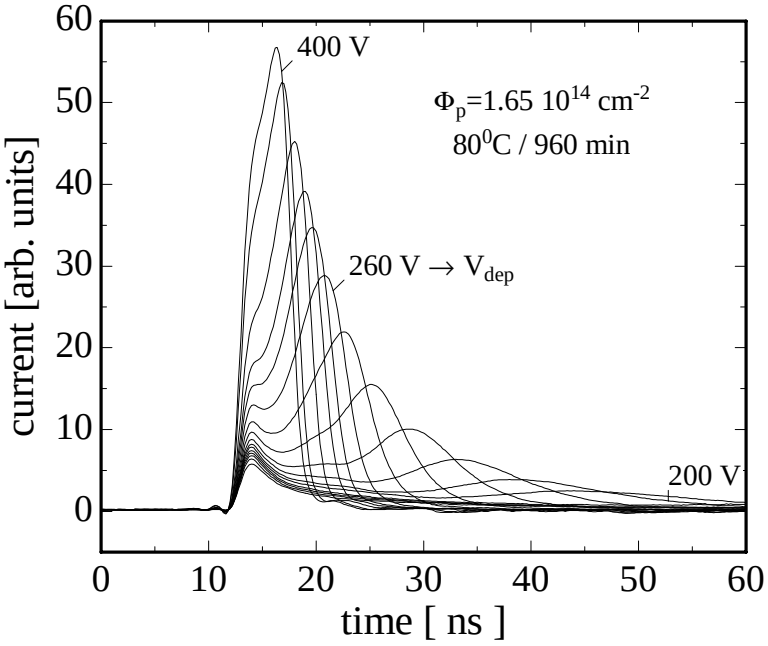

Fig 10b

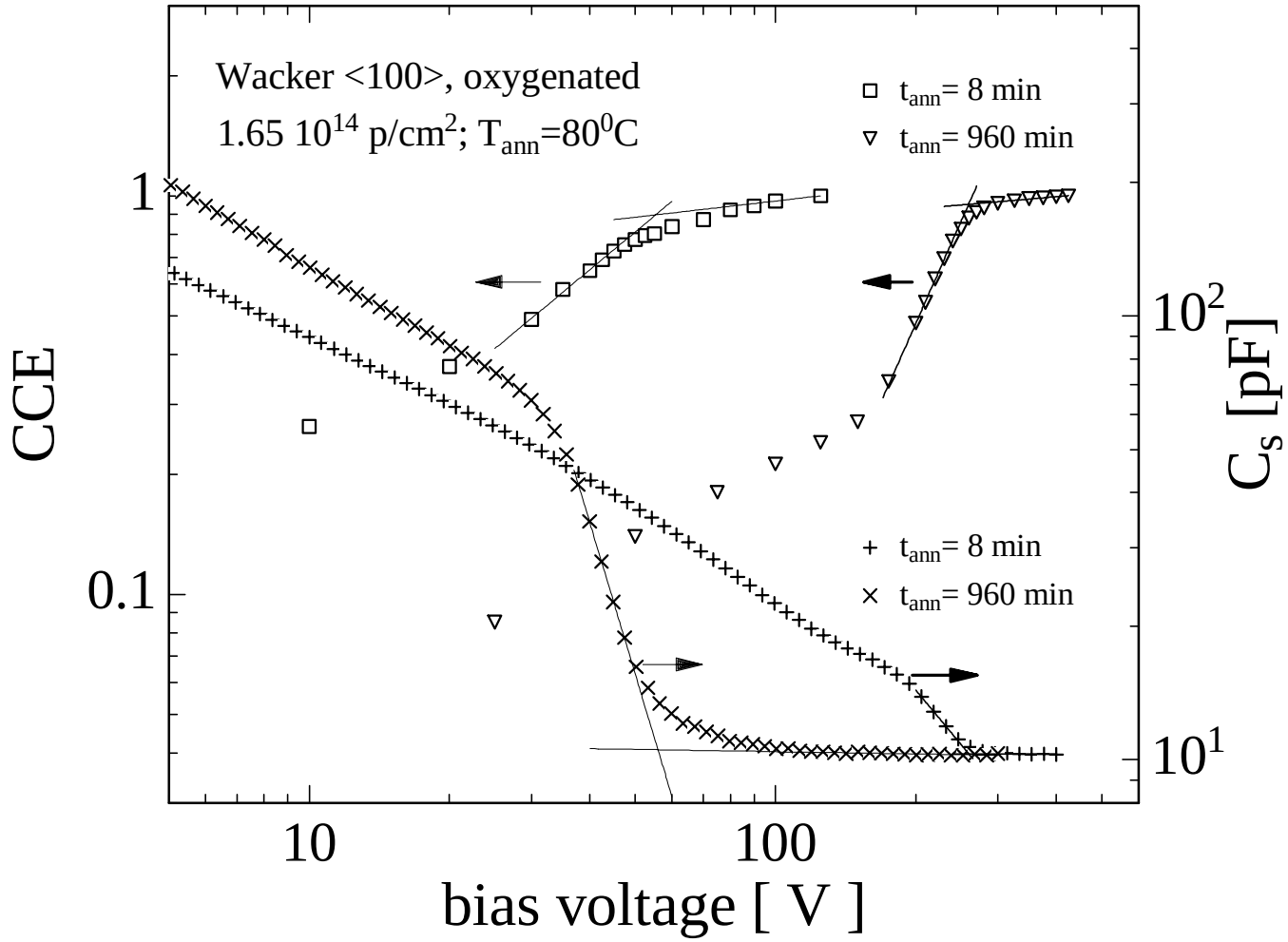
Wacker <100>, oxygenated
1.65 10^14 p/cm^2; T_ann=80^0C
t_ann= 8 min
t_ann= 960 min
t_ann= 8 min
t_ann= 960 min
CCE
C_S [pF]
1
0.1
10^2
10^1
10
100
bias voltage [V]

