High **E**nergy **R**esolution **A**nalysis

Deep **L**evel **T**ransient **S**pectroscpy

FT 1230 HERA DLTS System

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What is DLTS

What is needed for DLTS measurements

How to analise the measurement results

DLTS evaluations of the FT1230 DLTS system

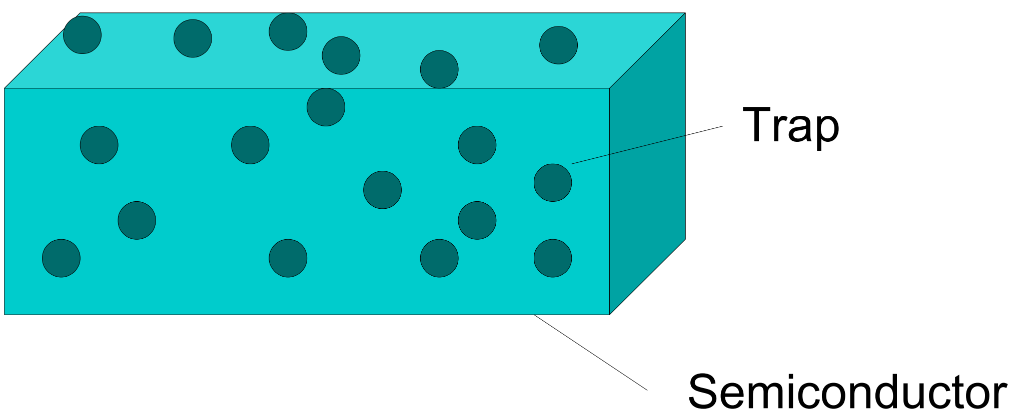
- Correlastion DLTS
- Fourier DLTS
- Laplace DLTS
- Deconvolution DLTS

Special measurement possiblities

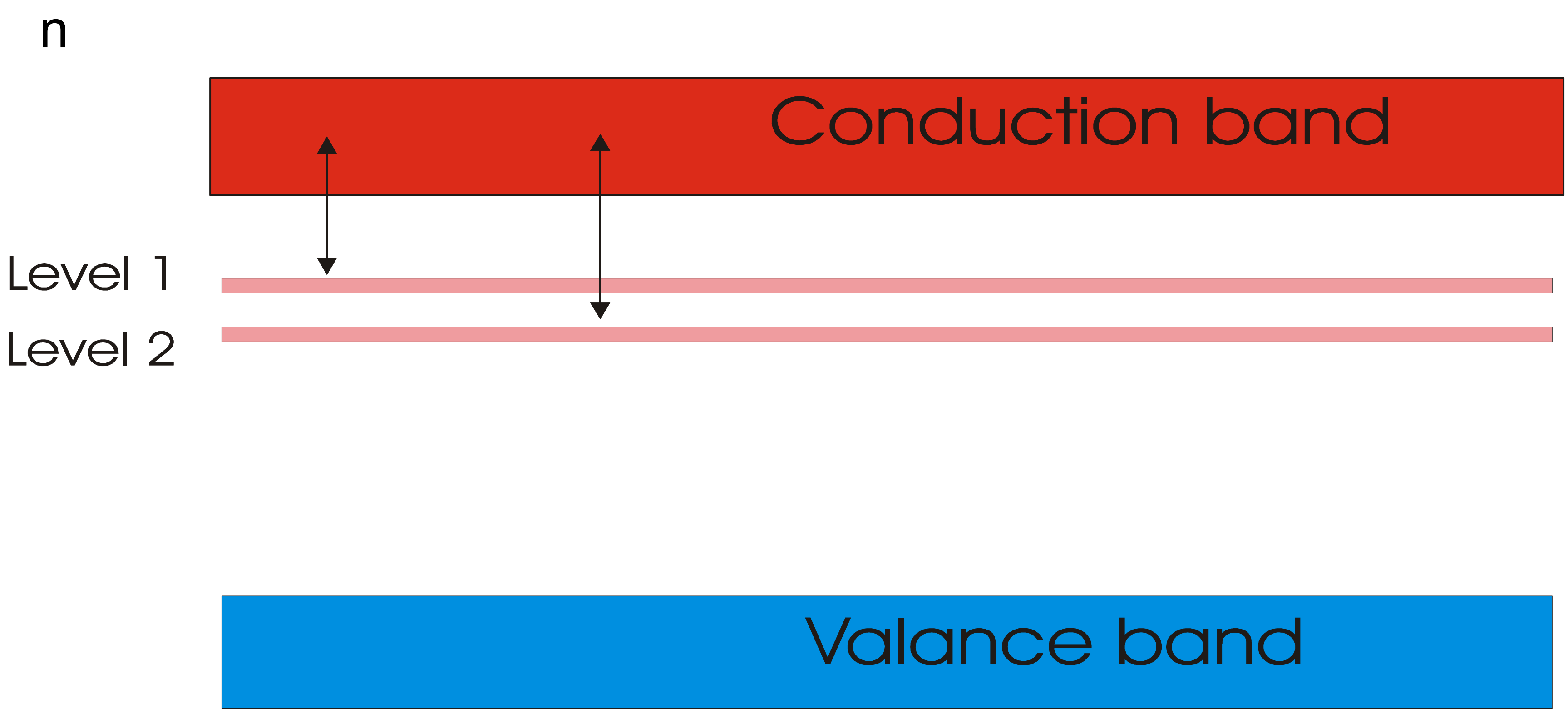
- Isothermarl timeconstant scan
- Direct capture measurements

We are looking at a semiconductor crystal with electric active atoms so called traps.
These are what we want to analyse
We want to know:

1. The total no. Traps, the trap concentration
2. The kind of the trap material,
3. The trap distribution



Band structure



1 level ; n>> p ; n>> N

$n1 = NT * \exp(-t/\tau)$ $\tau = \sigma_T \mathbf{X_T} \exp(-\Delta H_T / kT)$,

$Ln(\tau) = \ln(\sigma_T * X_T) - \Delta H_T / kT$,

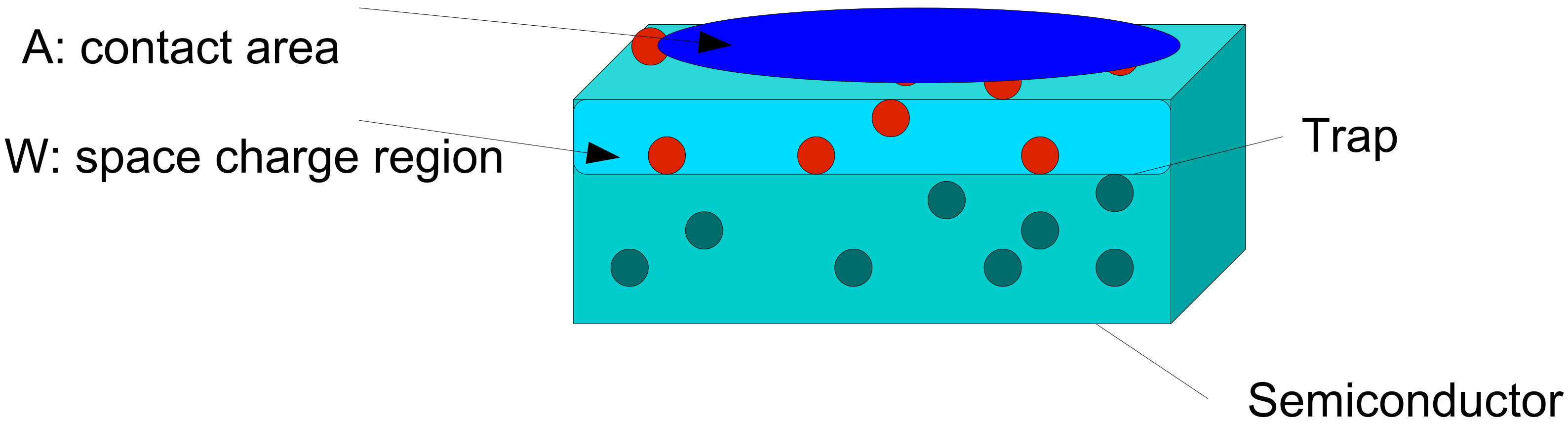
Arrhenius Plot: $Ln(\tau)$ vers. $1/T$, slope: ΔH_T , intercept: $\sigma_T * X_T$

1. n has to be detected. Possibly the capacitance of a diode or by the leakage current of a diode

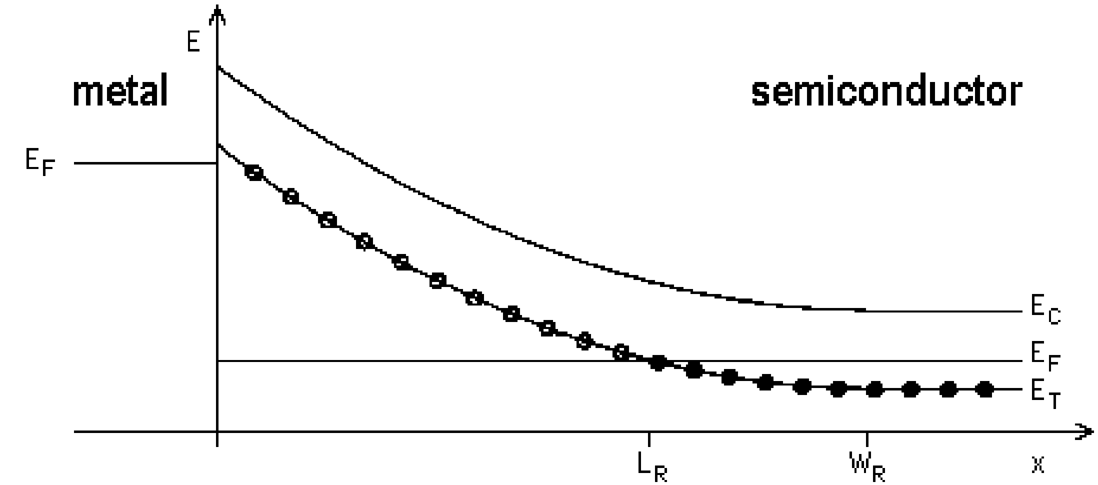
2. The change of the free electron concentration with time has to be detected to get the trap electron emission concentration and timeconstant

3. DC(t) has to be measured as a function of the temperature to get the Materal parameters Energy and capture cross section.

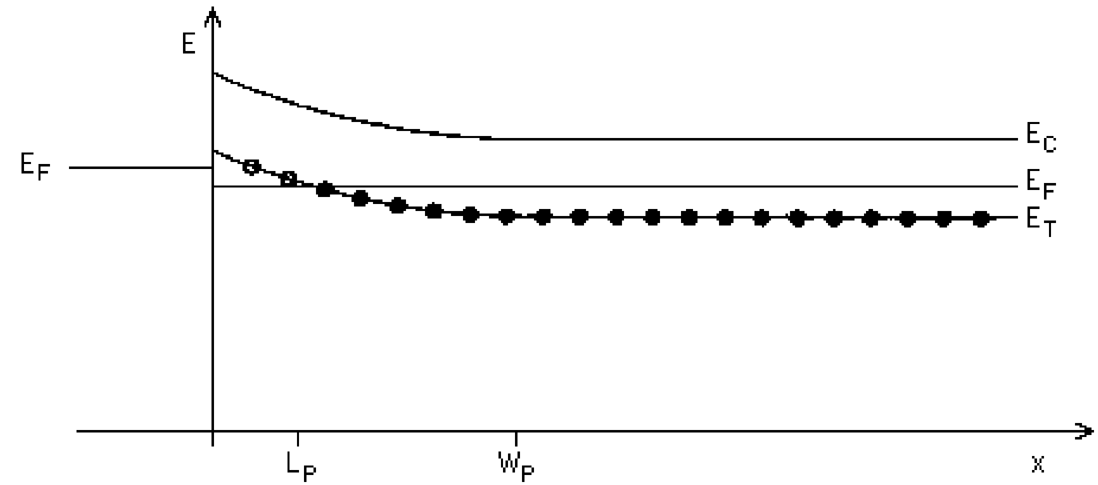
$C = \varepsilon A / W$



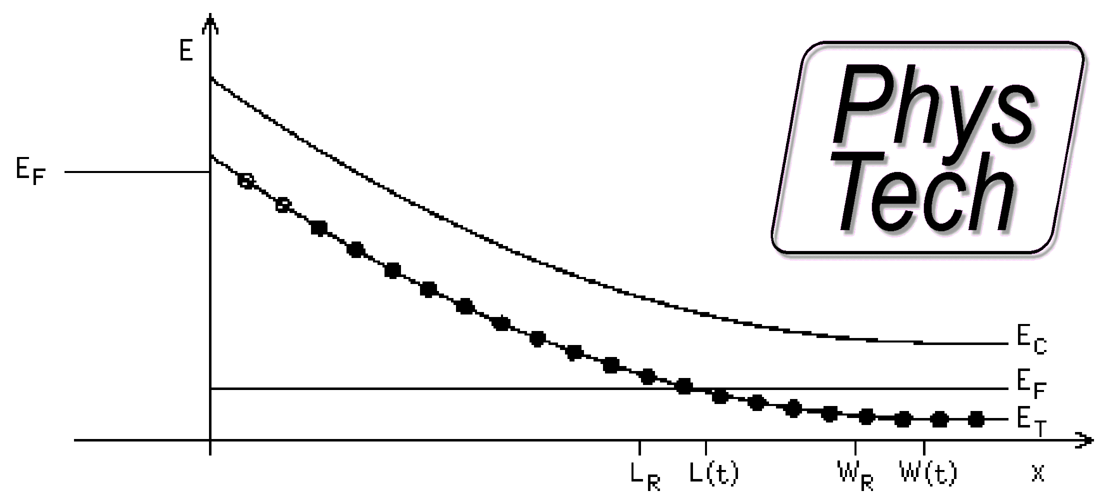
A Schottky diode (Metall-Semiconductor Contact) with a large reverse bias voltage



