materials

MDPI

Supplementary material

Evaluation of effective mass in InGaAsN/GaAs quantum wells using transient spectroscopy

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S1. Indium and nitrogen influence on the energy band offset of InGaAsN

According to reported energy band offsets (see Galluppi, M.; Geelhaar, L.; Riechert, H.; Nitrogen and indium dependence of the band offsets in InGaAsN quantum wells. Appl. Phys. Lett. 2005 86, 131925), the linear superposition of indium and nitrogen influence was assumed to be correct in narrow concentration region. As a result, the map of the energy band offsets for conduction and valence bands was reproduced as shown in Figure S1(a) and (b).

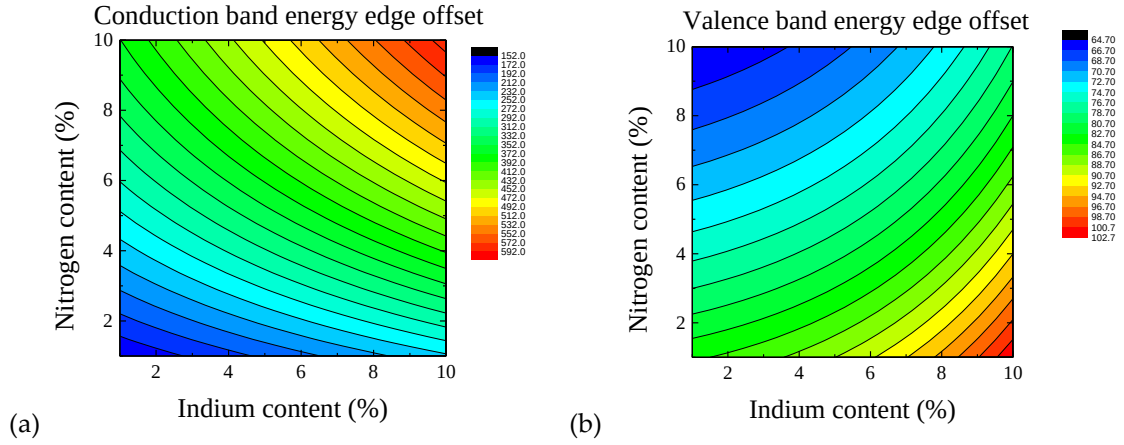


Figure S1. The energy band offsets for edges of (**a**) the conduction band and (**b**) the valence band.

S2. Quantum well layer thickness estimation

High-resolution x-ray diffractograms (HRXRD) were used to evaluate the quantum well thicknesses. Here follows HRXRD of investigated heterostructures.