Fig. 11

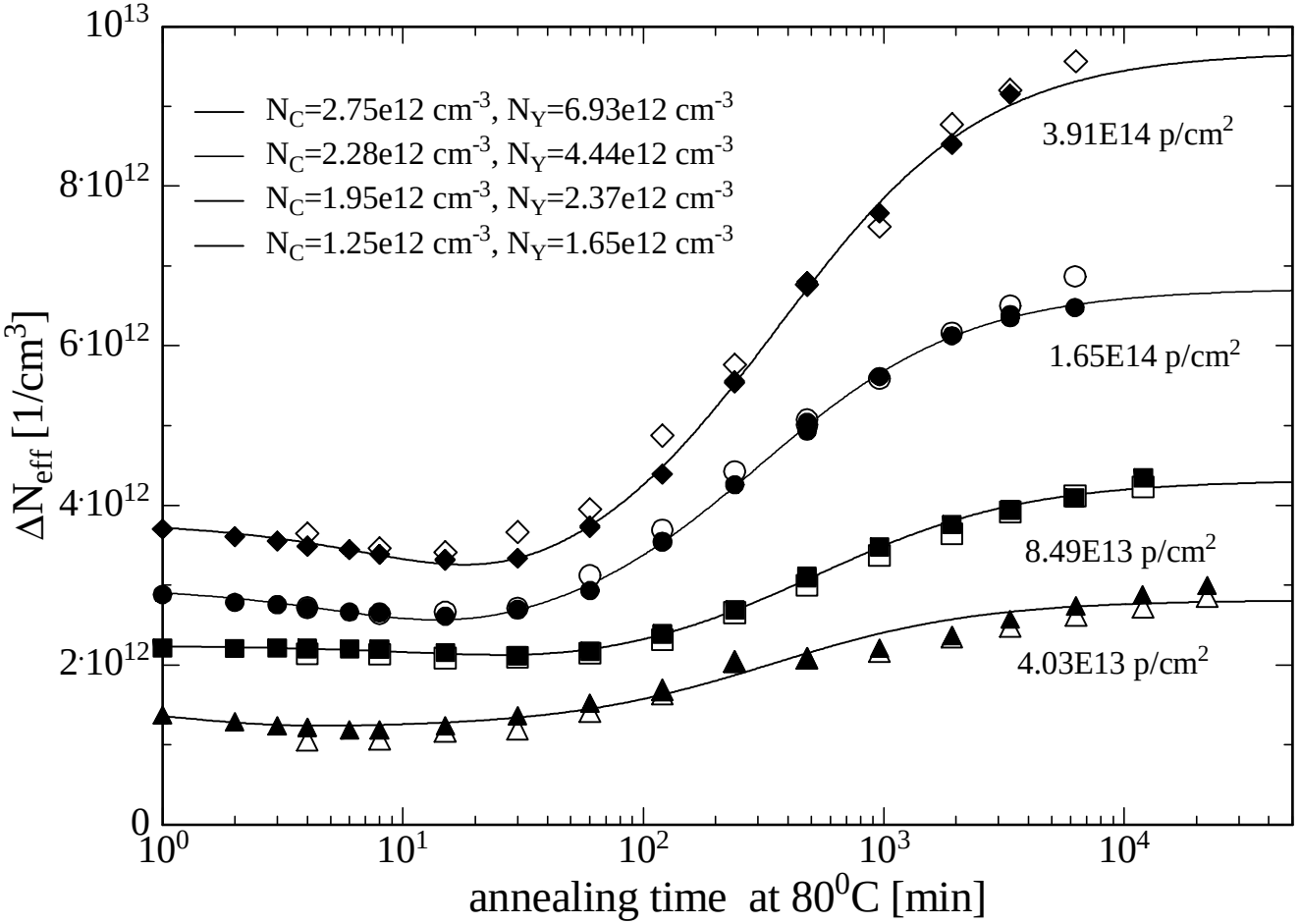
10^{13}
$8{\cdot}10^{12}$
$6{\cdot}10^{12}$
$4{\cdot}10^{12}$
$2{\cdot}10^{12}$
0
ΔN_{eff} [1/cm^3]
10^0
10^1
10^2
10^3
10^4
annealing time at 80^{0}C [min]
N_C=2.75e12 cm^{-3}, N_Y=6.93e12 cm^{-3}
N_C=2.28e12 cm^{-3}, N_Y=4.44e12 cm^{-3}
N_C=1.95e12 cm^{-3}, N_Y=2.37e12 cm^{-3}
N_C=1.25e12 cm^{-3}, N_Y=1.65e12 cm^{-3}
3.91E14 p/cm^2
1.65E14 p/cm^2
8.49E13 p/cm^2
4.03E13 p/cm^2