This diode with a small (nearly 0V) Reverse bias voltage



This diode back to the large reverse bias voltage



W, Lp,Lr,
needed for calculation the volume

$$\frac{C_0 - C(t)}{C_0} = \frac{N_T}{2 * N_S} * \frac{L_R^2 - L_P^2}{W_R^2} * \exp\left(-\frac{t}{tau_e}\right)$$

Approximation:

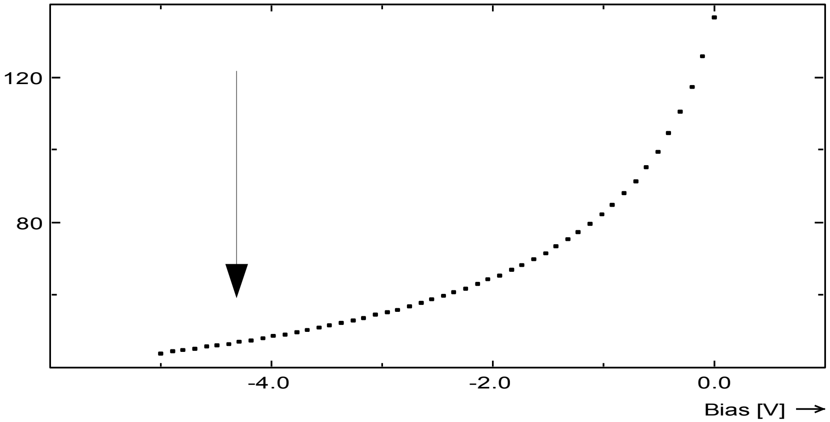
L_P --> 0 | Pulse --> 0 V

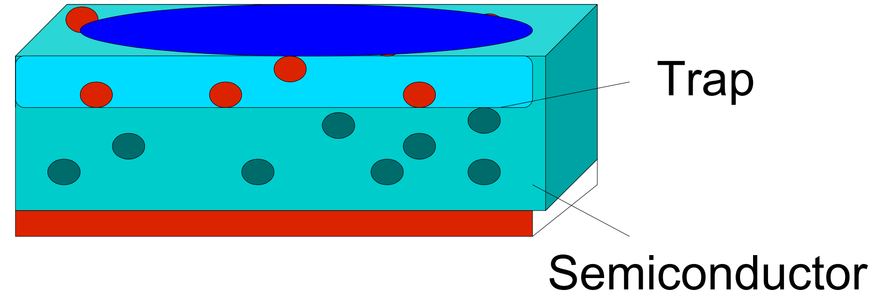
L_R --> W_R | high Bias

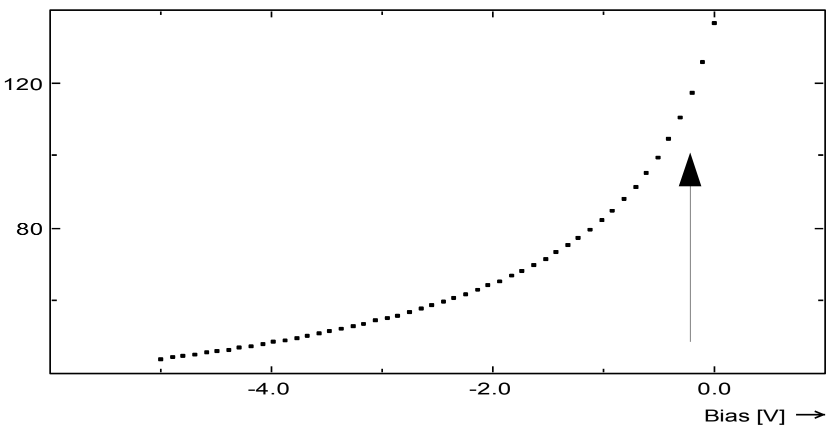
--->

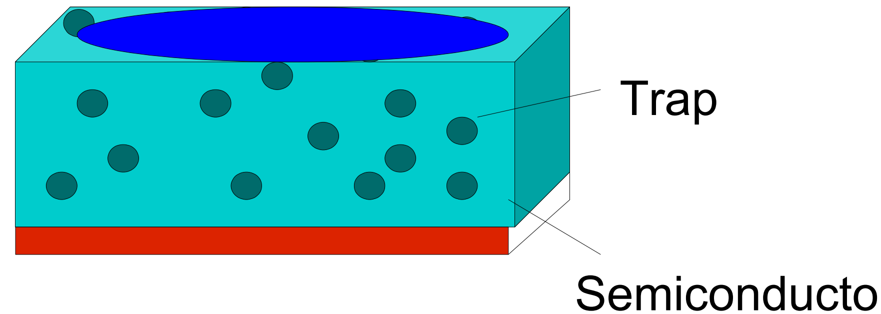
$$\frac{C_0 - C(t)}{C_0} = \frac{N_T}{2 * N_S} * \exp\left(-\frac{t}{tau_e}\right)$$

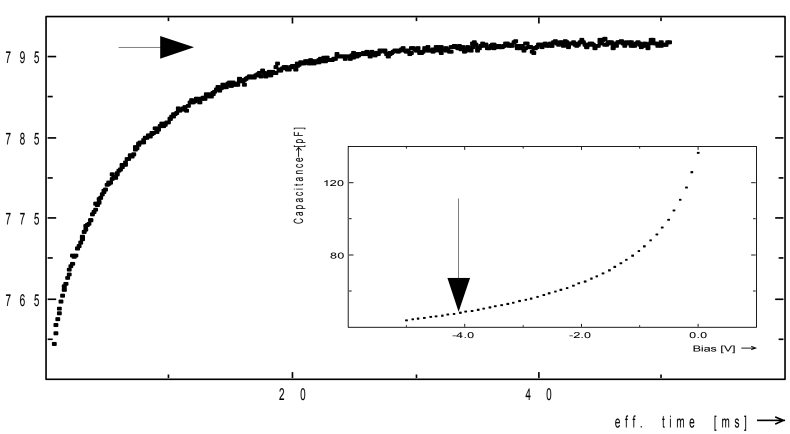
$$C_0 = \frac{eps * A}{W_R}$$

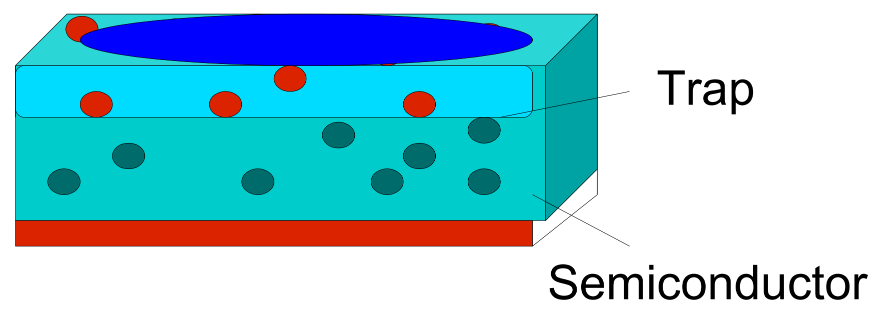

120
80
-4.0
-2.0
0.0
Bias [V] →


Trap
Semiconductor


120
80
-4.0
-2.0
0.0
Bias [V] →


Trap
Semiconductor


795
785
775
765
20
40
eff. time [ms] →
Capacitance→[pF]
120
80
-4.0
-2.0
0.0
Bias [V] →


Trap
Semiconductor

Needs

Sensitive capacitance meter (compensation mode)

Timedependant data acquisition

Variable sample temperature

Timeconstant evaluation software

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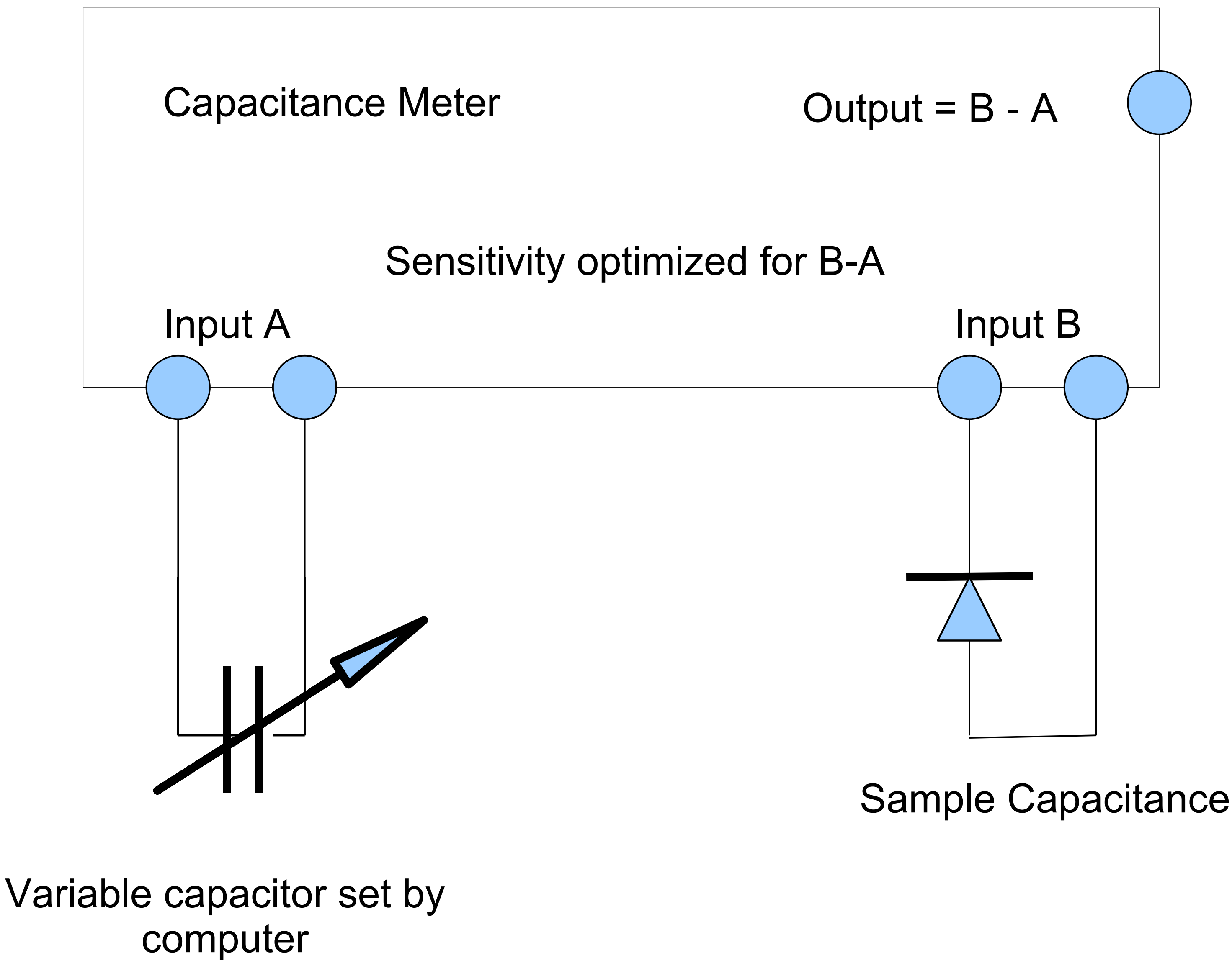
Phystech Sensitive capacitance meter (compensation mode)



Specifications:

Phystech Capacitancemeter

with automatic reverse bias capacitance compensation and automatic range setting

Compensation range	: **1 pF - 3300 pF**
HF - frequency	: 1 MHz
HF signal	: **20mV, 100mV**
ranges	: **5 pF - 2000 pF (4) (100mV)**
	(5000 pF)

Current measurement amplifier with automatic range setting
max. measurement current : 15 mA