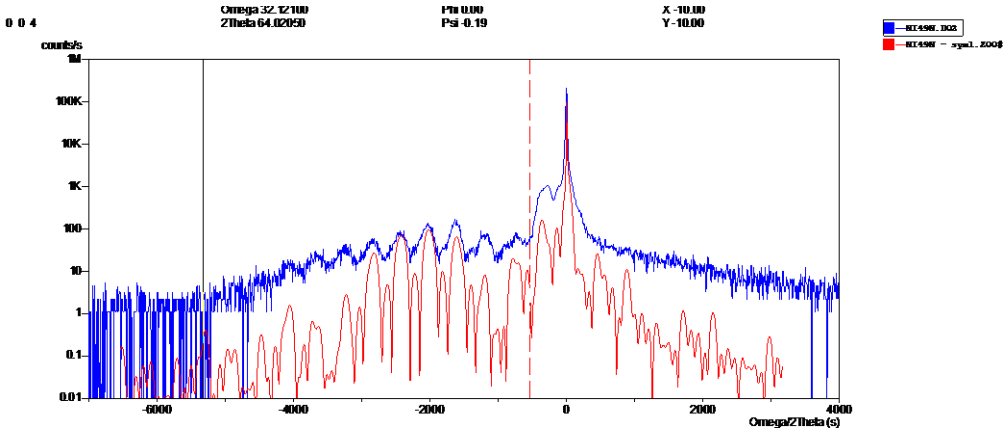
NI49n

3 x InGaAsN/GaAs QW **In – 14,2%;** **N – 0,63%**

d_{QW} – 15,5 nm

$d_{bariera}$ GaAs – 30 nm Eg_{CER} = 1,1799 eV, Eg_{BAC} = 1,1790 eV

d_{cap} – 44 nm



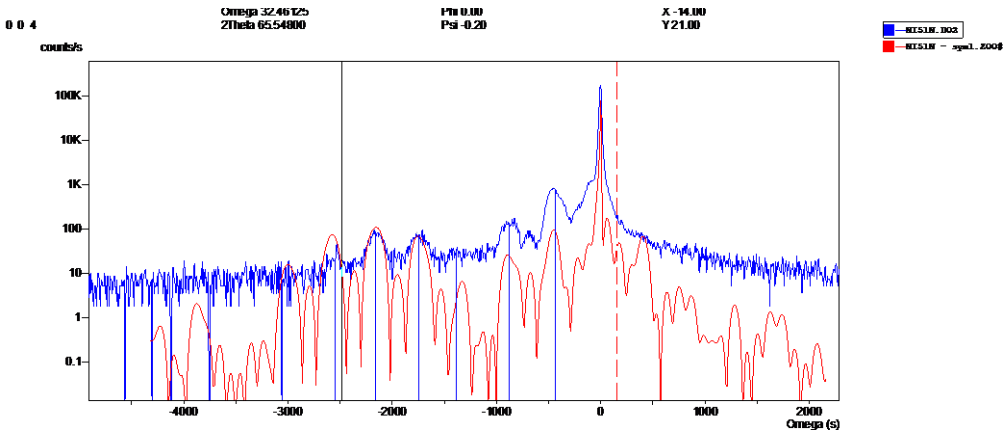
NI51n

3 x InGaAsN/GaAs QW **In – 14,0%;** **N – 0,44%**

d_{QW} – 16,8 nm

$d_{bariera}$ GaAs – 27,5 nm Eg_{CER} = 1,207 eV, Eg_{BAC} = 1,204 eV

d_{cap} – 40,0 nm



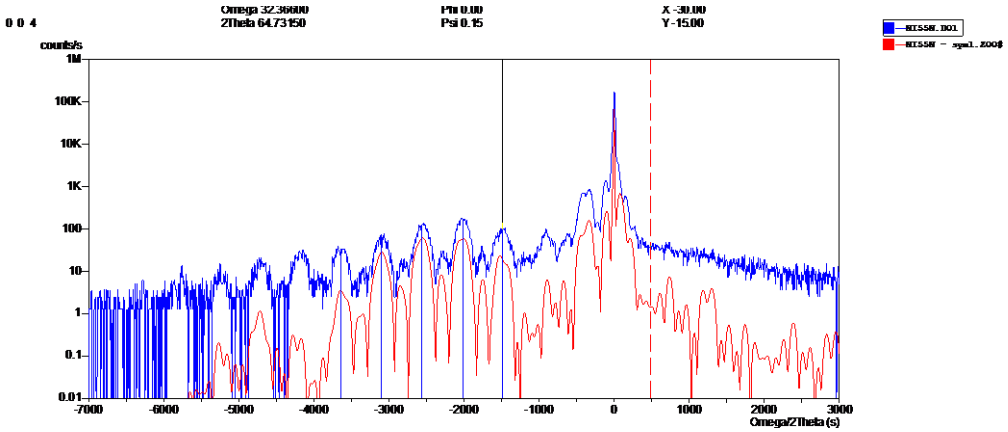
NI55n

3 x InGaAsN/GaAs QW **In – 15,2%;** **N – 0,42%**

d_{QW} – 12,6 nm

$d_{bariera}$ GaAs – 22 nm Eg_{CER} = 1,1998 eV, Eg_{BAC} = 1,200 eV

d_{cap} – 70 nm



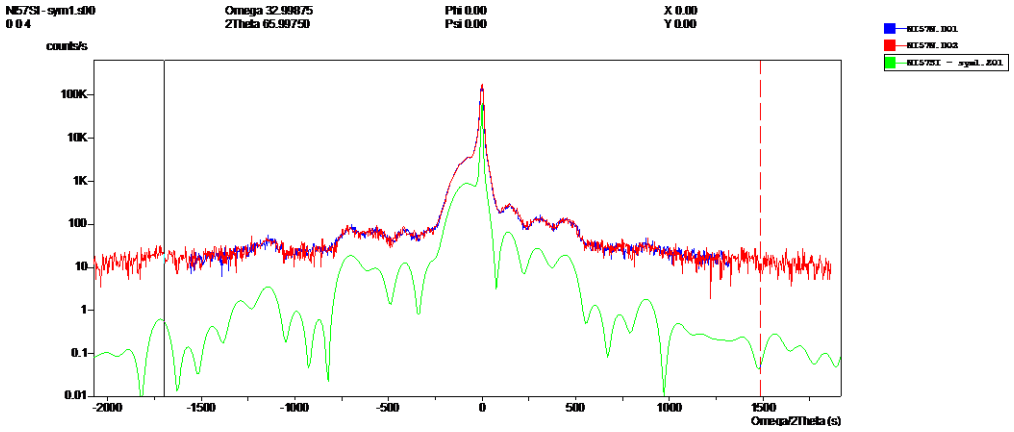
NI57n

3 x InGaAsN/GaAs QW **In – 3,4%; N – 0,39%**

d_{QW} – 11,2 nm

$d_{bariera}$ GaAs – 24,0 nm Eg_{CER} = 1,2577 eV, Eg_{BAC} = 1,2577

d_{cap} – 30 nm



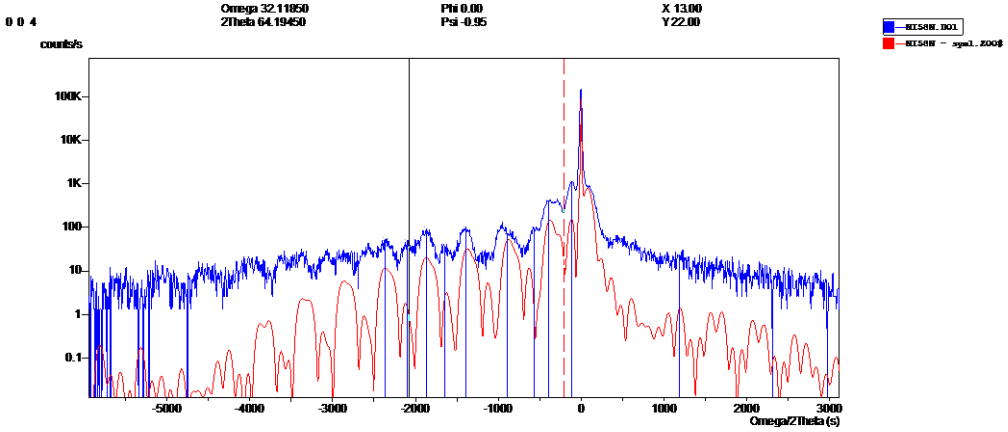
NI58 n

3 x InGaAsN/GaAs QW **In – 12,0%; N – 0,41%**

d_{QW} – 7,0 nm

$d_{bariera}$ GaAs – 31,0 nm Eg_{CER} = 1,2183 eV, Eg_{BAC} = 1,2191 eV

d_{cap} – 40 nm

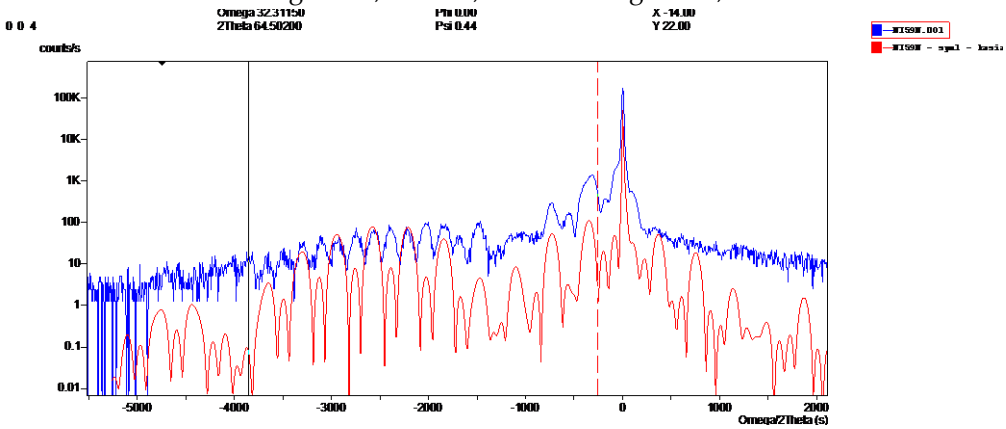


NI59n

3 x InGaAsN/GaAs QW **In – 15,5%;** **N – 0,29%**

d_{QW} – 14 nm

$d_{bariera}$ GaAs – 37,0 nm Eg_{CER} = 1,2123 eV, Eg_{BAC} = 1,2171 eV



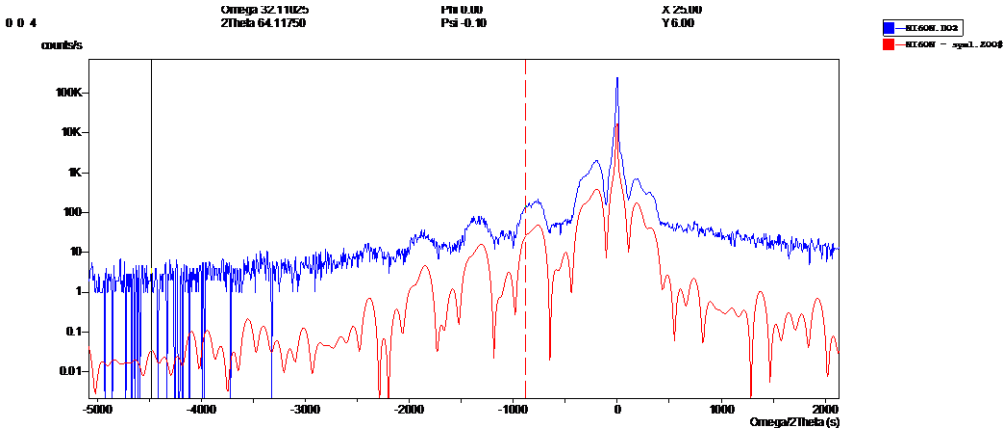
NI60n

3 x InGaAsN/GaAs QW **In – 6,0%;** **N – 0,33%**