Fig. 12

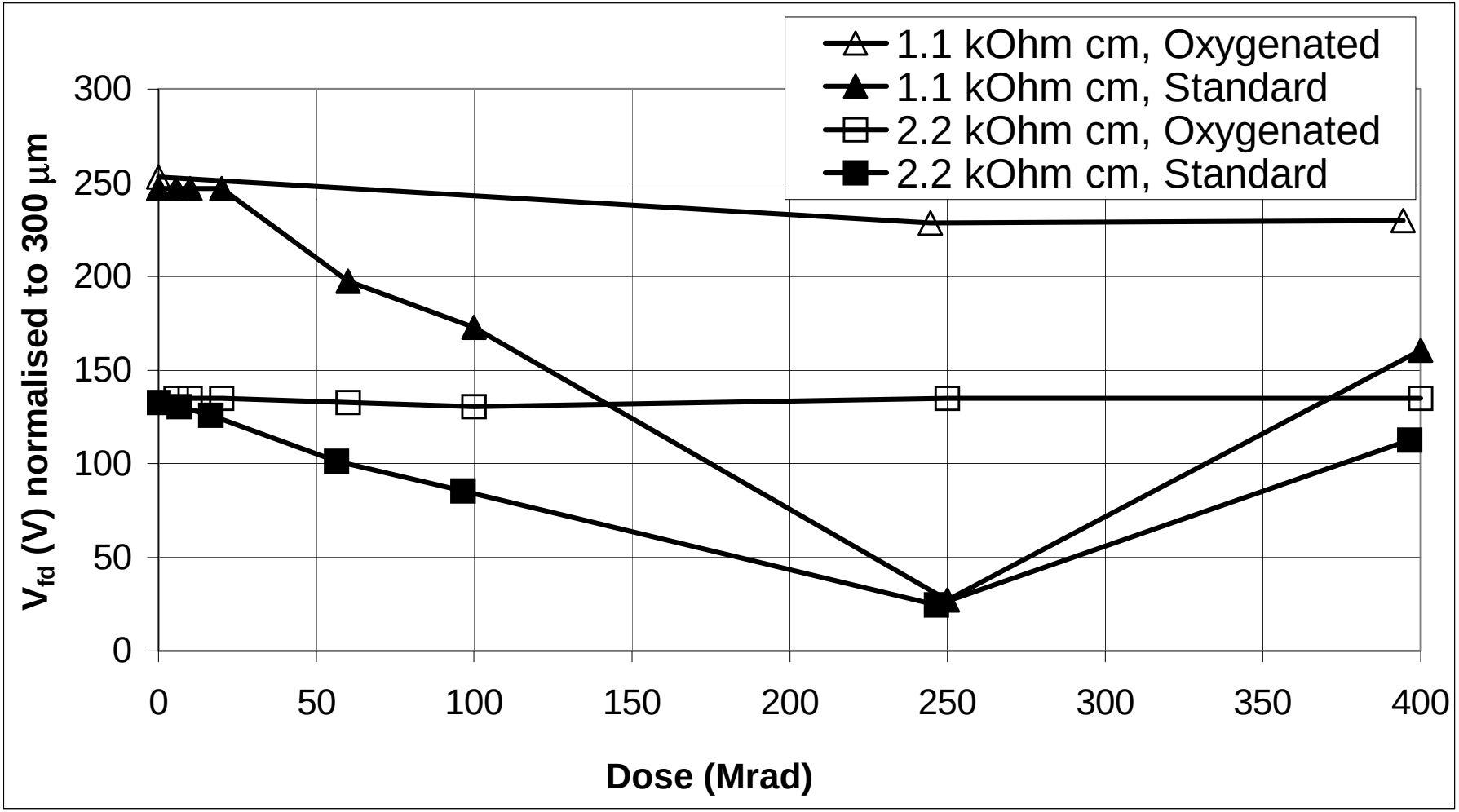
1.1 kOhm cm, Oxygenated
1.1 kOhm cm, Standard
2.2 kOhm cm, Oxygenated
2.2 kOhm cm, Standard
V_{fd} (V) normalised to 300 µm
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
Dose (Mrad)

Fig.13:

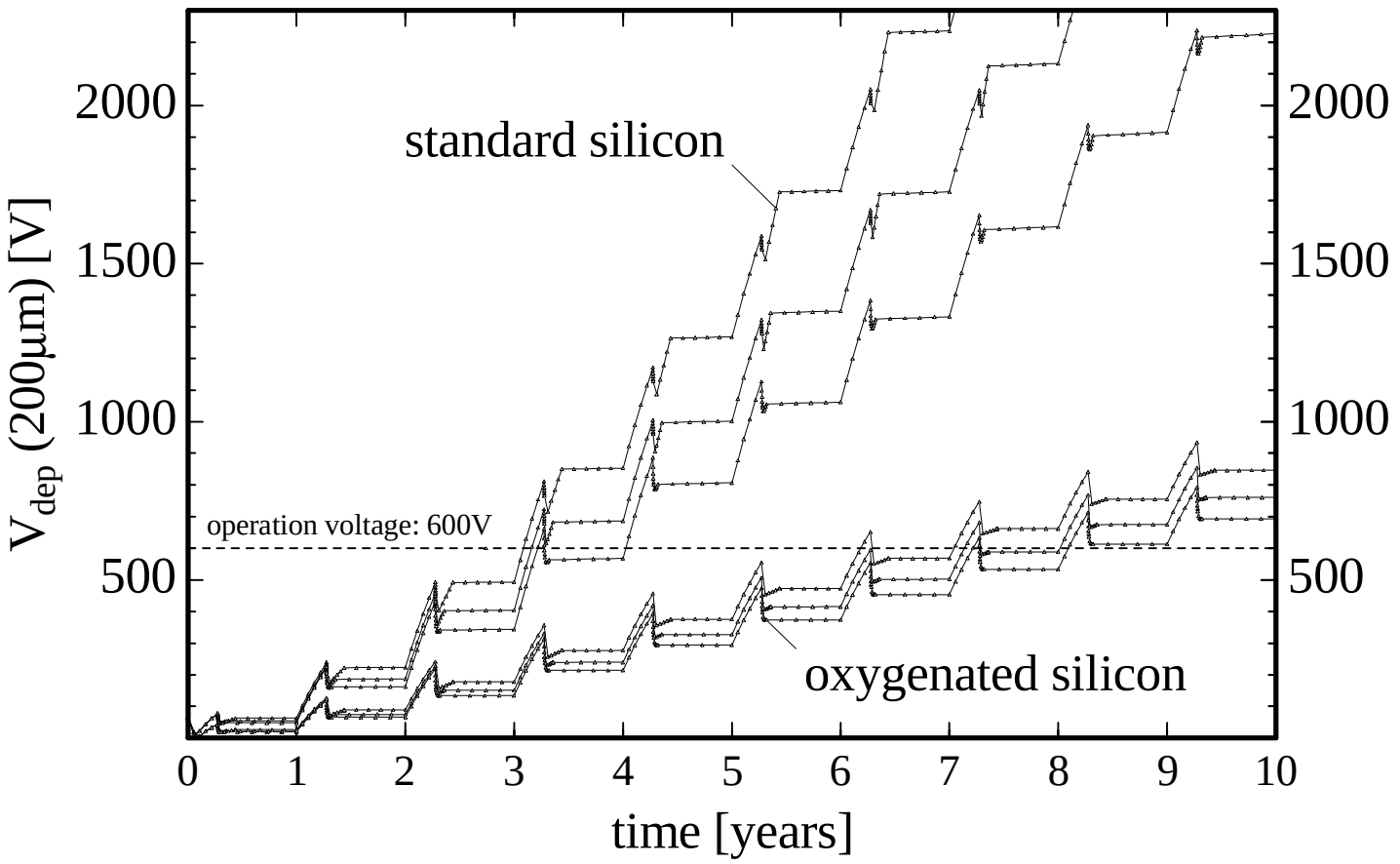
standard silicon
oxygenated silicon
operation voltage: 600V
V_{dep} (200µm) [V]
time [years]
0
1
2
3
4
5
6
7
8
9
10
500
1000
1500
2000

Fig. 14a

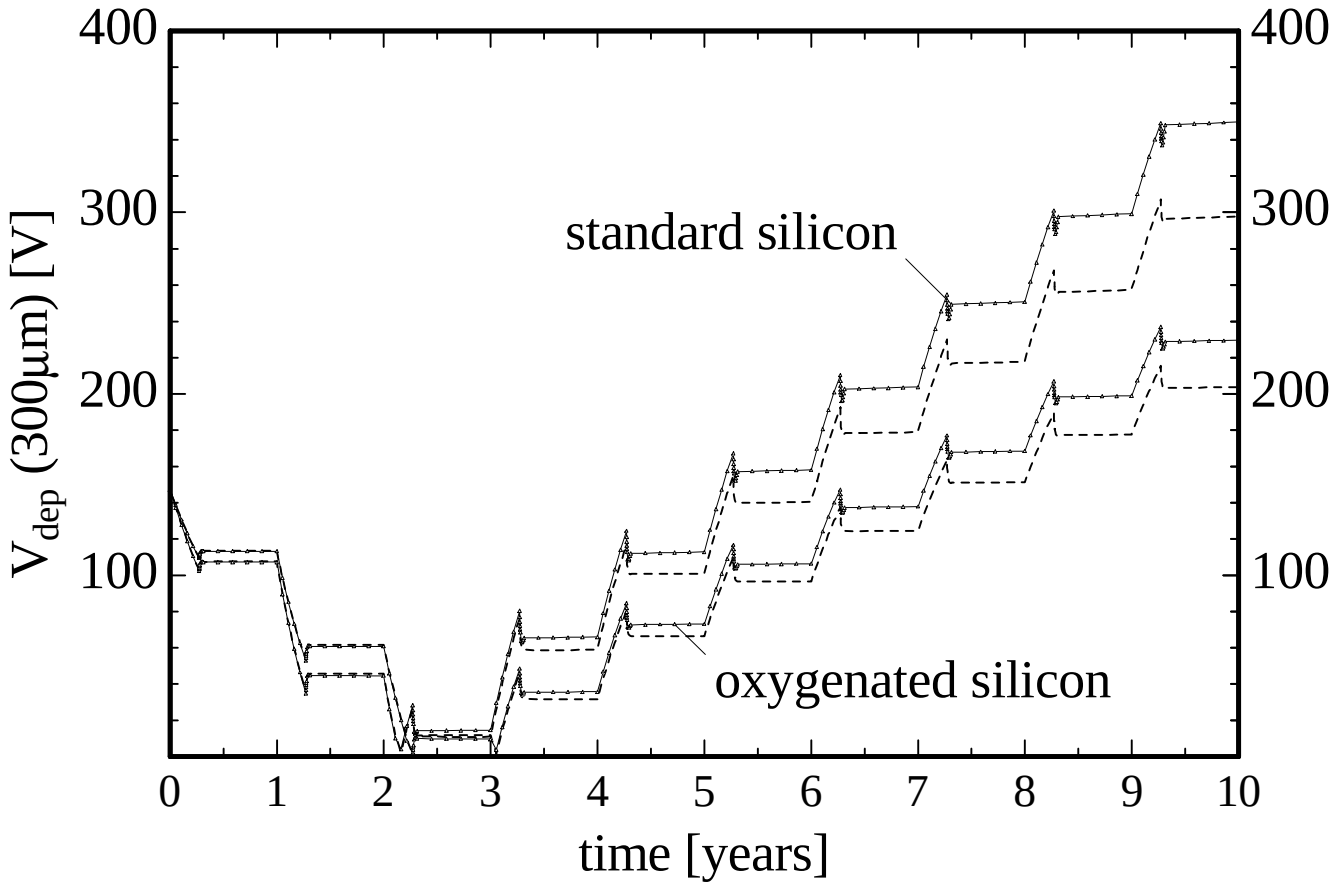
400
300
200
100
V_{dep} (300µm) [V]
standard silicon
oxygenated silicon
0
1
2
3
4
5
6
7
8
9
10
time [years]