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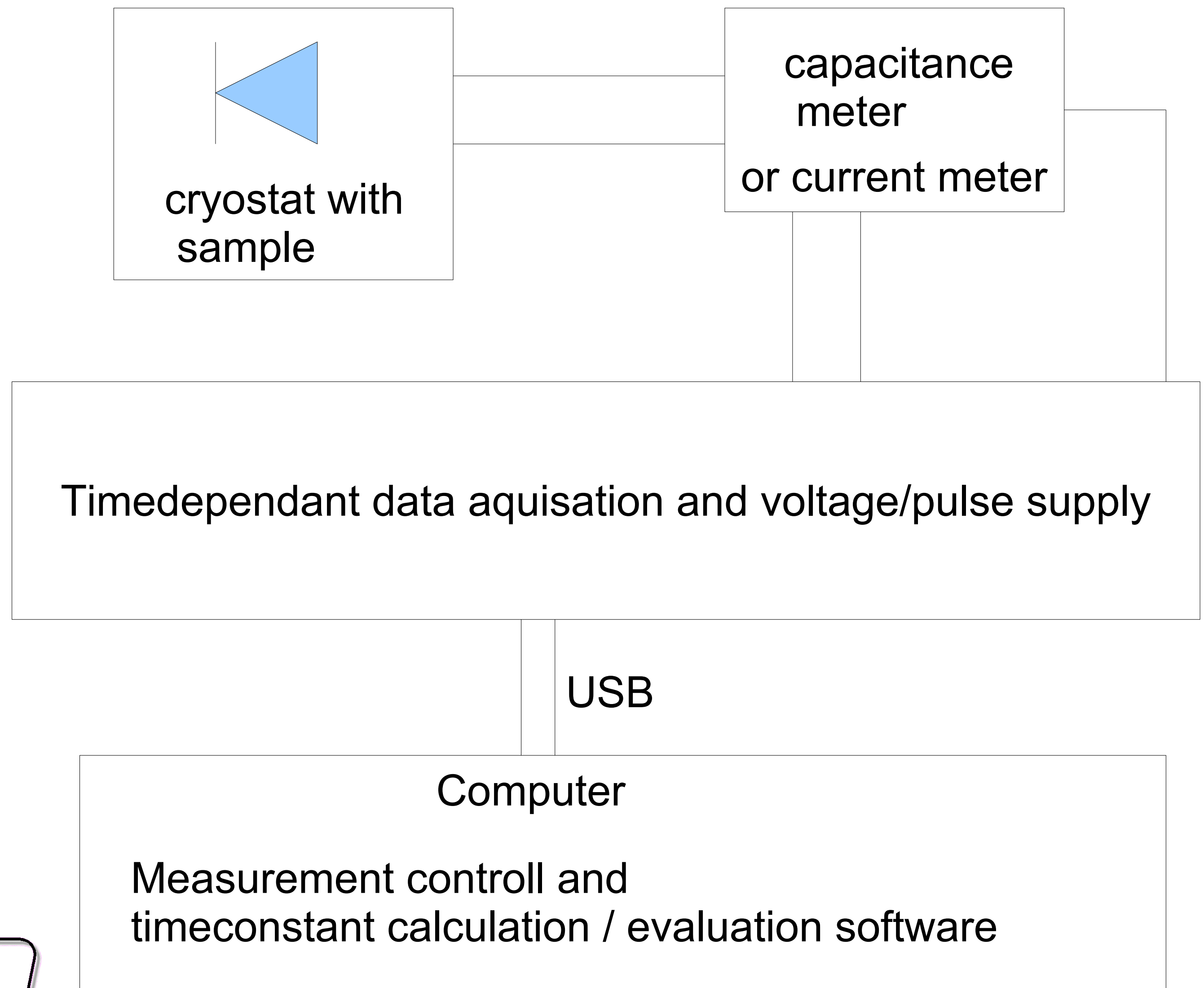
HERA DLTS FT1230



Specifications:

Bias-/Pulsvoltage source

voltage range	: -/+ 20V (optional +/- 100V)
voltage setting resolution	: 0.3 mV (1.5mV with 100V option)
internal shortest Pulswidth	: 10 micro second (1V/micros)
external fast pulse generator	**: 20 ns** (+/- 10V)
longest Pulswidth	**: > 100h**

optical pulse trigger available at the option port for TTL modulation inputs of Laser power supplies

Computer controlled Amplifier with automatic gain setting

gain range	: **1 - 100 000**

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Specifications:

Digital transient recorder
with variable oversampling technic

max. samplings per transient	: **2E6 (buffered), 2E9 (streaming)**
fastest sampling intervall	: **850 nano seconds**
shortest period width	: **27 micro seconds**
longest periodwidth	: **110 h**

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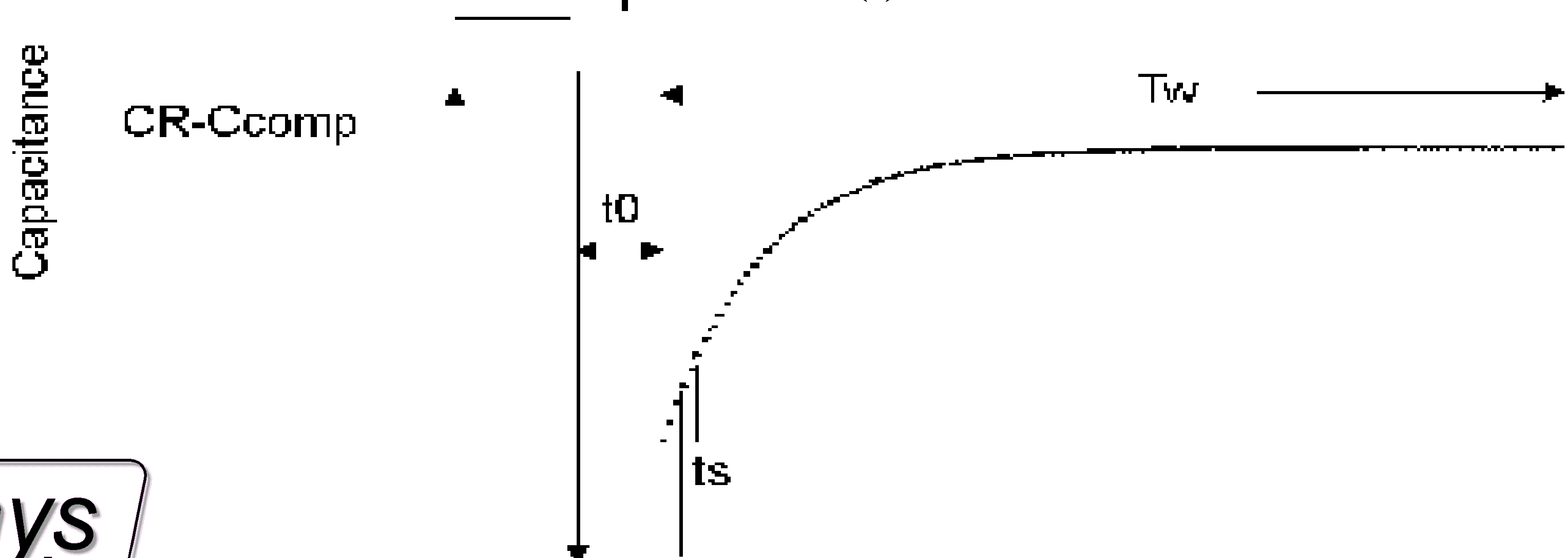
Timedependant measurement

Compensation: $C_0 = 0$

$$C(t) = C_0 + \Delta C * \exp(-t/\Pi)$$



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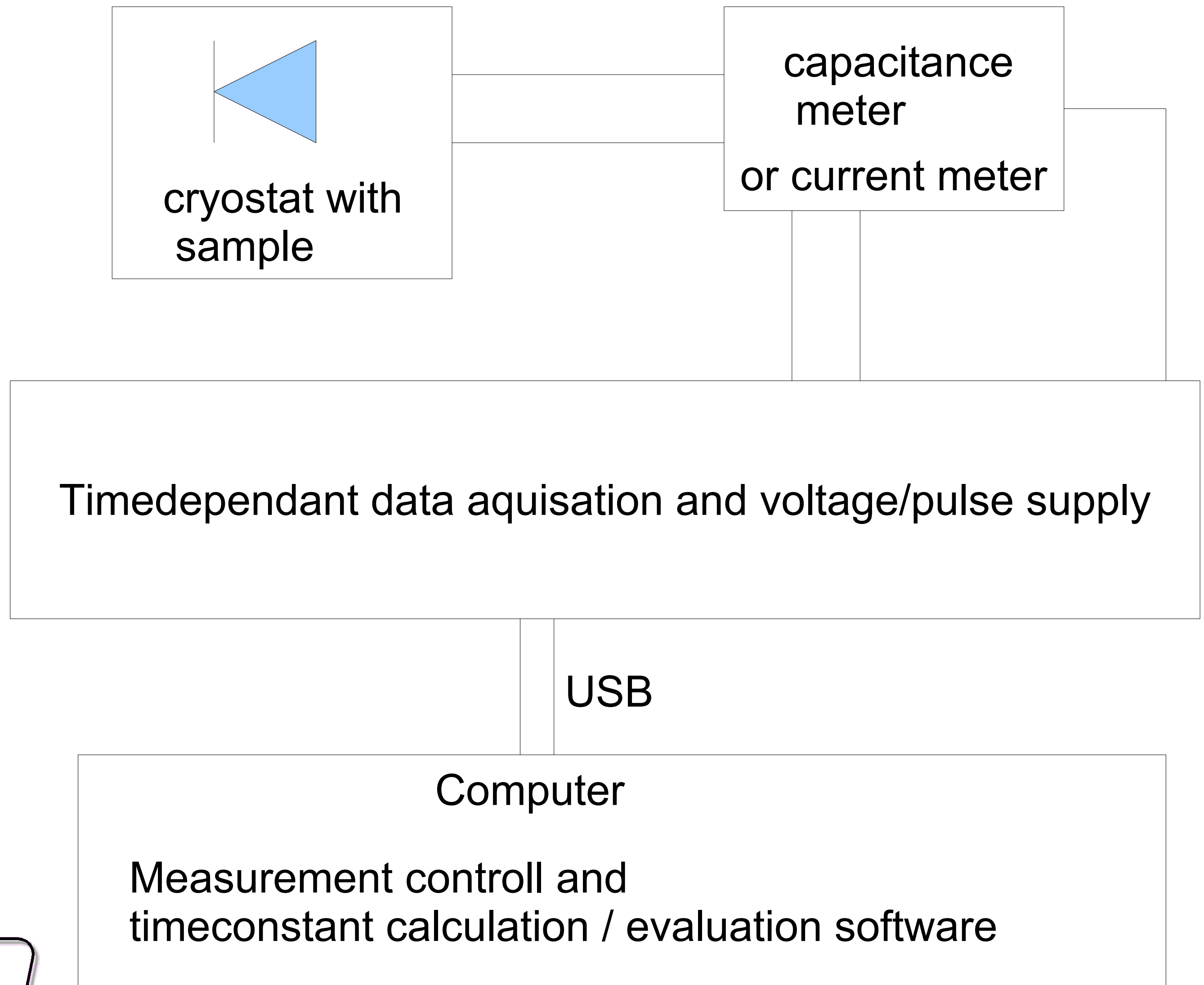
HERA DLTS FT1230



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Name = @A_004.T1A
ID = ID
Date = 30.03.2010
Type = n-Si
Area = 1.00E-02 cm²
Ns = 1.00E+14 cm⁻³
t0 = 117.19 ms
TW = 10.00 s
tP = 100.00 us
UR = -5.00 V
UP = -0.50 V
300
200
100
0
140
180
220
260
T [K] →
acer
292.90K
305.00K
291.71K
0% Off

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0.0 V+spcl 13
KEYSIGHT
SETPOINT
ALL OFF
336 Temperature Controller
Phys Tech
FT-1030
HERA DLTS

FT 1230 HERA DLTS features

- C/V , I/V
- C-DLTS / Capacitance - DLTS
- I-DLTS / Current - DLTS
- CC-DLTS / Constant Cap. DLTS
- Laplace DLTS
- ITS (ICTS)
- MIS Analysis / Zerbst DLTS

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HERA-DLTS System FT 1230
available DLTS modes

• C-DLTS	(Capacitance DLTS)
• CC-DLTS	(Constant Capacitance DLTS , with CC option)
• I-DLTS	(Current DLTS)
• Q-DLTS	(Charge -DLTS)
• FET DLTS	(3 term DLTS 2nd voltage source included)
• DD-DLTS	(Transient difference DLTS)
• ITS	(Isothermal Transient (C or I) Spectroscopy)
• O-DLTS, PICS	(Photon induced transient (C or I) spectroscopy
• Capture DLTS	(capturing transient measurement)
• Laplace-DLTS	(Logarithmic transient measurements and evaluat.)
• MIS - Nss DLTS	(Surface states density measurement and evaluations)
• MIS - Zerbst DLTS	(Minorier carrier generation / lifetime measurem.)
• C(V), I(V), C(t),I(t)	
• TSC und TSCAP	(Temperature Stimulated Current , ... Capacitance

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Phystech FT1230 HERA DLTS system	Other, Analog DLTS Systems
Uses 28 correlator functions	Only 1 correlator function used
Only **one** temperature scan for any Arrehnius plot necessary	For any 1 (or 2) data points in an Arrhenius plot a separate measured temperature scan is necessary.
Every transient measurement is independant of the next one. A temperature scan can be holded and a C/V,IV or period width scan can be added.	A parameter set can not be changed during a temeprature scan.
More than 18 different measurementfiles with different parametersets as reverse bias voltage, pulse voltage , pulse widths, pulse mode etc. can be measured in one temperature cycle.	Only one measurement parameter set can be measured in one temperature cycle. see above
After one temperature scan measurement all data for use of different DLTS analysis as correlation DLTS (28 correlators), Fourier DLTS, Laplace DLTS can be used. The results (Arrhenius plots) of it are mathematically independant and can be used for comparisoins..	Only correlation DLTS is is measured and can be evaluated.
C/V´s, I/V´s and C(t) can be measured during the temperature scan in one temperature cycle. The results can be used for Ns (T) correction.	The Lock-in measurement of DC can not interupted during the temperature cycle. A Ns(T) correction of the trapconcentration is not possible (from a measurement).