d_{QW} – 10,0 nm

$d_{bariera}$ GaAs – 25 nm Eg_{CER} = 1,2607 eV, Eg_{BAC} = 1,2608 eV

d_{cap} – 38 nm



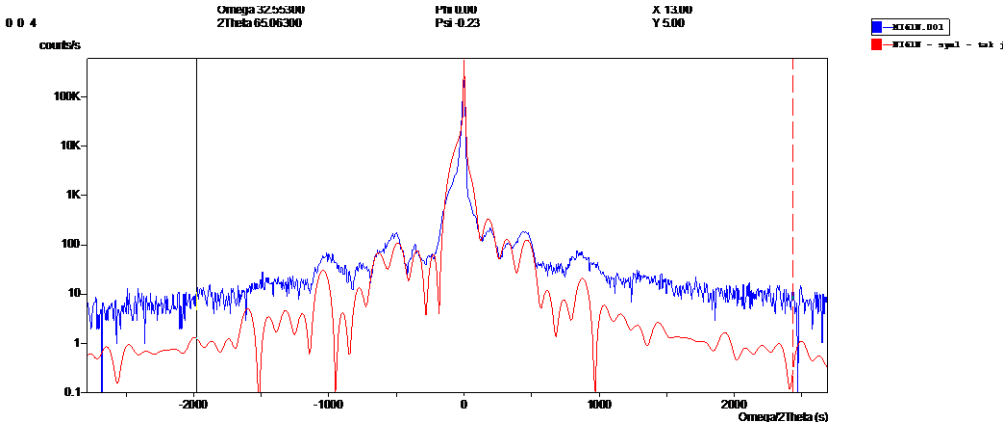
NI61 n

3 x InGaAsN/GaAs QW **In – 2,8%;** **N – 0,45%**

d_{QW} – 10,0 nm

$d_{bariera}$ GaAs – 28 nm Eg_{CER} = 1,2391 eV, Eg_{BAC} = 1,2476 eV

d_{cap} – 28 nm



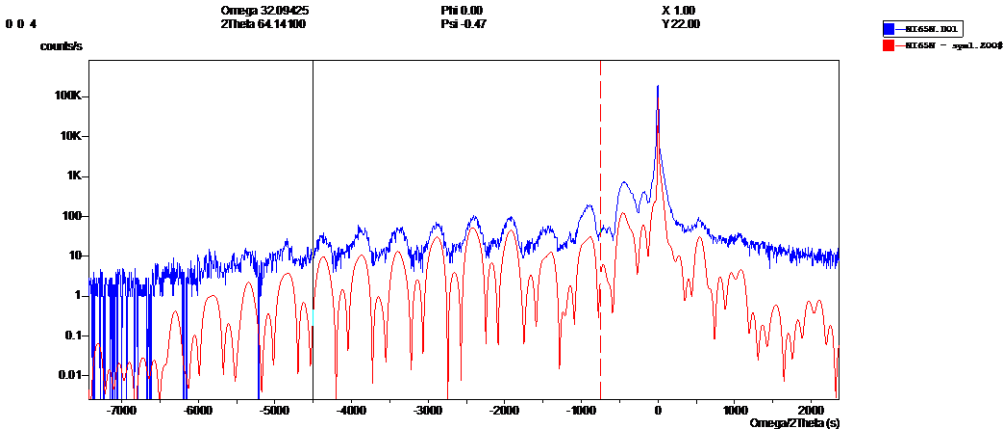
NI65 n

3 x InGaAsN/GaAs QW 1st layer In – 11,0% N – 0,5% d = 8,5 nm

2nd layer In- 21,0% N – 0,1% d = 5,6 nm

$d_{bariera}$ GaAs – 24,2 nm Eg_{CER} = 1,200 eV, Eg_{BAC} = 1,2029 eV

d_{cap} – 32 nm



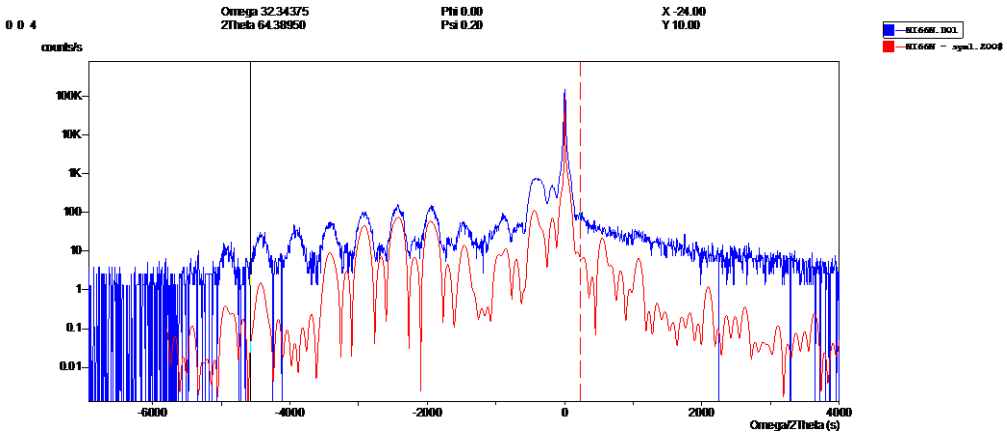
NI66 n

3 x InGaAsN/GaAs QW **In – 15%; N – 0,34%**

d_{QW} – 13,8 nm

$d_{bariera}$ GaAs – 23,9 nm Eg_{CER} = 1,212 eV, Eg_{BAC} = 1,2129 eV

d_{cap} – 35,7 nm



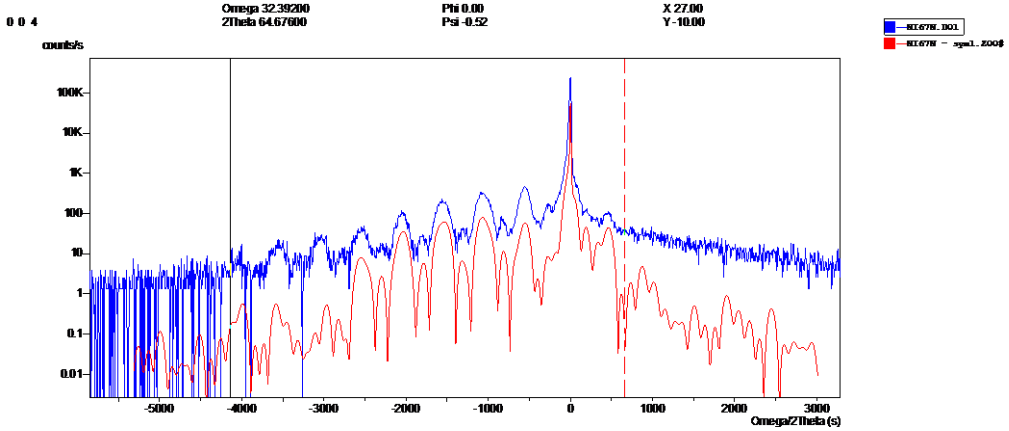
NI67 n

3 x InGaAsN/GaAs QW **In – 10,0%;** **N – 0,25%**

d_{QW} – 10 nm

$d_{bariera}$ GaAs – 25,4 nm Eg_{CER} = 1,256 eV, Eg_{BAC} = 1,2576 eV

d_{cap} – 32 nm



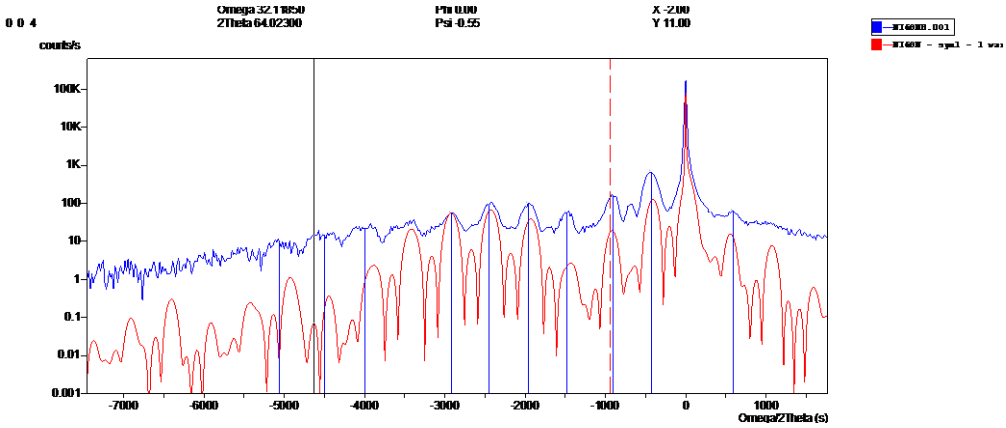
NI68 n

3 x

InGaAsN- **In – 16,0%;** **N – 0,24%** **d – 12,5 nm**

$d_{bariera}$ GaAs – 25,2 nm Eg_{CER} = 1,22 eV, Eg_{BAC} = 1,211 eV

d_{cap} – 0 nm



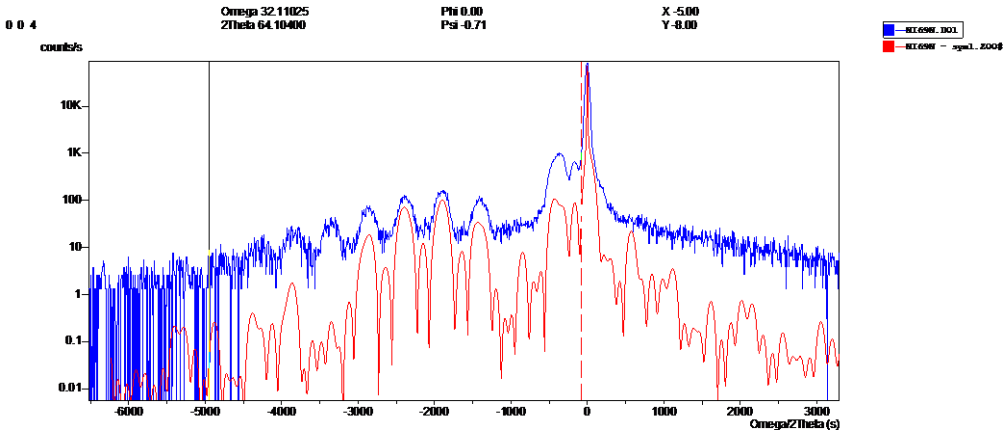
NI69 n

3 x InGaAsN/GaAs QW **In – 13,2%;** **N – 0,36%**

d_{QW} – 15,5 nm