Fig. 14b

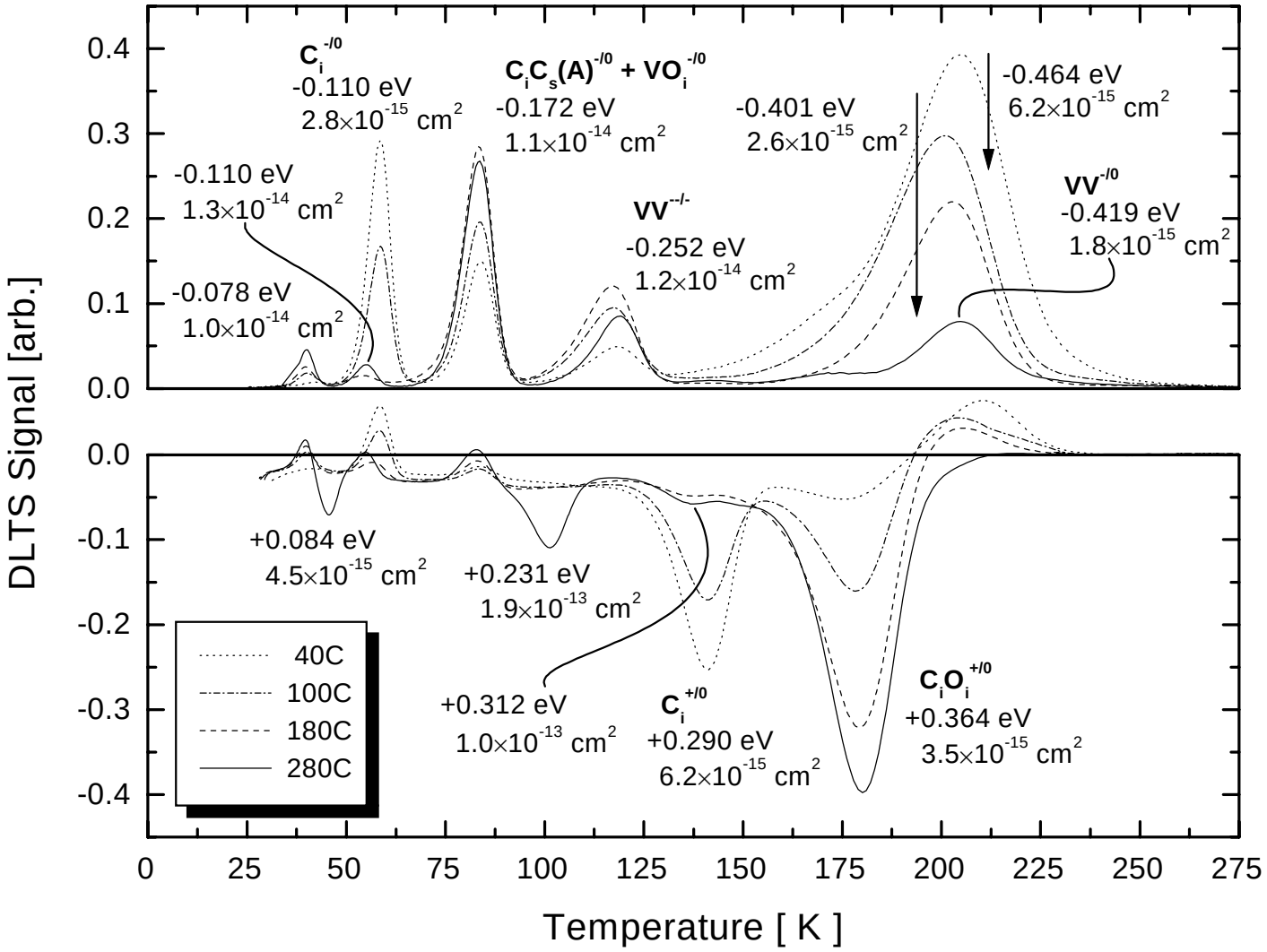
DLTS Signal [arb.]
Temperature [K]
$C_i^{-/0}$
-0.110 eV
2.8×10^-15 cm^2
$C_iC_s(A)^{-/0}$ + $VO_i^{-/0}$
-0.172 eV
1.1×10^-14 cm^2
-0.401 eV
2.6×10^-15 cm^2
-0.464 eV
6.2×10^-15 cm^2
-0.110 eV
1.3×10^-14 cm^2
$VV^{--/-}$
-0.252 eV
1.2×10^-14 cm^2
$VV^{-/0}$
-0.419 eV
1.8×10^-15 cm^2
-0.078 eV
1.0×10^-14 cm^2
+0.084 eV
4.5×10^-15 cm^2
+0.231 eV
1.9×10^-13 cm^2
40C
100C
180C
280C
+0.312 eV
1.0×10^-13 cm^2
$C_i^{+/0}$
+0.290 eV
6.2×10^-15 cm^2
$C_iO_i^{+/0}$
+0.364 eV
3.5×10^-15 cm^2