Phystech FT1230 HERA DLTS system	Other Analog DLTS Systems
The Constant Capacitance mode (CC-DLTS or V-DLTS) keeps also the reverse bias capacitance over the temperature (C(T) constant as well as the time dependant capacitance due to the emission process (C(t,T).	The CC-DLTS (if available) can only keep the capacitance constant during the emission process canstant. It can not change the reverse bias due to temperature dependant change of the capacitance.
Measurements with electrical pulses and with optical pulses can be done in the same temperature cycle.	Only one pulse mode in one temperature cycle is possible.
Due to the direct measurement of the emission also other emission processes can be observed and evaluated (MIS, Nss, Zerbst DLTS etc.).	Due to the fact, that only the correlated signal is measured other timedependances as exponential ones can not be analysed.
Overlapping emission processes can be separated by using the deconvolution of the DC correlator signals or with inverse Laplace transformation of the emission transient.	Overlapping levels can only be separated by asymetric Gauss fit.

Measurement options

1. Voltage dependant measurements
   Capacitance versus voltage
   Current versus voltage

2. Timedependant measurements
   Capacitance versus time
   Current versus time

Parameters:
Temperature, no. of data points, low/high limits, resolution, sensitivity, electrical / optical pulse values

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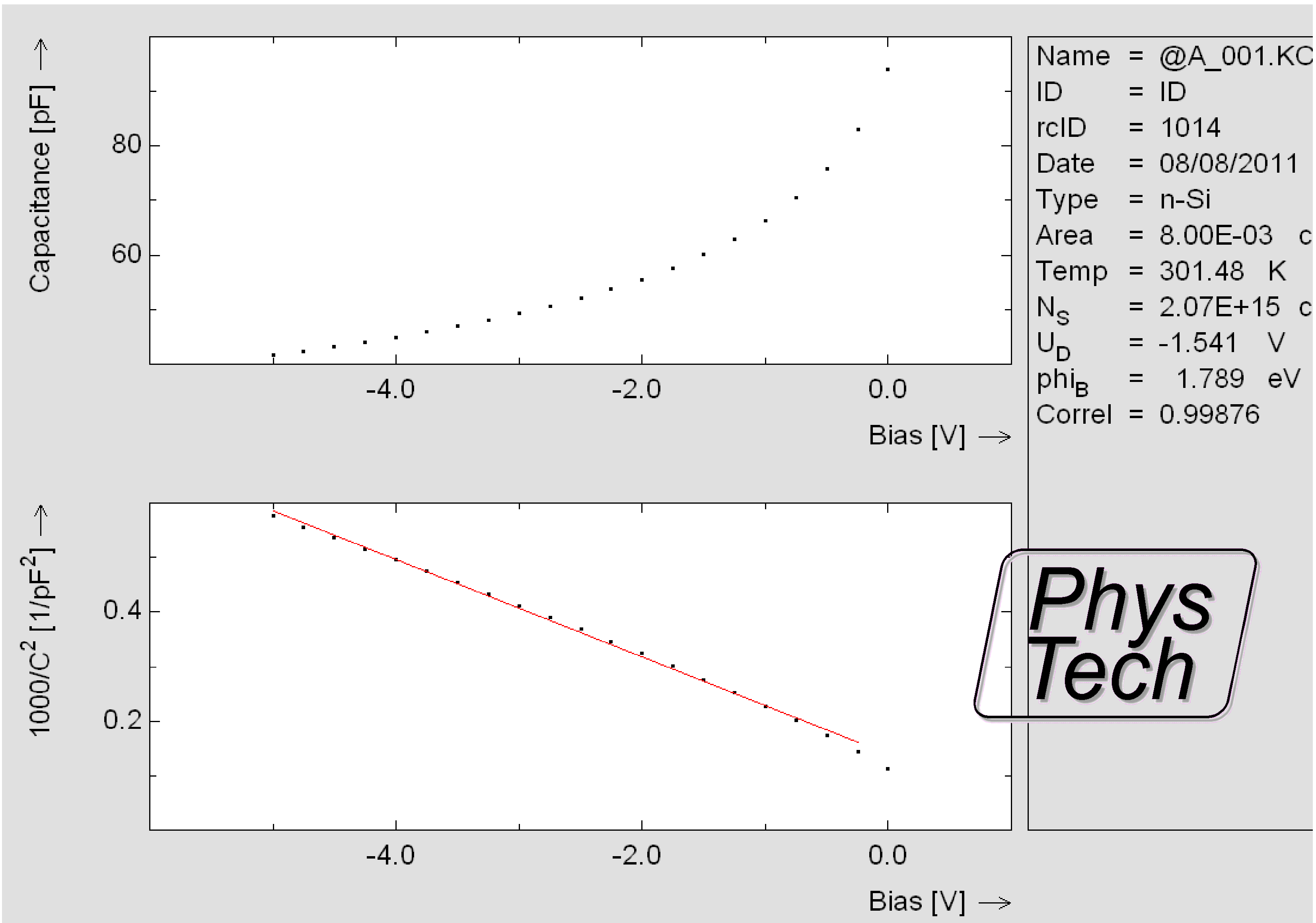
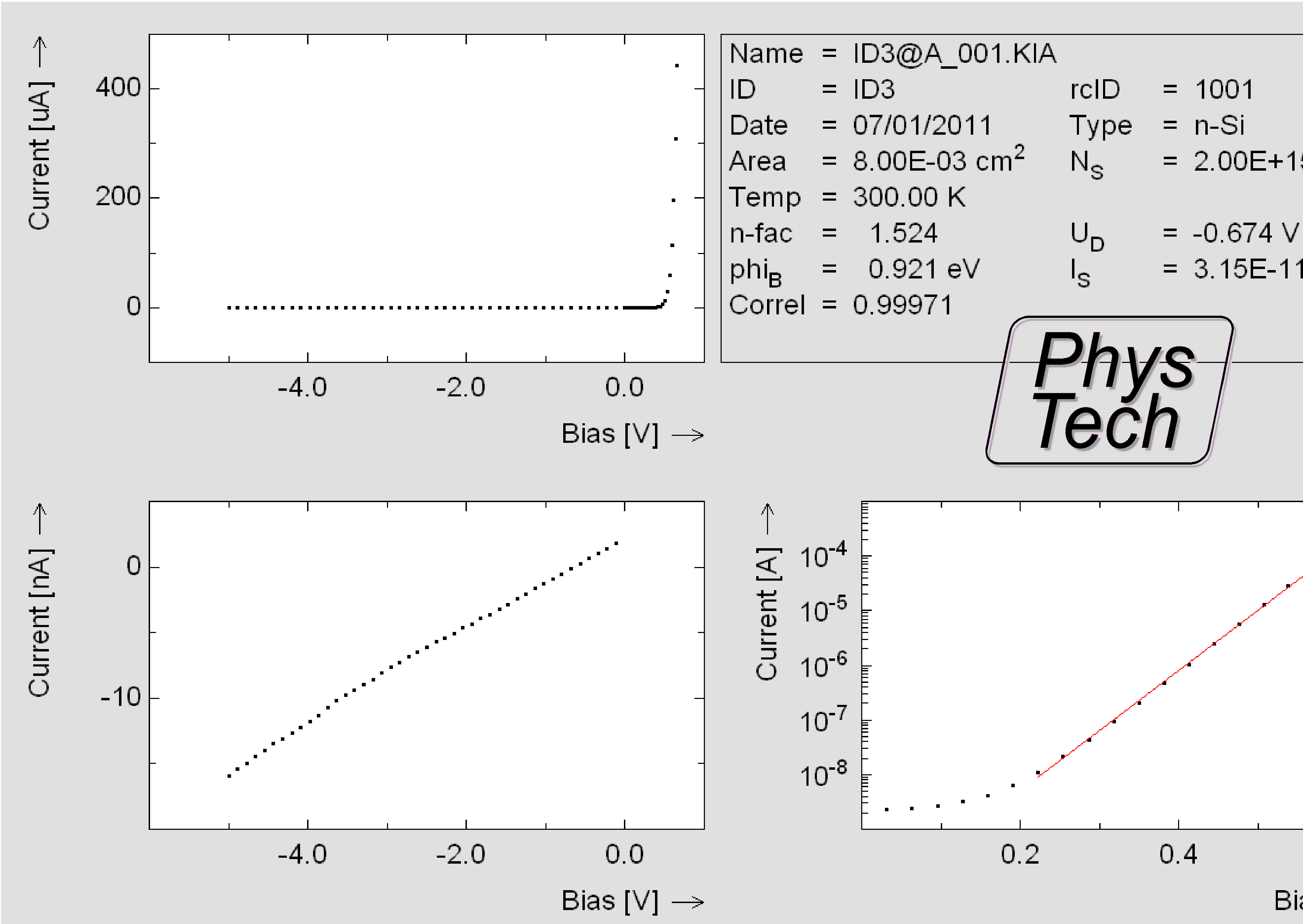
1. Voltage dependant measurements




Current [uA] →
400
200
0
-4.0
-2.0
0.0
Bias [V] →
Name = ID3@A_001.KIA
ID = ID3
rcID = 1001
Date = 07/01/2011
Type = n-Si
Area = 8.00E-03 cm2
NS = 2.00E+15
Temp = 300.00 K
n-fac = 1.524
UD = -0.674 V
phiB = 0.921 eV
IS = 3.15E-11
Correl = 0.99971
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Current [nA] →
0
-10
-4.0
-2.0
0.0
Bias [V] →
Current [A] →
10-4
10-5
10-6
10-7
10-8
0.2
0.4
Bia

Timedependant measurements

Capacitance or current measurement as function of time after an electrical or optical filling of the traps.

HERA DLTS Evaluations

Correlation DLTS (Tempscan, Periodwidthscan, Frequencyscan)

Fourier DLTS (Direct Transient Analysis)

Laplace DLTS (Direct Transient Analysis)

Deconvolution HERA DLTS (Tempscan , Periodwidthscan)