$d_{bariera}$ GaAs – 22,5nm Eg_{CER} = 1,22 eV, Eg_{BAC} = 1,22

d_{cap} – 32 nm



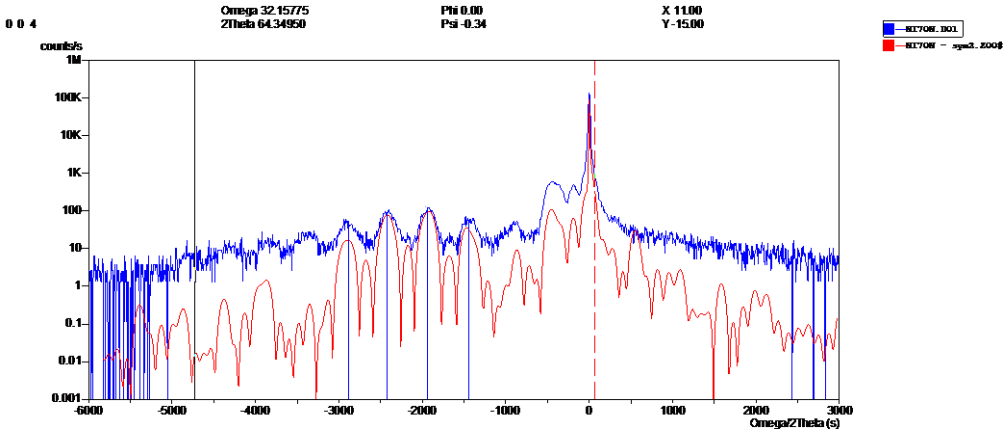
NI70 n

3 x InGaAsN/GaAs QW **In – 13,3%;** **N – 0,32%**

d_{QW} – 15,8 nm

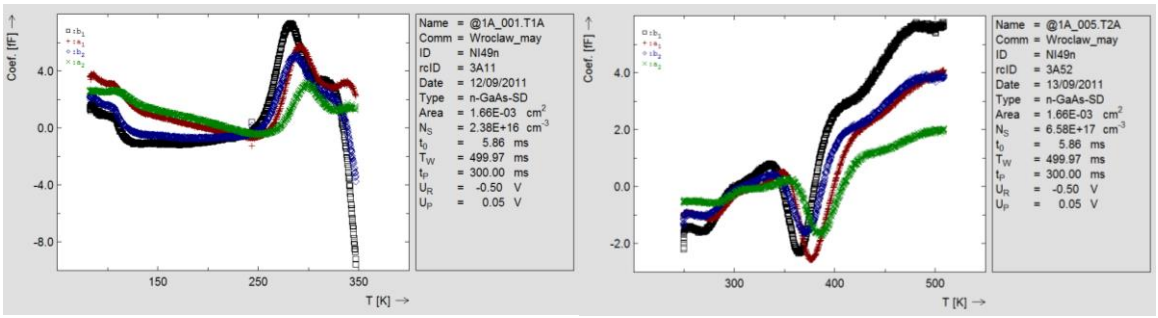
$d_{bariera}$ GaAs – 22,2 nm Eg_{CER} = 1,225 eV, Eg_{BAC} = 1,226 Ev

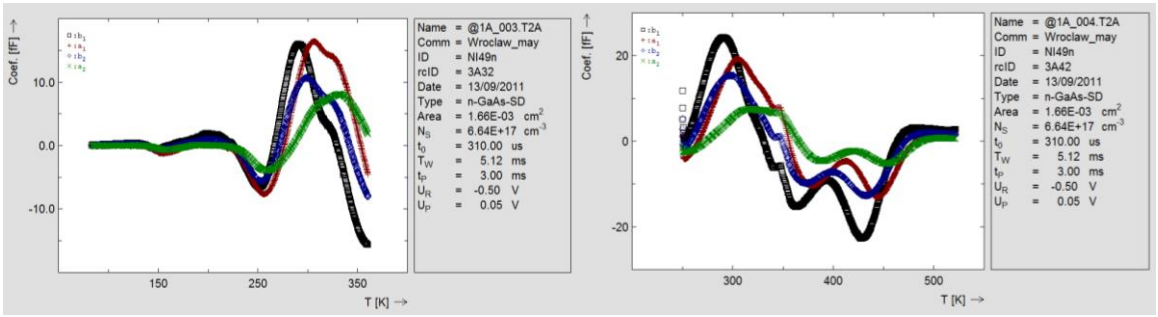
d_{cap} – 33 nm



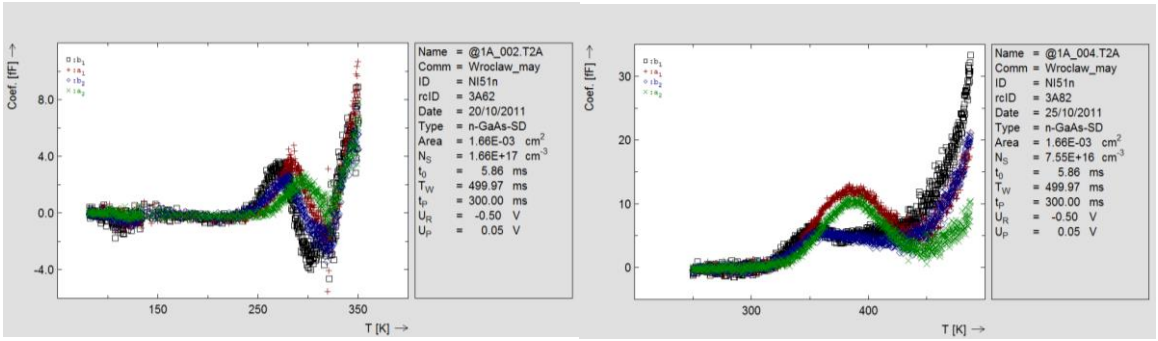
S3. Deep-level transient spectroscopy data

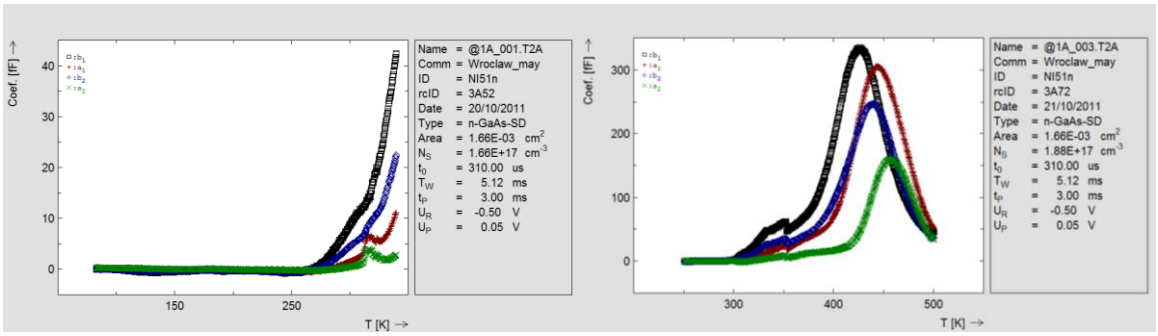
NI49n



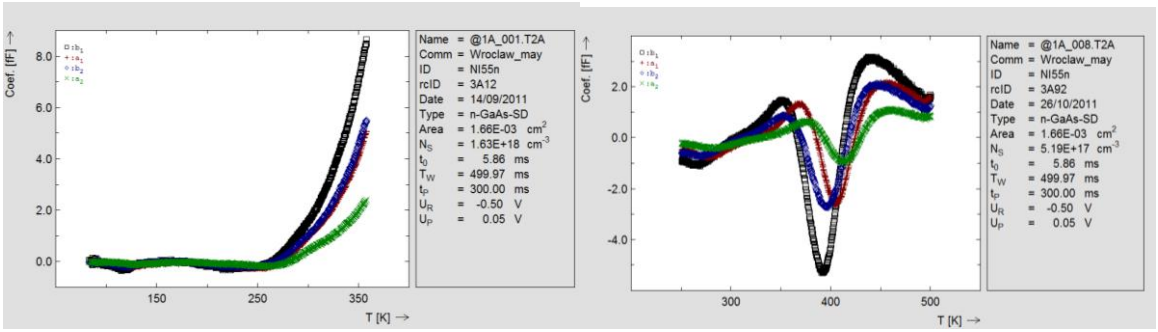


NI51n





NI55n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N_S = 1.63E+18 cm⁻³
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T_W = 499.97 ms
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U_P = 0.05 V
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ID = NI55n
rcID = 3A92
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N_S = 5.19E+17 cm⁻³
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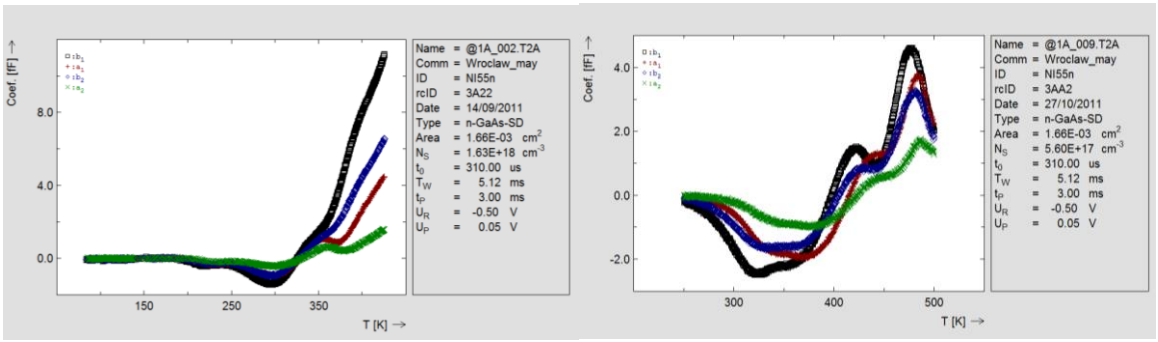
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U_P = 0.05 V
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rcID = 3AA2
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N_S = 5.60E+17 cm⁻³
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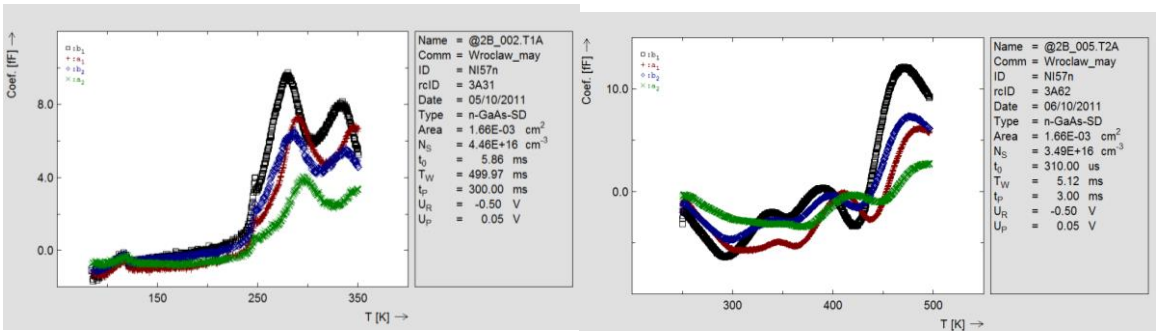
U_P = 0.05 V