Fig. 15

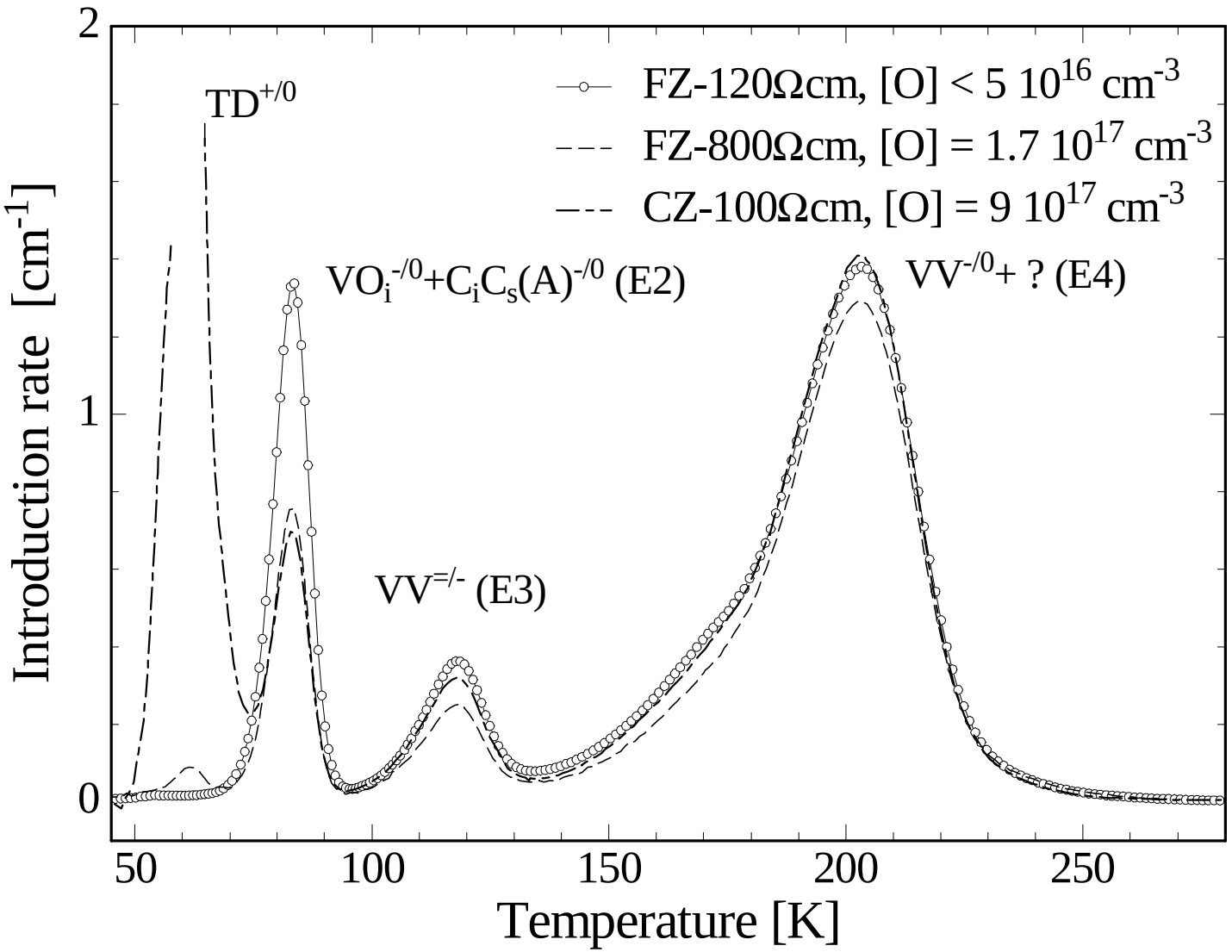
2
1
0
Introduction rate [cm^{-1}]
50
100
150
200
250
Temperature [K]
TD$^{+/0}$
FZ-120Ωcm, [O] < 5 10^{16} cm^{-3}
FZ-800Ωcm, [O] = 1.7 10^{17} cm^{-3}
CZ-100Ωcm, [O] = 9 10^{17} cm^{-3}
VO$_i^{-/0}$+C$_i$C$_s$(A)$^{-/0}$ (E2)
VV$^{=/-}$ (E3)
VV$^{-/0}$+ ? (E4)