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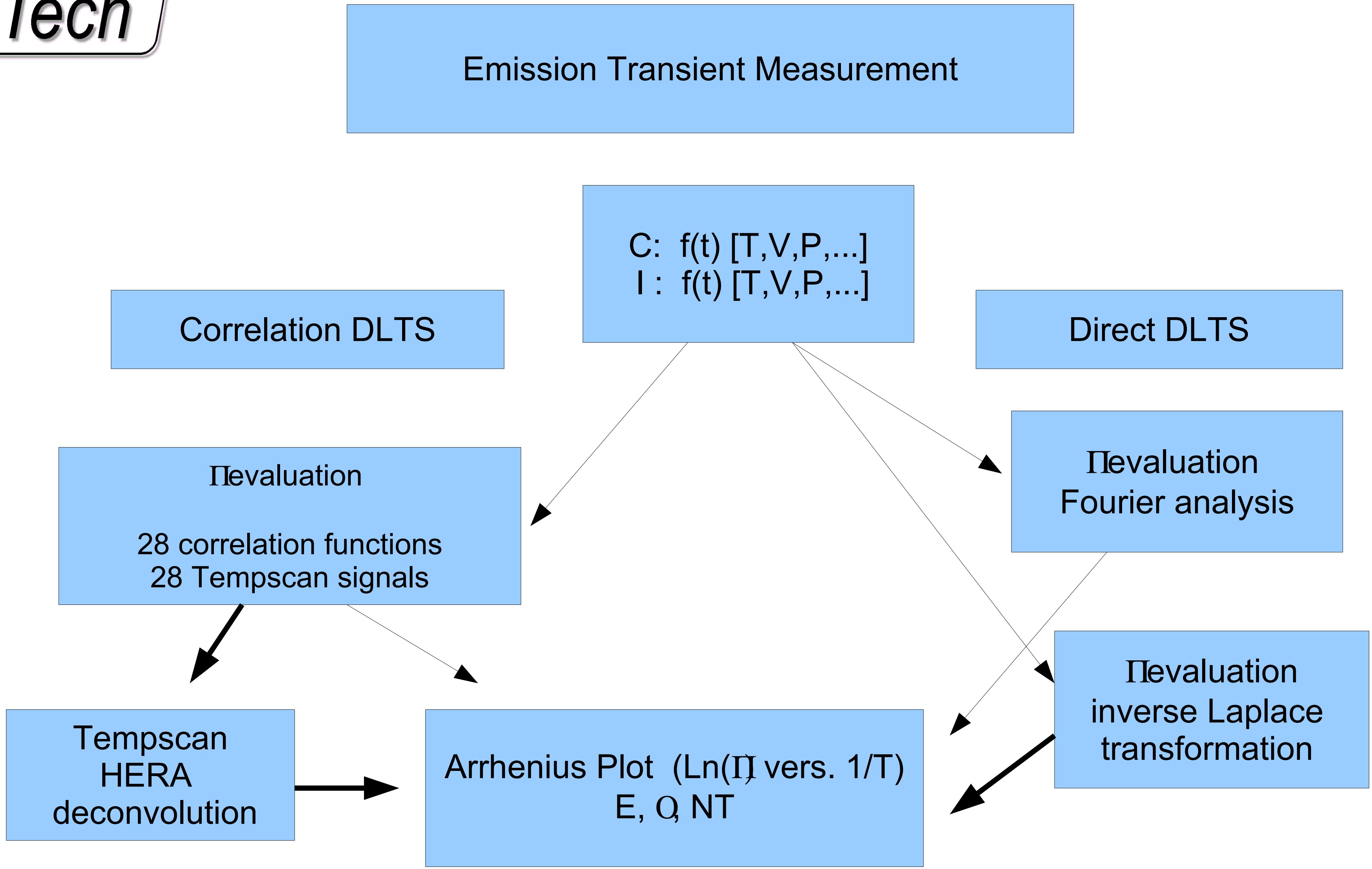
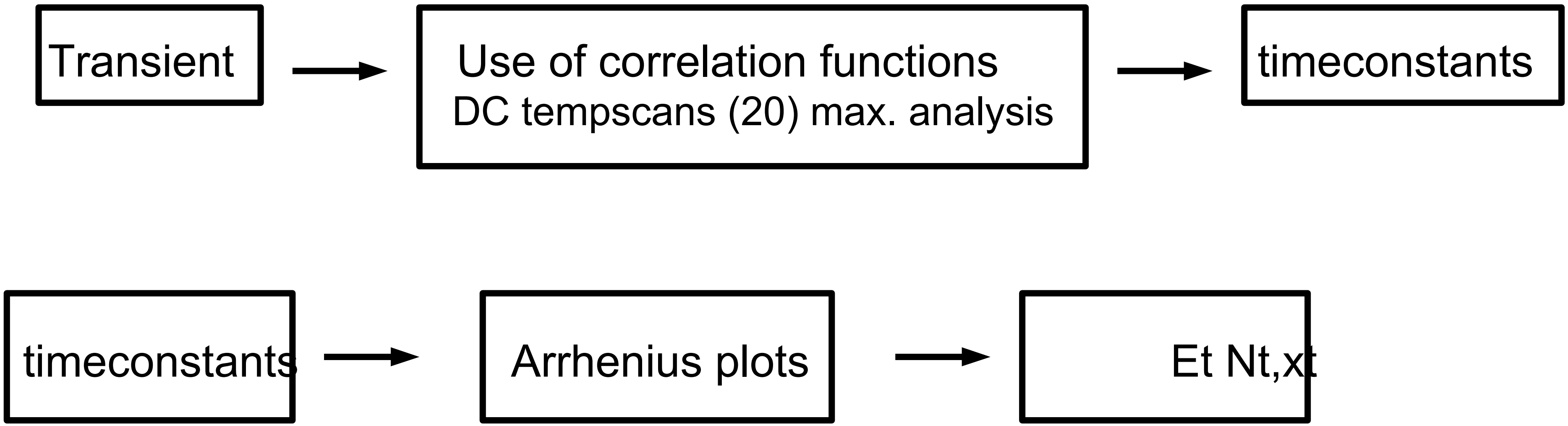


Emission Transient Measurement
C: f(t) [T,V,P,...]
I : f(t) [T,V,P,...]
Correlation DLTS
Direct DLTS
Πevaluation
28 correlation functions
28 Tempscan signals
Πevaluation
Fourier analysis
Πevaluation
inverse Laplace
transformation
Tempscan
HERA
deconvolution
Arrhenius Plot (Ln(Π) vers. 1/T)
E, Ο, NT

Correlation DLTS (DC -Tempscan Analysis)



HERA DLTS Evaluations

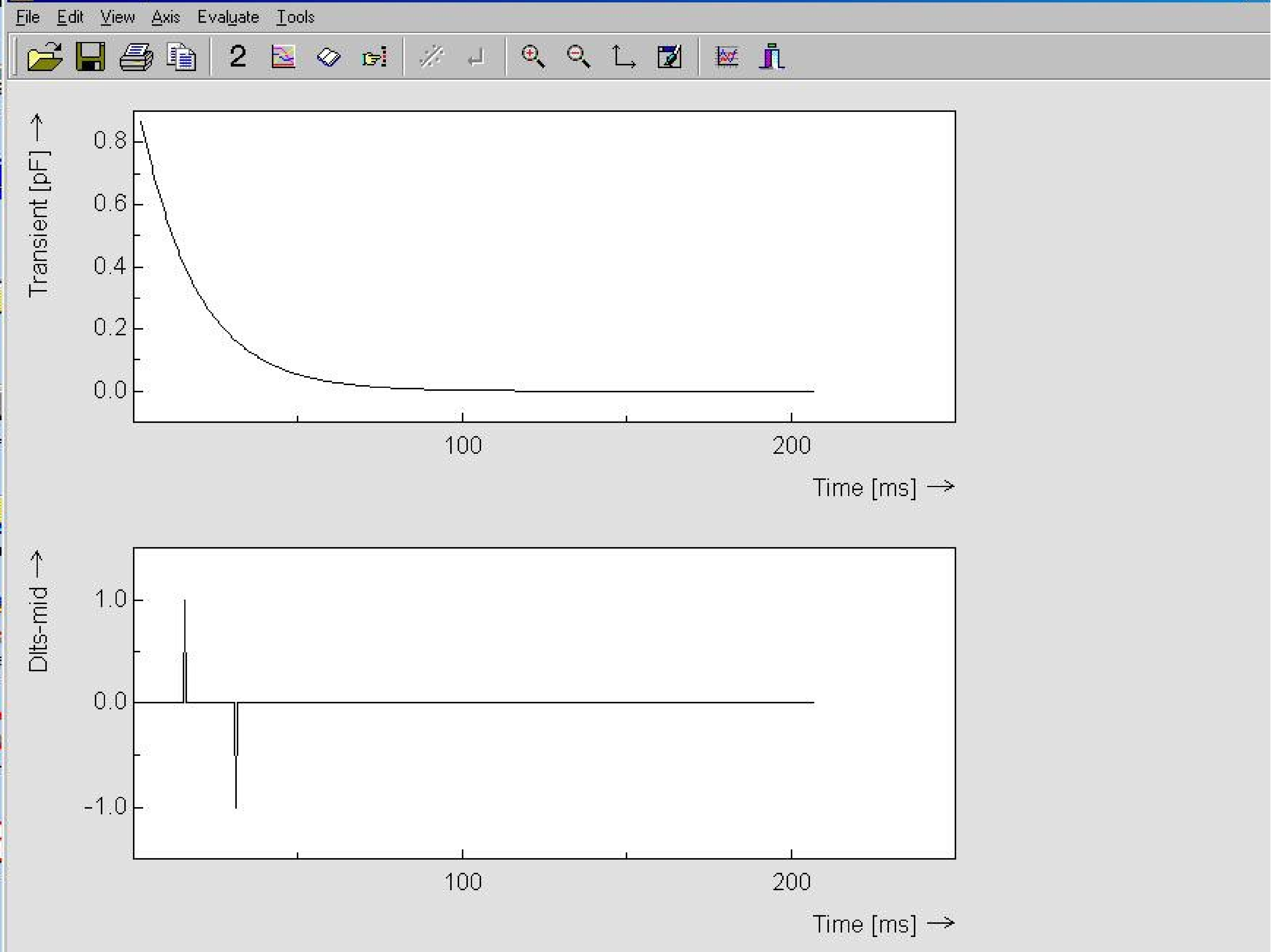
Correlation DLTS (Tempscan, Periodwidthscan, Frequencyscan)

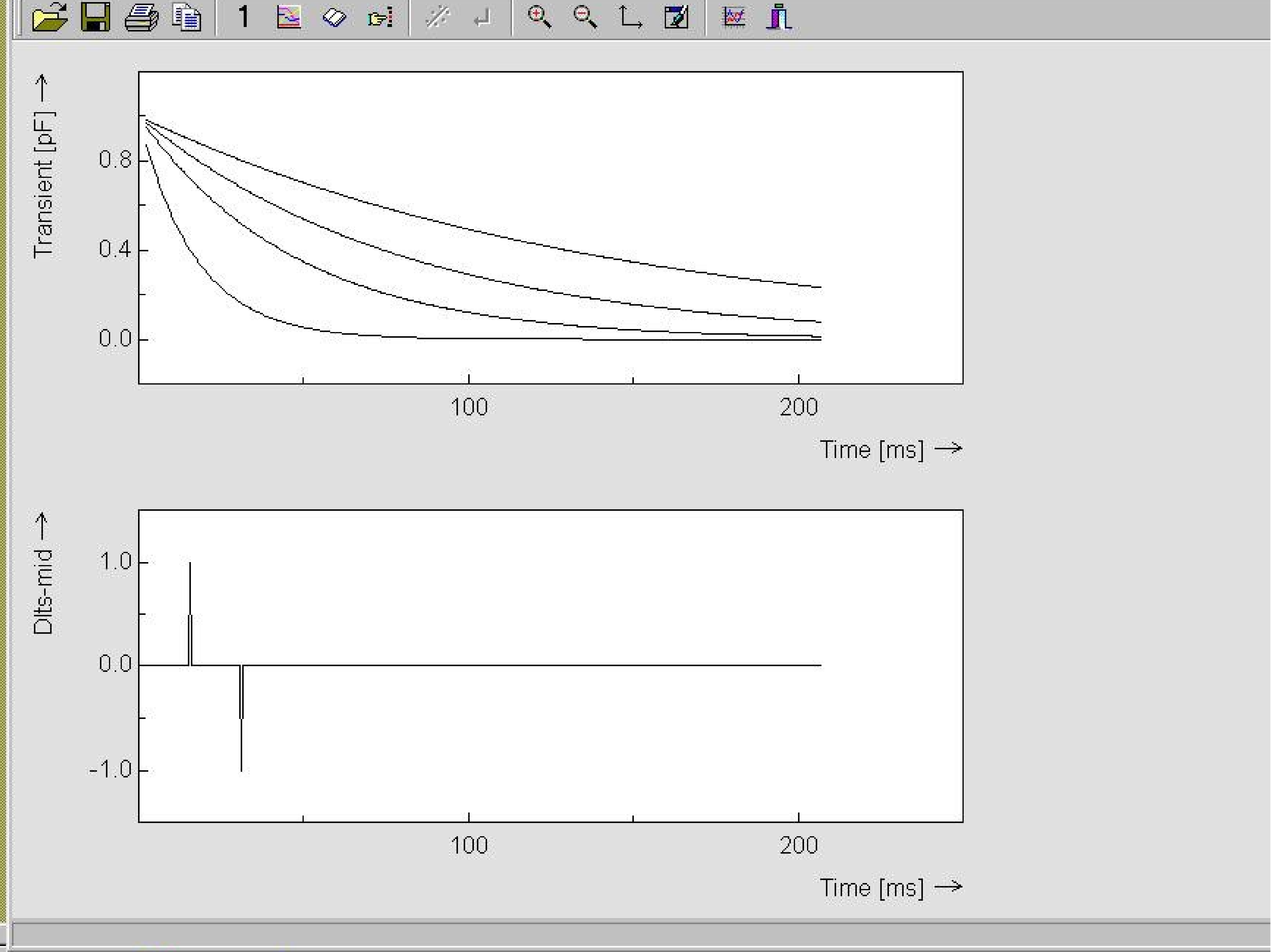
Fourier DLTS (Direct Transient Analysis)

Laplace DLTS (Direct Transient Analysis)