NI57n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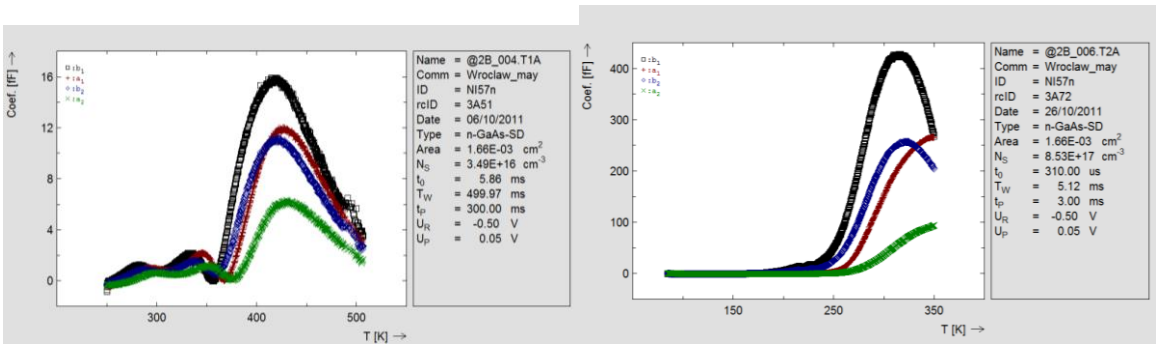
U_P = 0.05 V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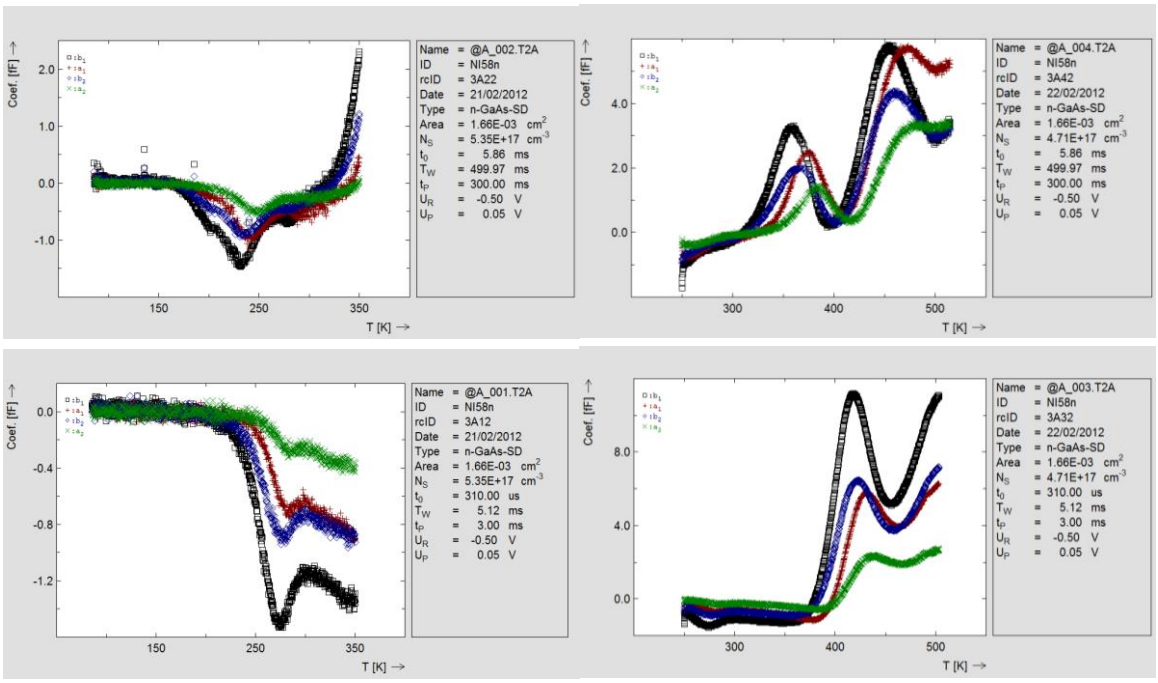
NI58n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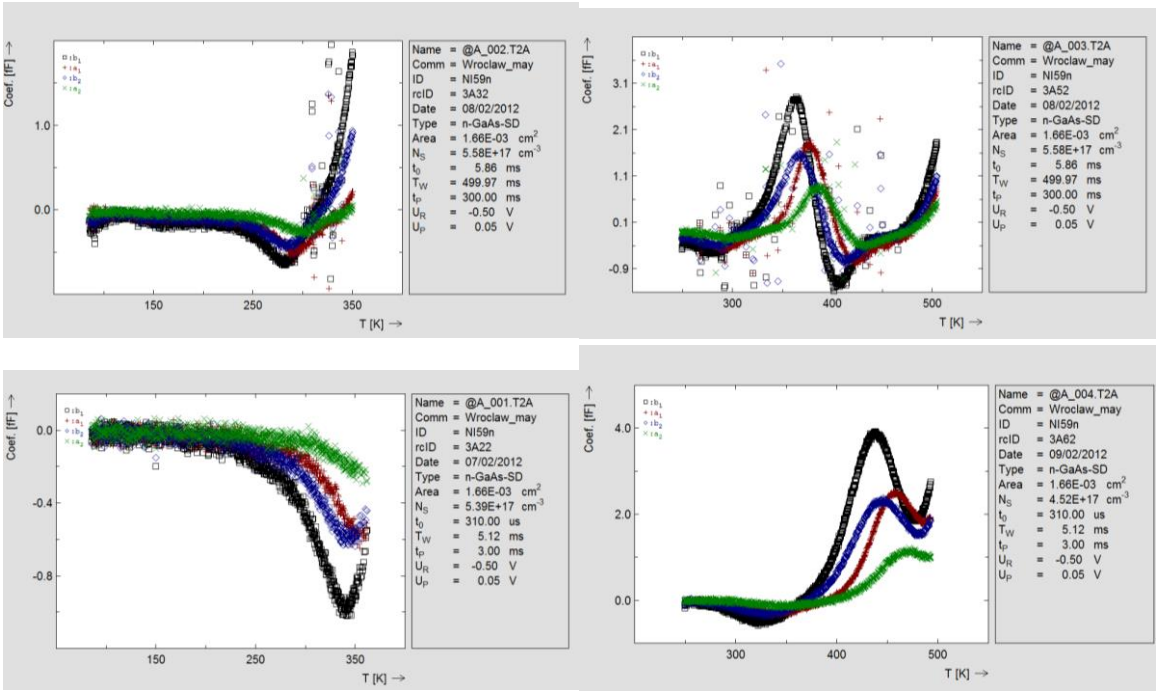
NI59n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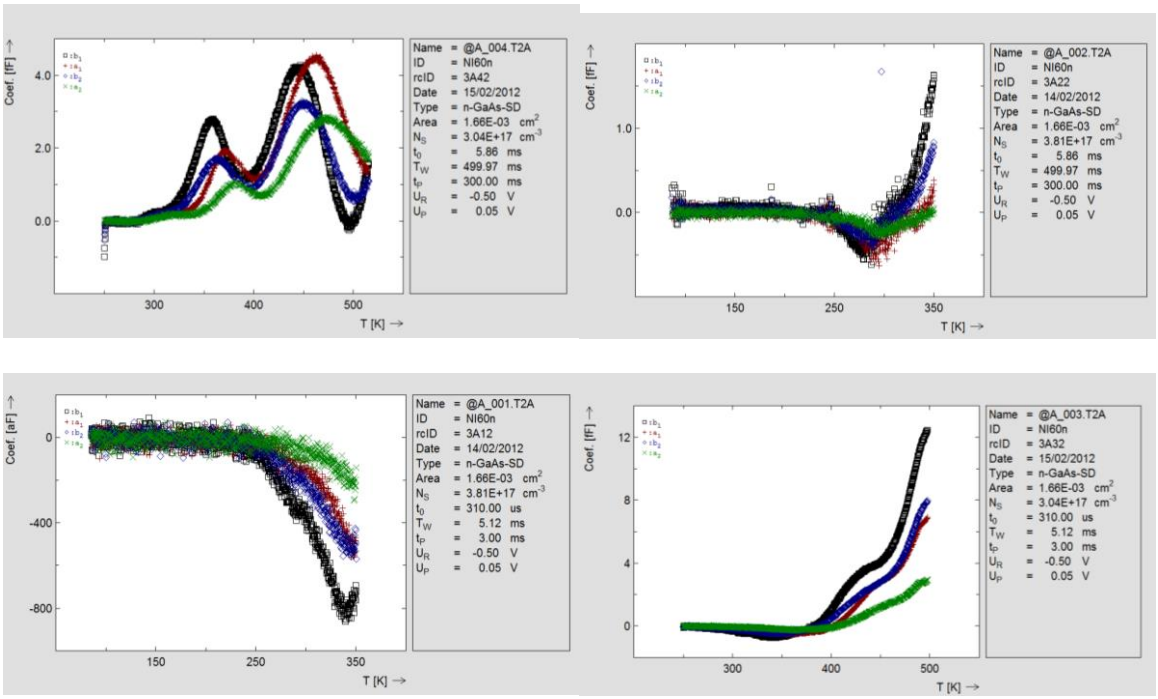
NI60n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TW = 5.12 ms
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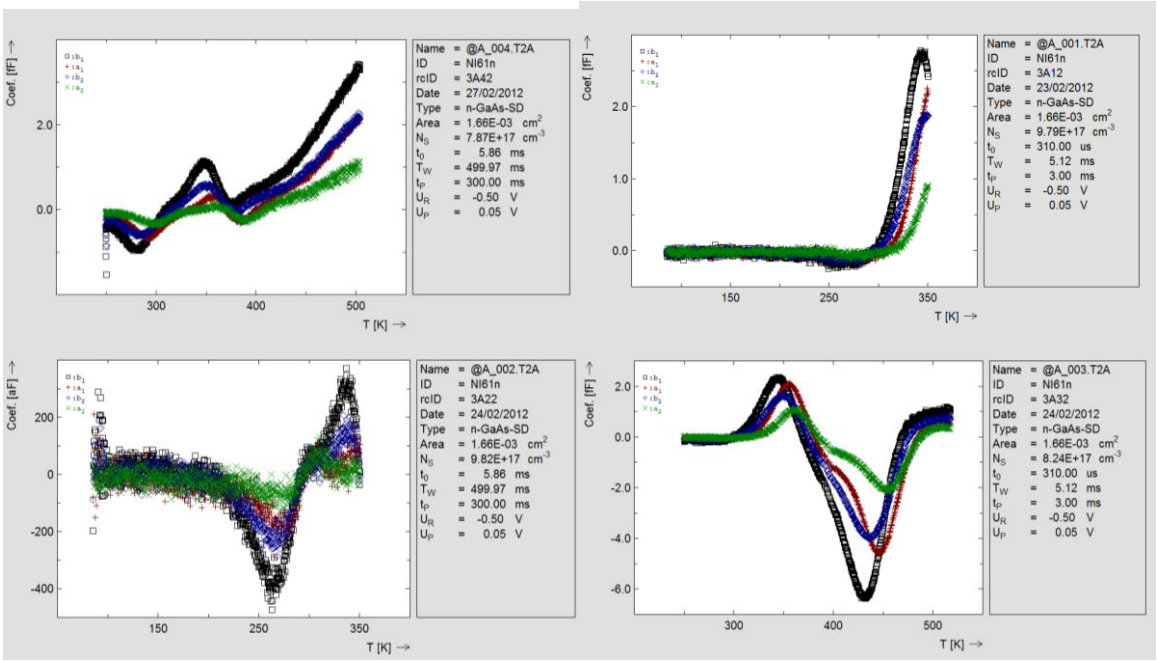
NI61n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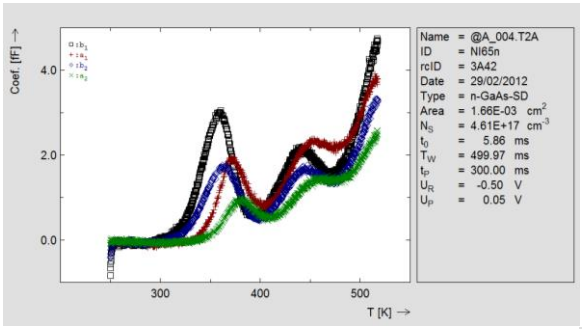
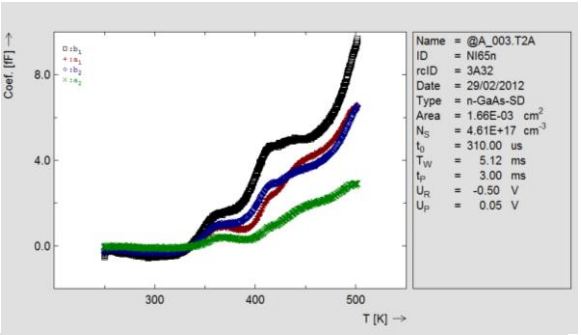
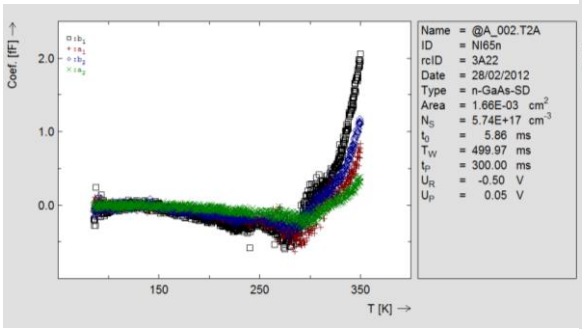
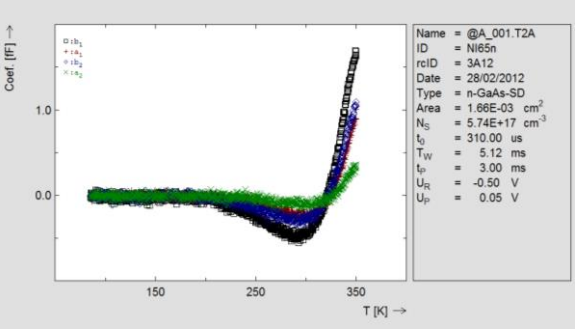
NS = 9.79E+17 cm-3
t0 = 310.00 us
TW = 5.12 ms
tP = 3.00 ms
UR = -0.50 V
UP = 0.05 V
Coef. [aF]
T [K]
Name = @A_002.T2A
ID = NI61n
rcID = 3A22
Date = 24/02/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm2
NS = 9.82E+17 cm-3
t0 = 5.86 ms
TW = 499.97 ms
tP = 300.00 ms
UR = -0.50 V
UP = 0.05 V
Coef. [fF]
T [K]
Name = @A_003.T2A
ID = NI61n
rcID = 3A32
Date = 24/02/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm2
NS = 8.24E+17 cm-3
t0 = 310.00 us
TW = 5.12 ms
tP = 3.00 ms
UR = -0.50 V
UP = 0.05 V