Fig. 16

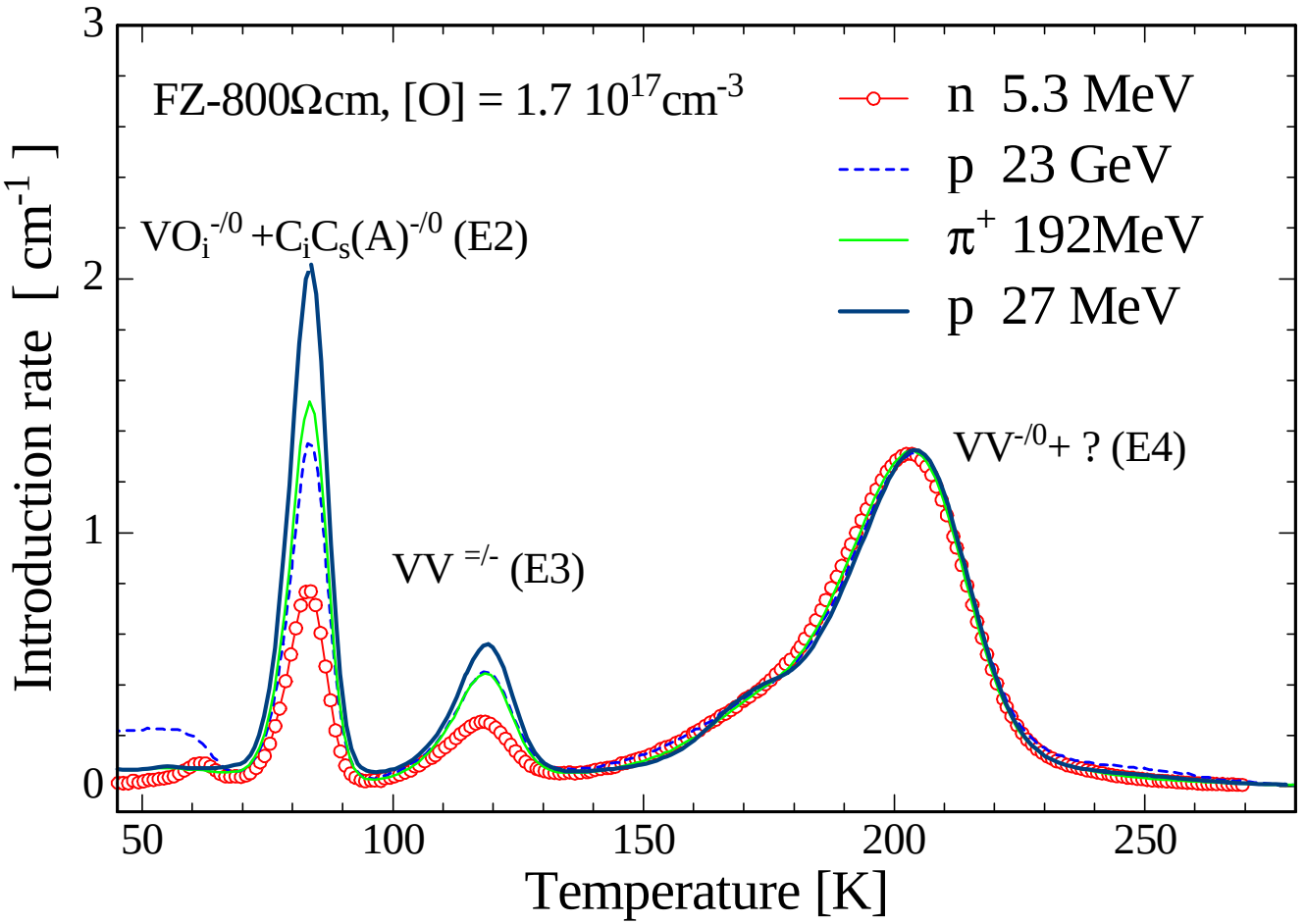
FZ-800Ωcm, [O] = 1.7 10^17cm^-3
n 5.3 MeV
p 23 GeV
π+ 192MeV
p 27 MeV
VOi-/0 +CiCs(A)-/0 (E2)
VV =/- (E3)
VV-/0+ ? (E4)
Introduction rate [cm-1]
Temperature [K]
0
1
2
3
50
100
150
200
250