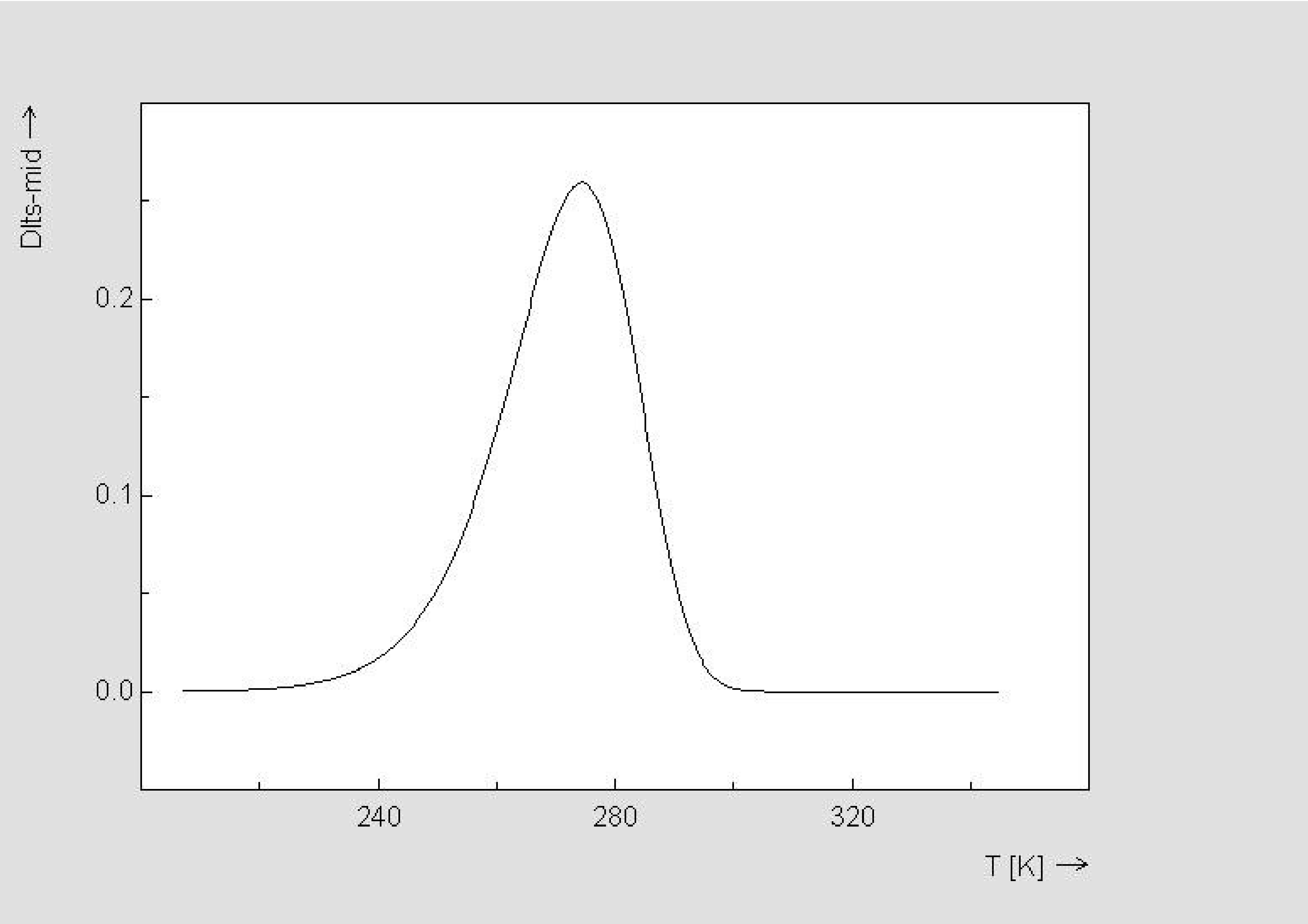
Deconvolution HERA DLTS (Tempscan , Periodwidthscan)

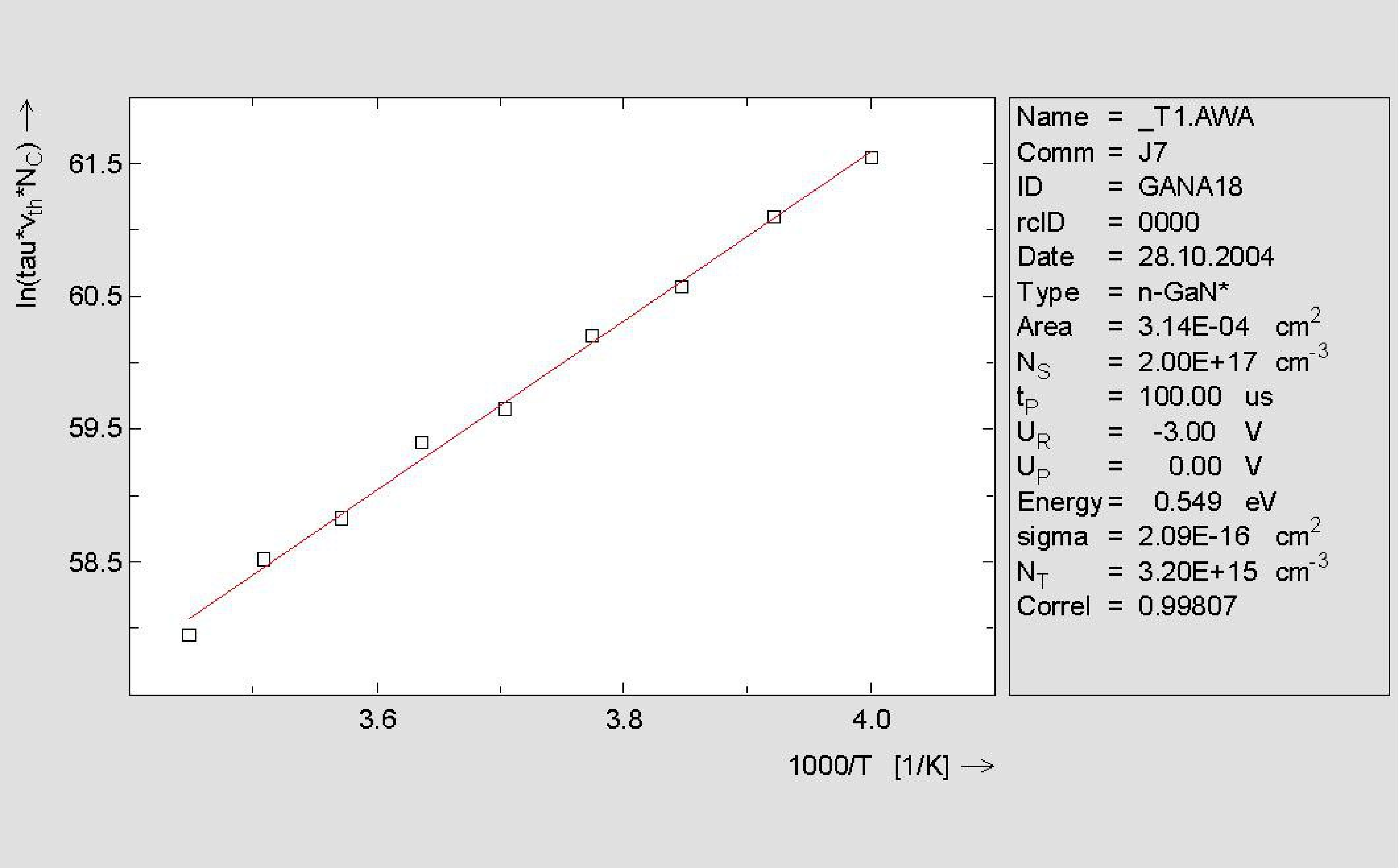
PhysTech


File Edit View Axis Evaluate Tools
2
Transient [pF]
0.8
0.6
0.4
0.2
0.0
100
200
Time [ms]
Dlts-mid
1.0
0.0
-1.0
100
200
Time [ms]



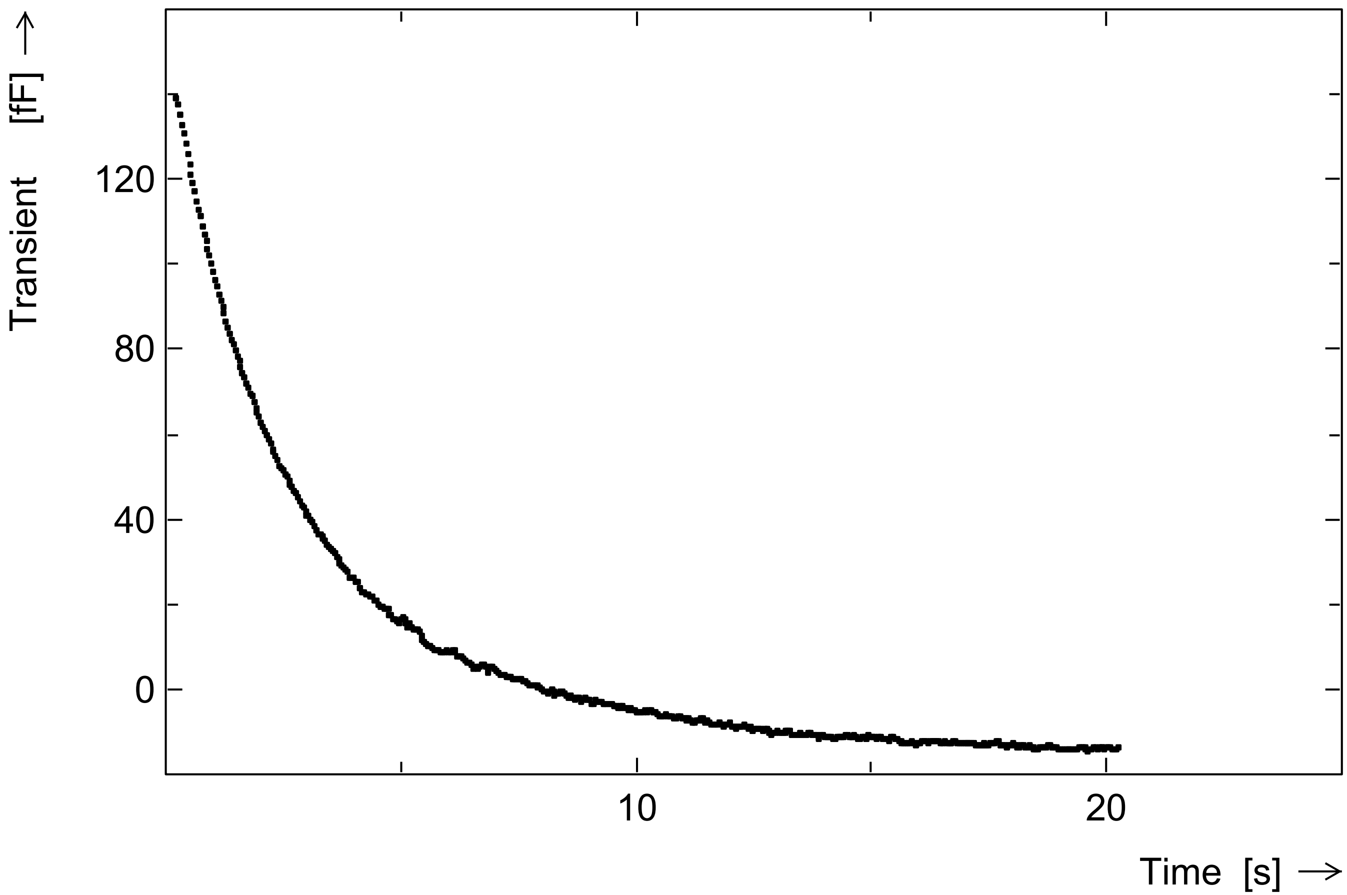
1
Transient [pF]
0.8
0.4
0.0
100
200
Time [ms]
Dlts-mid
1.0
0.0
-1.0
100
200
Time [ms]


Dlts-mid →
0.2
0.1
0.0
240
280
320
T [K] →

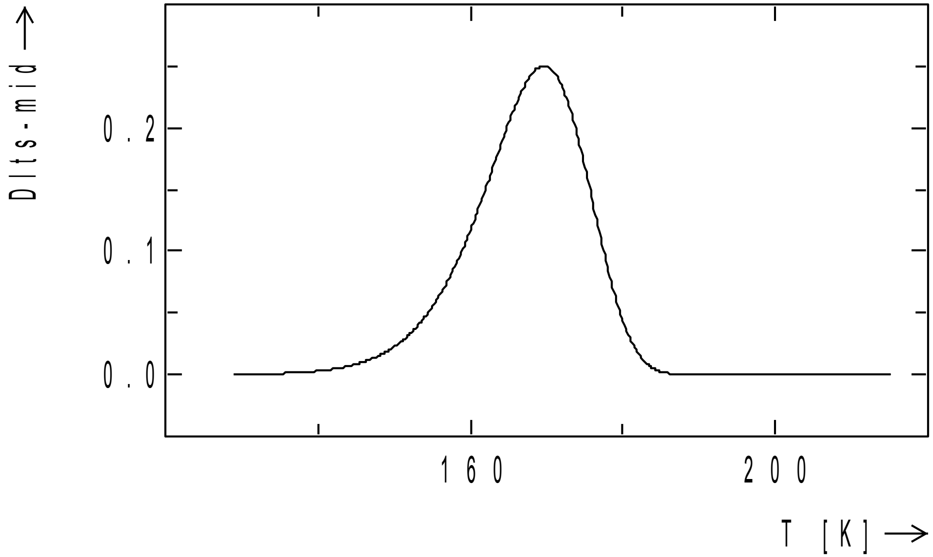


ln(tau*v_th*N_C) →
61.5
60.5
59.5
58.5
3.6
3.8
4.0
1000/T [1/K] →
Name = _T1.AWA
Comm = J7
ID = GANA18
rcID = 0000
Date = 28.10.2004
Type = n-GaN*
Area = 3.14E-04 cm2
NS = 2.00E+17 cm-3
tP = 100.00 us
UR = -3.00 V
UP = 0.00 V
Energy = 0.549 eV
sigma = 2.09E-16 cm2
NT = 3.20E+15 cm-3
Correl = 0.99807