NI65n

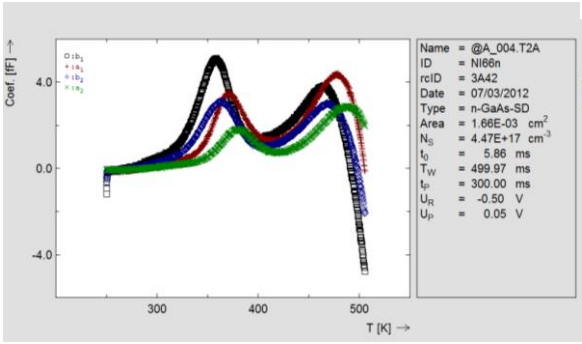

Coef. [fF]
T [K]
Name = @A_004.T2A
ID = NI65n
rcID = 3A42
Date = 29/02/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 4.61E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V

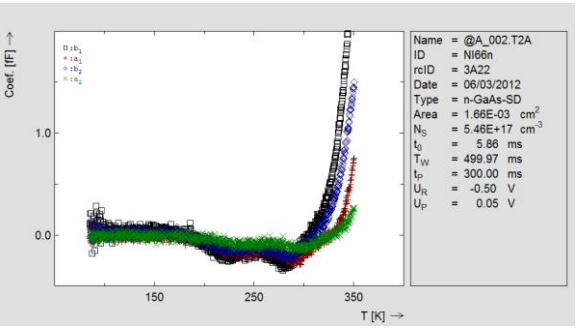

Coef. [fF]
T [K]
Name = @A_003.T2A
ID = NI65n
rcID = 3A32
Date = 29/02/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 4.61E+17 cm⁻³
t_0 = 310.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V