Fig. 17

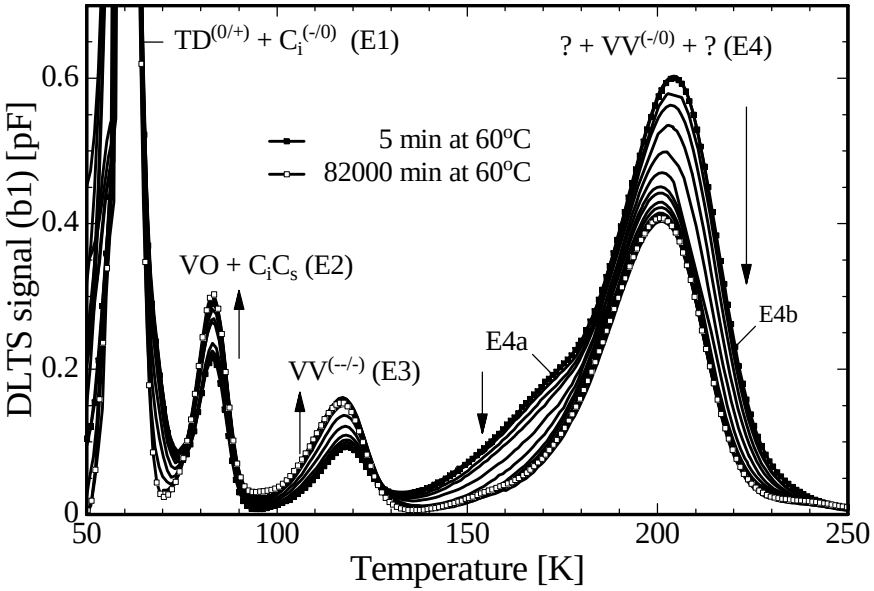

Fig. 18a

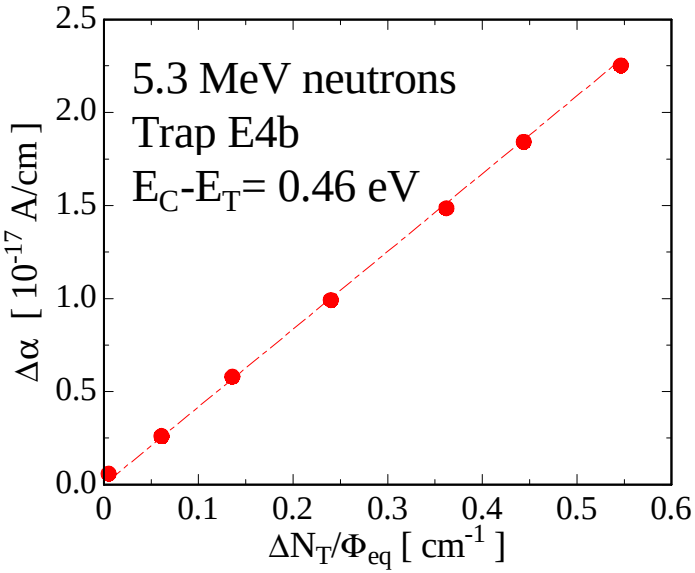

Fig18b

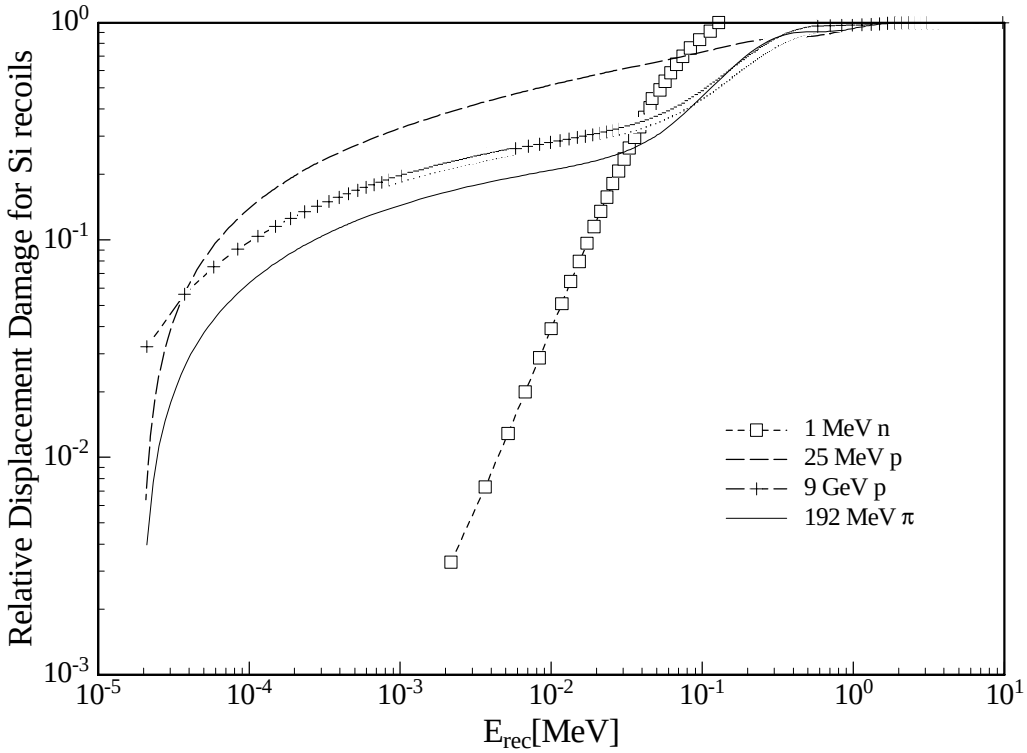
Relative Displacement Damage for Si recoils
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
E_{rec}[MeV]
1 MeV n
25 MeV p
9 GeV p
192 MeV π

Fig. 19