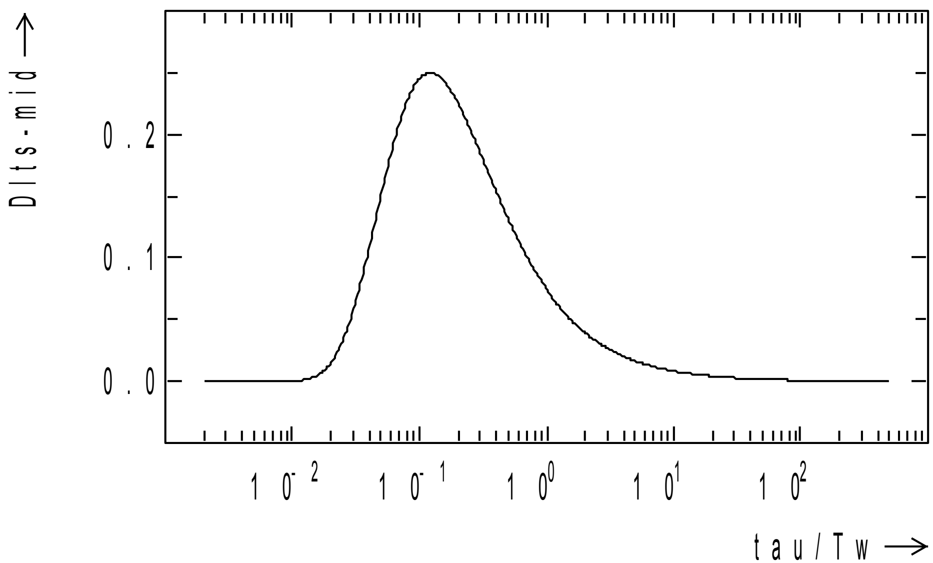
tau(a1,b1)	= 3.206 s	Amplitude	= 139.409 fF
tau(a2,b2)	= 2.664 s	NT	= 3.09E+15 cm^{-3}
tau(b1,b2)	= 2.368 s	NTs	= 7.44E+15 cm^{-3}
tau(a1,a2)	= 3.163 s	Energy	= 0.636 eV
tau(Tw/4)	= 2.341 s	tau,ts/Tw	= 0.16,1.31
tau(Tw'/2)	= 2.860 s	ExpClass	= 0.83
tau(a0,b1)	= 4.641 s	TauClass	= 44

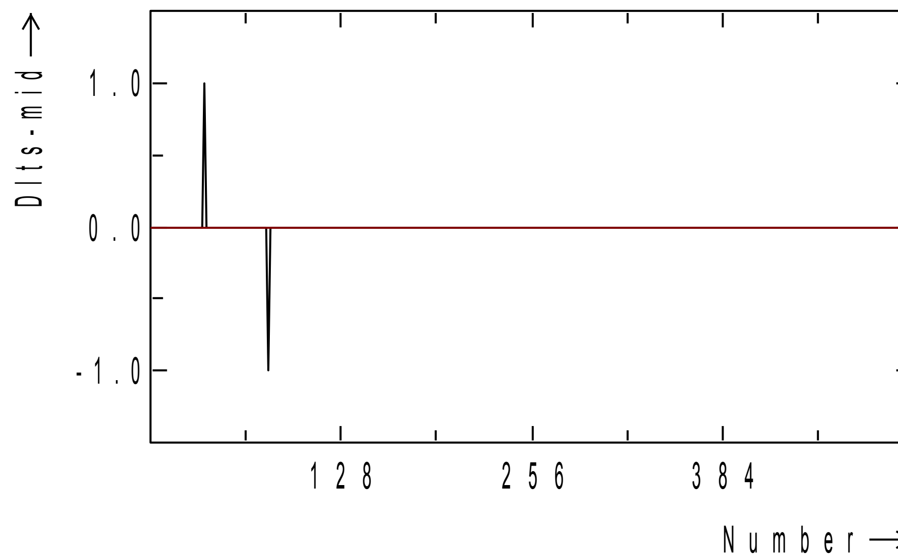


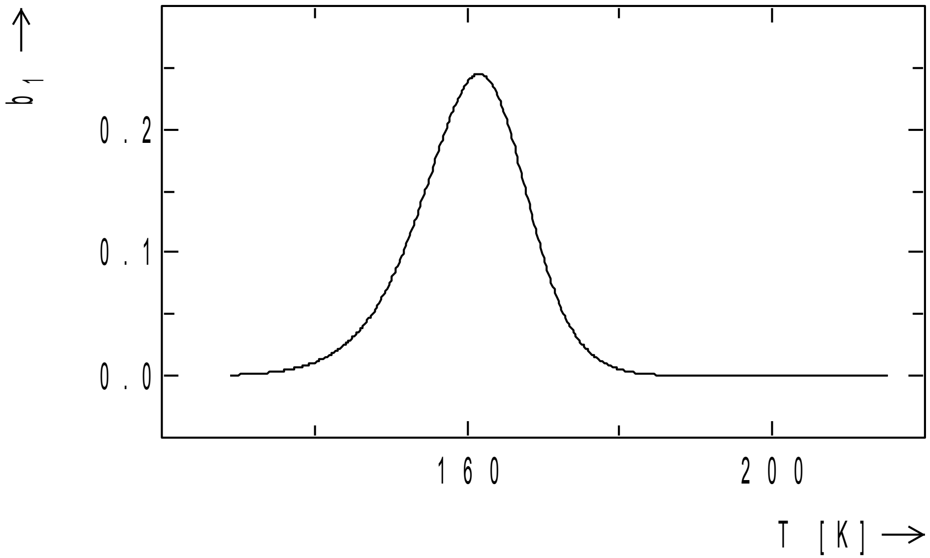
Name	=	@A_003.YEA
Comm	=	J7
ID	=	GANA18
rcID	=	1020
Date	=	29.10.2004
Type	=	n-GaN*
Area	=	3.14E-04 cm^2
N_S	=	2.07E+17 cm^{-3}
Temp	=	250.00 K
T_W	=	20.00 s
t_P	=	100.00 us
U_R	=	-3.00 V
U_P	=	-0.10 V
C_R	=	18.67 pF
I_R	=	-1.61 nA



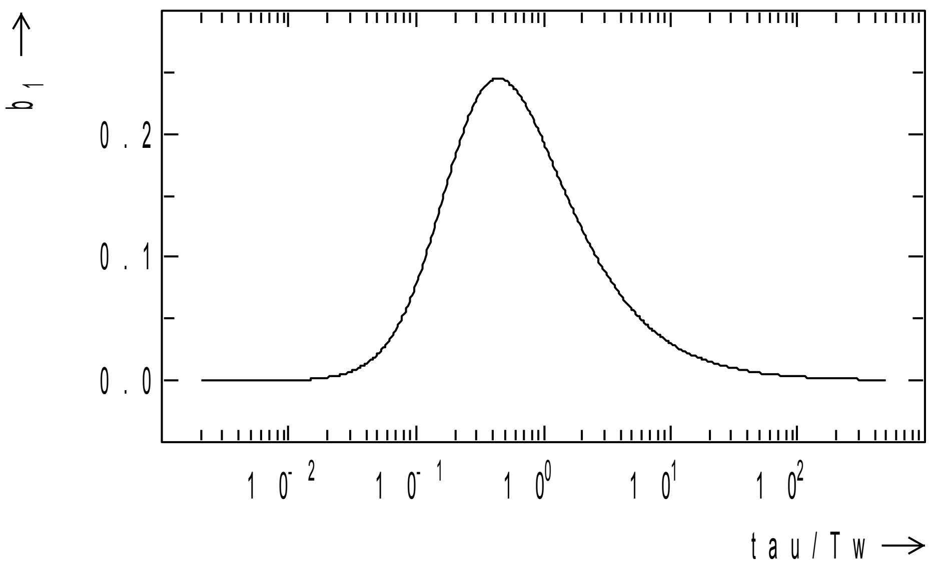
Name	= Dlts-mid		
ArNo.	= 22	Points	= 512
Tw	= 2.048E-01s	t0	= 2.800E-03s
Tw/t0-eff	= 7.314E+01		
AmpMax	= 2.500E-01	tauMax/Tw	= 1.212E-01
tauMax	= 2.483E-02s	TempMax	= 169.67 K
Integ	= 3.003E-01	<tau/Tw>	= 2.084E-01
Width	= 1.082E+00	WidthRat	= 1.439E+00
SNR	= 4.514E-02		

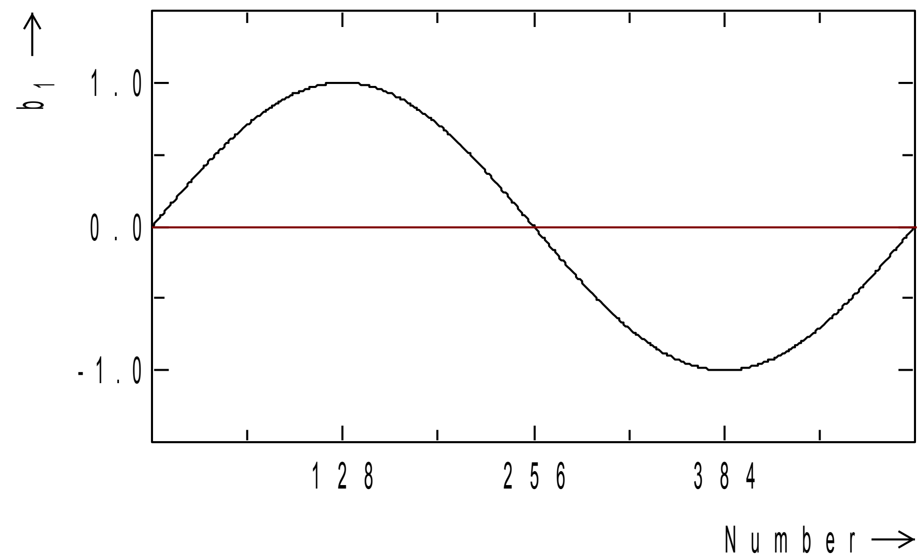


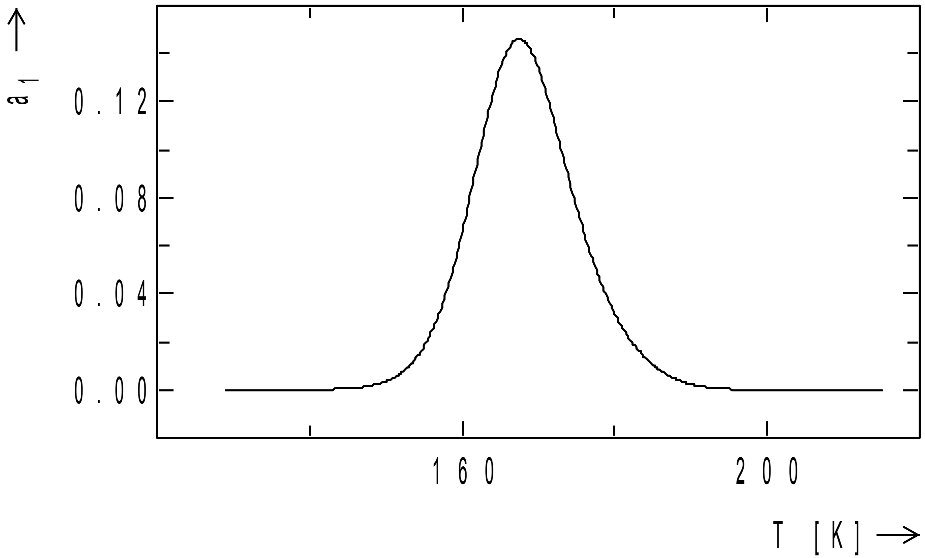




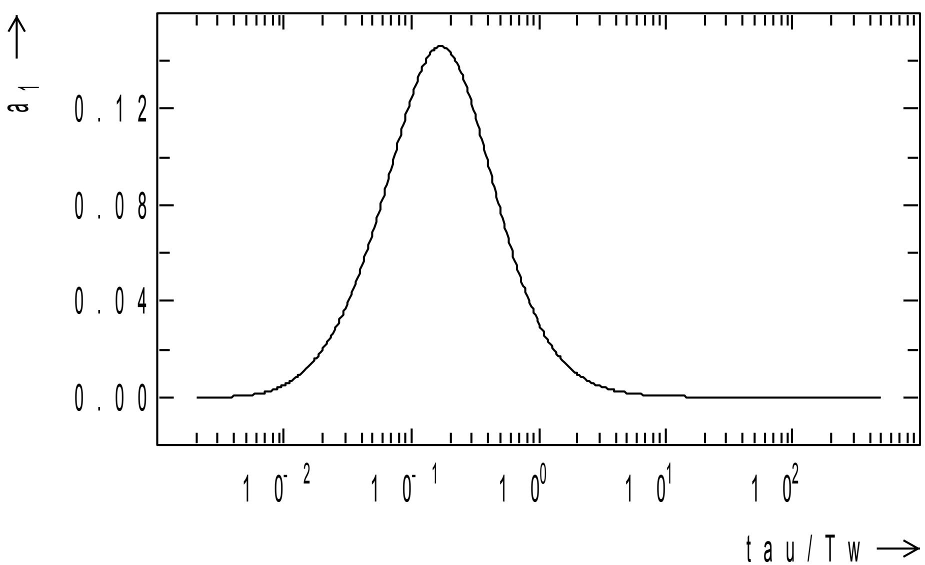
Name	= b_1		
ArNo.	= 1	Points	= 512
Tw	= 2.048E-01s	t0	= 2.800E-03s
Tw/t0-eff	= 7.314E+01		
AmpMax	= 2.448E-01	tauMax/Tw	= 4.404E-01
tauMax	= 9.019E-02s	TempMax	= 161.57 K
Integ	= 3.214E-01	<tau/Tw>	= 6.699E-01
Width	= 1.157E+00	WidthRat	= 1.277E+00
SNR	= 1.000E+00		