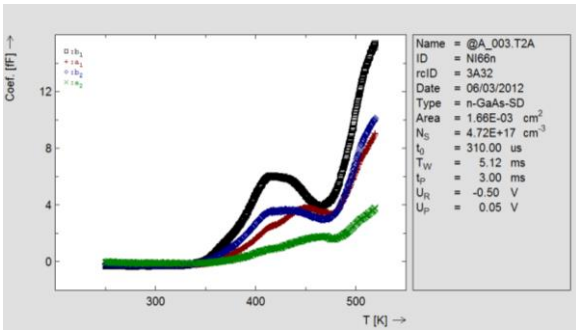

Coef. [fF]
T [K]
Name = @A_002.T2A
ID = NI65n
rcID = 3A22
Date = 28/02/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 5.74E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V

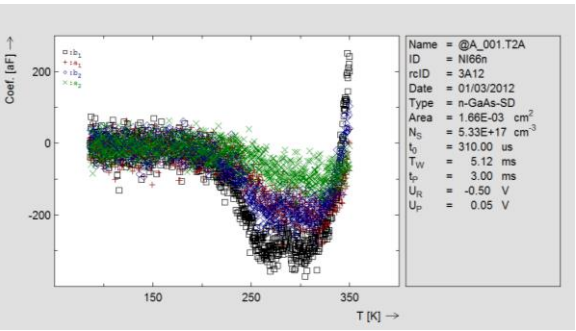

Coef. [fF]
T [K]
Name = @A_001.T2A
ID = NI65n
rcID = 3A12
Date = 28/02/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 5.74E+17 cm⁻³
t_0 = 310.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V

NI66n

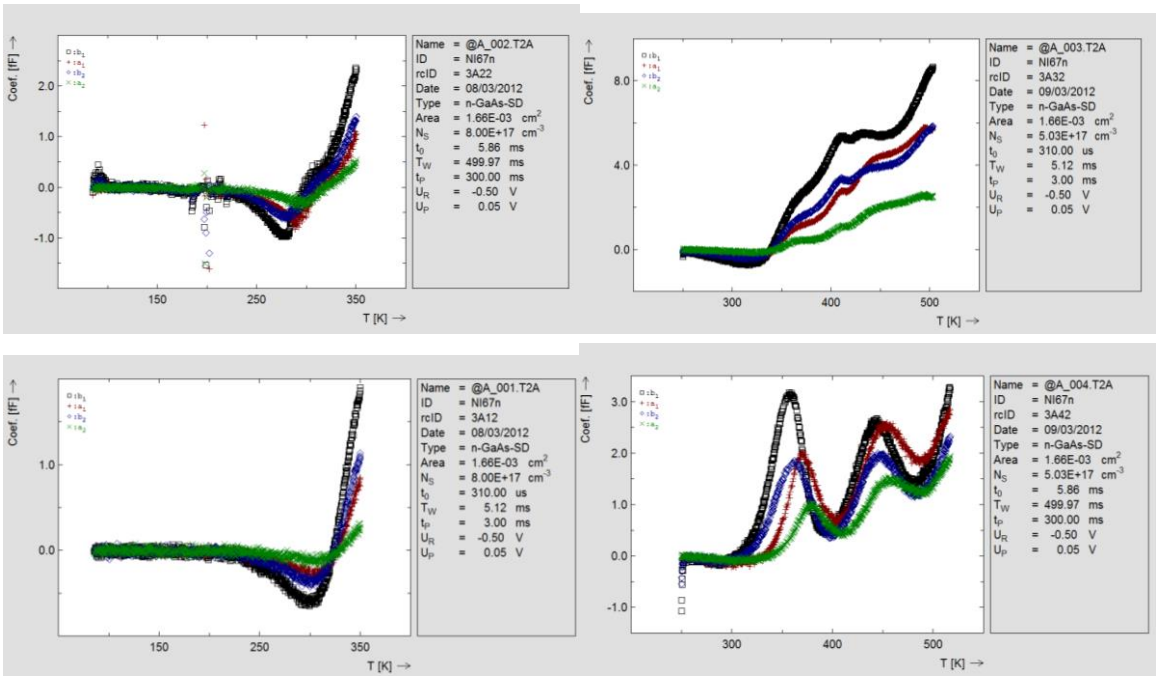

Coef. [fF]
T [K]
Name = @A_004.T2A
ID = NI66n
rcID = 3A42
Date = 07/03/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 4.47E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V


Coef. [fF]
T [K]
Name = @A_002.T2A
ID = NI66n
rcID = 3A22
Date = 06/03/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 5.46E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V

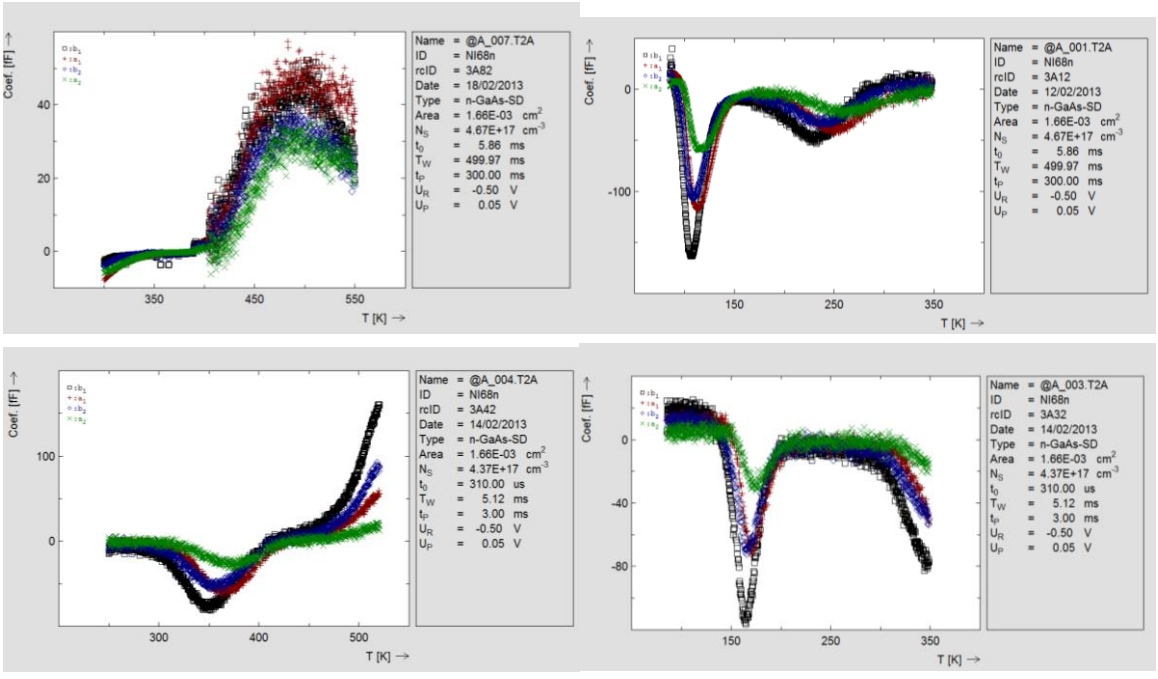

Coef. [fF]
T [K]
Name = @A_003.T2A
ID = NI66n
rcID = 3A32
Date = 06/03/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 4.72E+17 cm⁻³
t_0 = 310.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V


Coef. [aF]
T [K]
Name = @A_001.T2A
ID = NI66n
rcID = 3A12
Date = 01/03/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 5.33E+17 cm⁻³
t_0 = 310.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V

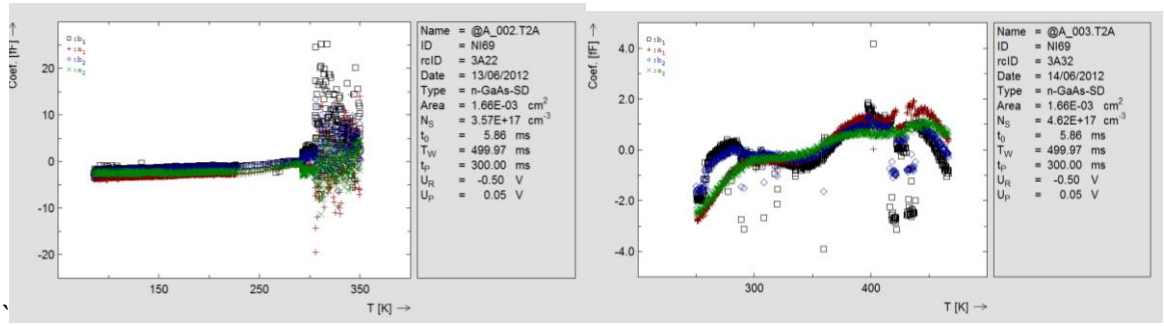
NI67n

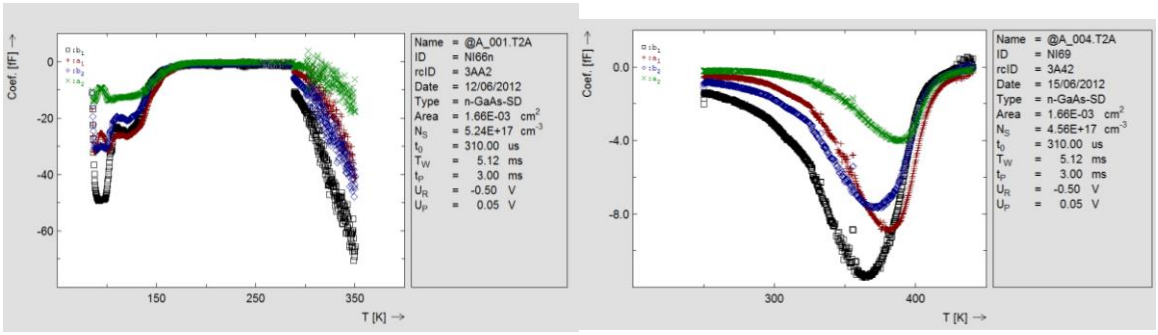

Coef. [fF] →
T [K] →
Name = @A_002.T2A
ID = NI67n
rcID = 3A22
Date = 08/03/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 8.00E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V
Name = @A_003.T2A
ID = NI67n
rcID = 3A32
Date = 09/03/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 5.03E+17 cm⁻³
t_0 = 310.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V
Name = @A_001.T2A
ID = NI67n
rcID = 3A12
Date = 08/03/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 8.00E+17 cm⁻³
t_0 = 310.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V
Name = @A_004.T2A
ID = NI67n
rcID = 3A42
Date = 09/03/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 5.03E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V

NI68n

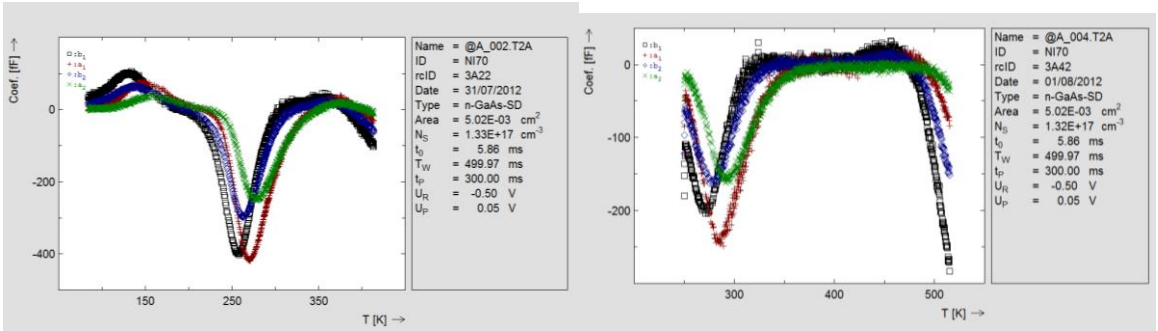

Coef. [fF] →
T [K] →
Name = @A_007.T2A
ID = NI68n
rcID = 3A82
Date = 18/02/2013
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 4.67E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V
Name = @A_001.T2A
ID = NI68n
rcID = 3A12
Date = 12/02/2013
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 4.67E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V
Name = @A_004.T2A
ID = NI68n
rcID = 3A42
Date = 14/02/2013
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 4.37E+17 cm⁻³
t_0 = 310.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V
Name = @A_003.T2A
ID = NI68n
rcID = 3A32
Date = 14/02/2013
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 4.37E+17 cm⁻³
t_0 = 310.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V

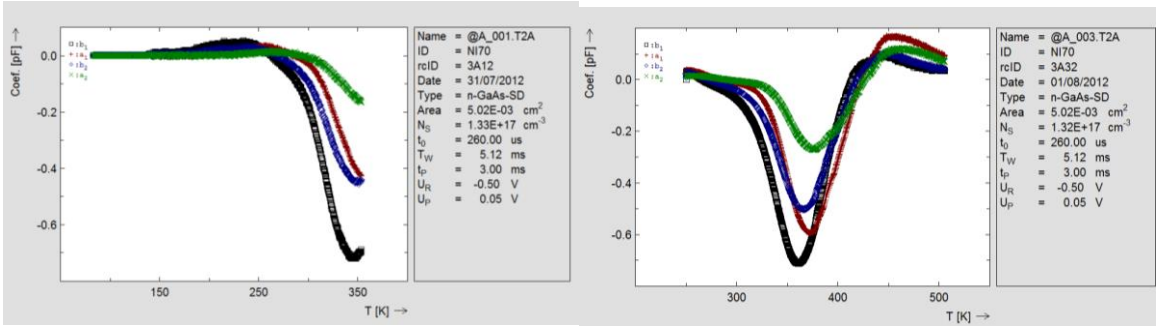
NI69n


Coef. [fF] →
T [K] →
Name = @A_002.T2A
ID = NI69
rcID = 3A22
Date = 13/06/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 3.57E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V
Name = @A_003.T2A
ID = NI69
rcID = 3A32
Date = 14/06/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 4.62E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V

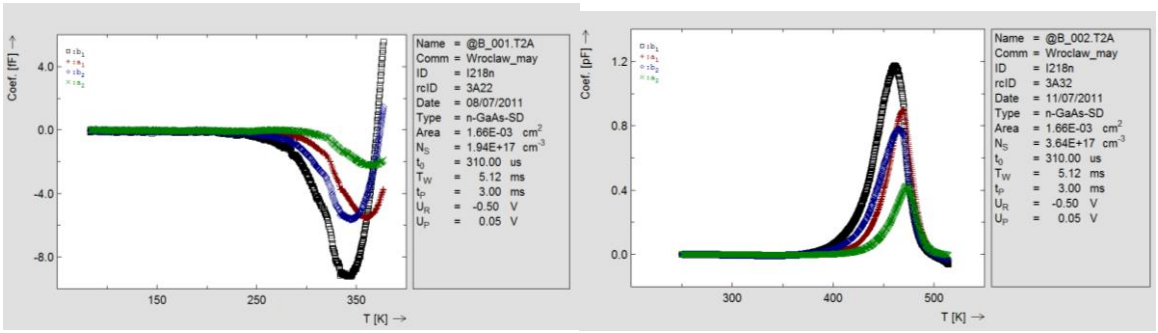

Coef. [fF] →
T [K] →
Name = @A_001.T2A
ID = NI66n
rcID = 3AA2
Date = 12/06/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 5.24E+17 cm⁻³
t_0 = 310.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V
Name = @A_004.T2A
ID = NI69
rcID = 3A42
Date = 15/06/2012
Type = n-GaAs-SD
Area = 1.66E-03 cm²
N_S = 4.56E+17 cm⁻³
t_0 = 310.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V

NI70n


Coef. [fF] →
T [K] →
Name = @A_002.T2A
ID = NI70
rcID = 3A22
Date = 31/07/2012
Type = n-GaAs-SD
Area = 5.02E-03 cm²
N_S = 1.33E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V
Name = @A_004.T2A
ID = NI70
rcID = 3A42
Date = 01/08/2012
Type = n-GaAs-SD
Area = 5.02E-03 cm²
N_S = 1.32E+17 cm⁻³
t_0 = 5.86 ms
T_W = 499.97 ms
t_P = 300.00 ms
U_R = -0.50 V
U_P = 0.05 V


Coef. [pF] →
T [K] →
Name = @A_001.T2A
ID = NI70
rcID = 3A12
Date = 31/07/2012
Type = n-GaAs-SD
Area = 5.02E-03 cm²
N_S = 1.33E+17 cm⁻³
t_0 = 260.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V
Name = @A_003.T2A
ID = NI70
rcID = 3A32
Date = 01/08/2012
Type = n-GaAs-SD
Area = 5.02E-03 cm²
N_S = 1.32E+17 cm⁻³
t_0 = 260.00 us
T_W = 5.12 ms
t_P = 3.00 ms
U_R = -0.50 V
U_P = 0.05 V

I218n


Coef. [fF] →
4.0
0.0
-4.0
-8.0
150
250
350
T [K] →
Name = @B_001.T2A
Comm = Wroclaw_may
ID = I218n
rcID = 3A22
Date = 08/07/2011
Type = n-GaAs-SD
Area = 1.66E-03 cm2
NS = 1.94E+17 cm-3
t0 = 310.00 us
TW = 5.12 ms
tP = 3.00 ms
UR = -0.50 V
UP = 0.05 V
Coef. [pF] →
1.2
0.8
0.4
0.0
300
400
500
T [K] →
Name = @B_002.T2A
Comm = Wroclaw_may
ID = I218n
rcID = 3A32
Date = 11/07/2011
Type = n-GaAs-SD
Area = 1.66E-03 cm2
NS = 3.64E+17 cm-3
t0 = 310.00 us
TW = 5.12 ms
tP = 3.00 ms
UR = -0.50 V
UP = 0.05 V