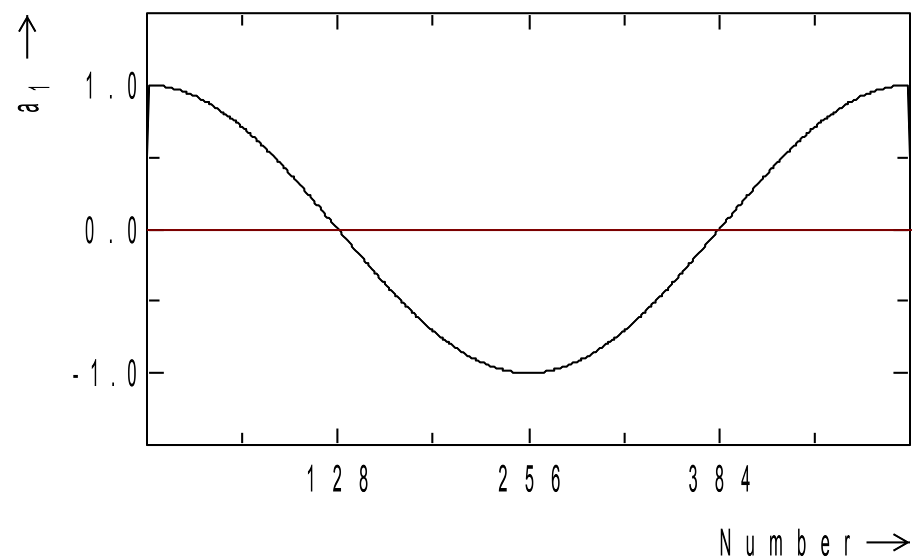


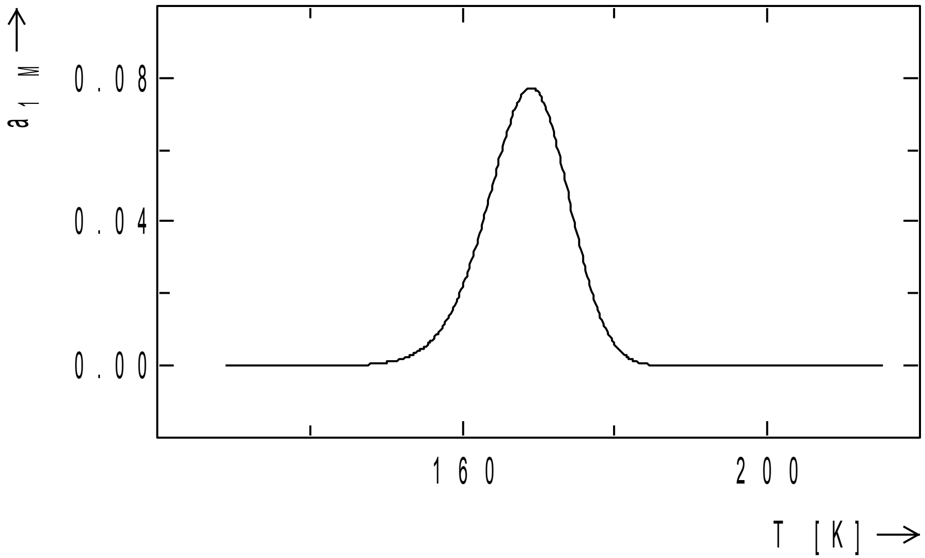




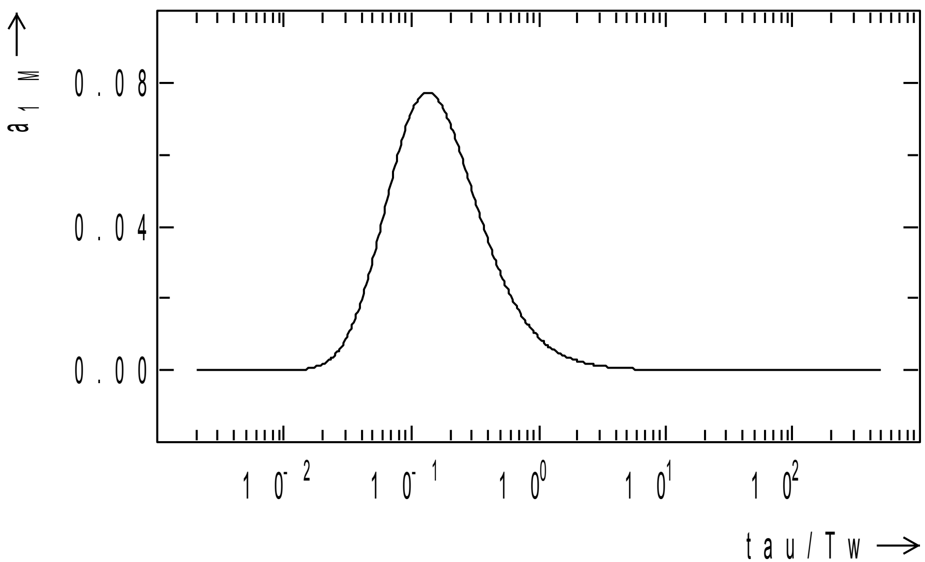
Name	= a_1		
ArNo.	= 5	Points	= 512
Tw	= 2.048E-01s	t0	= 2.800E-03s
Tw/t0-eff	= 7.314E+01		
AmpMax	= 1.461E-01	tauMax/Tw	= 1.699E-01
tauMax	= 3.480E-02s	TempMax	= 167.43 K
Integ	= 1.614E-01	<tau/Tw>	= 1.673E-01
Width	= 9.844E-01	WidthRat	= 9.783E-01
SNR	= 5.976E-01		

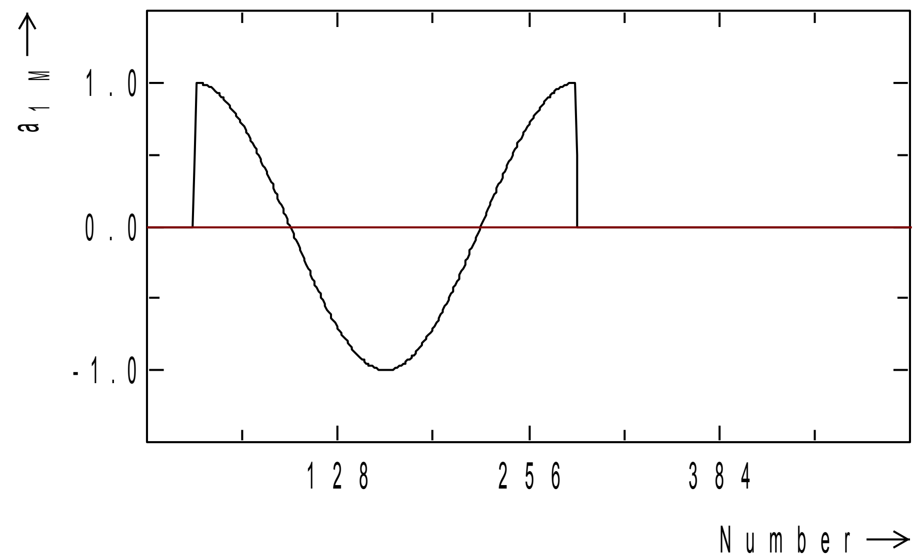


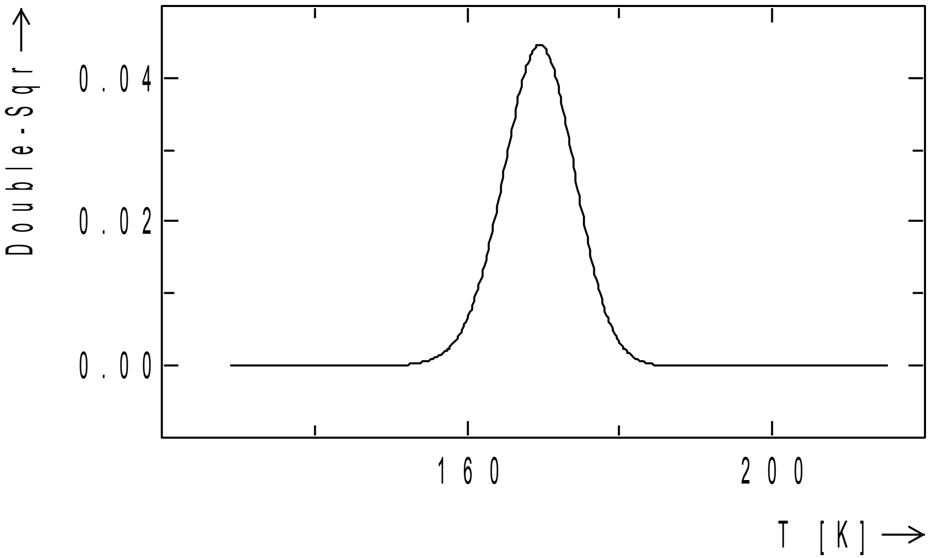




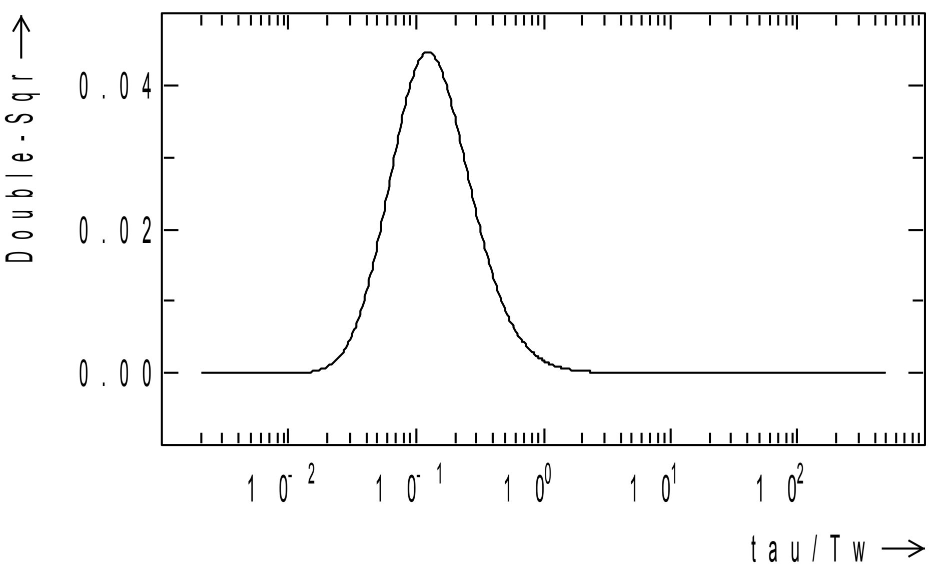
Name	= a_{1M}		
ArNo.	= 15	Points	= 512
T w	= 2.048E-01s	t0	= 2.800E-03s
Tw/t0-eff	= 7.314E+01		
AmpMax	= 7.726E-02	tauMax/Tw	= 1.338E-01
tauMax	= 2.741E-02s	TempMax	= 168.98 K
Integ	= 6.951E-02	<tau/Tw>	= 1.637E-01
Width	= 8.221E-01	WidthRat	= 1.171E+00
SNR	= 2.236E-01		

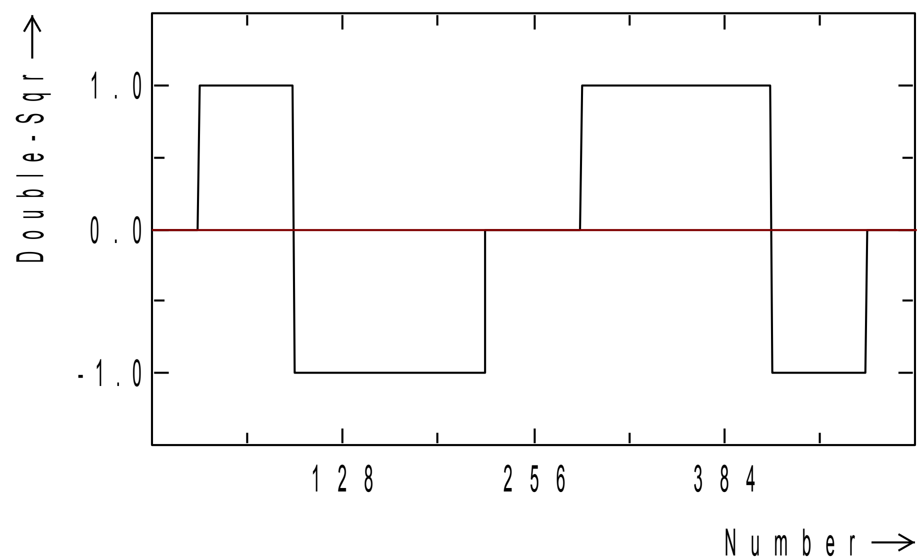


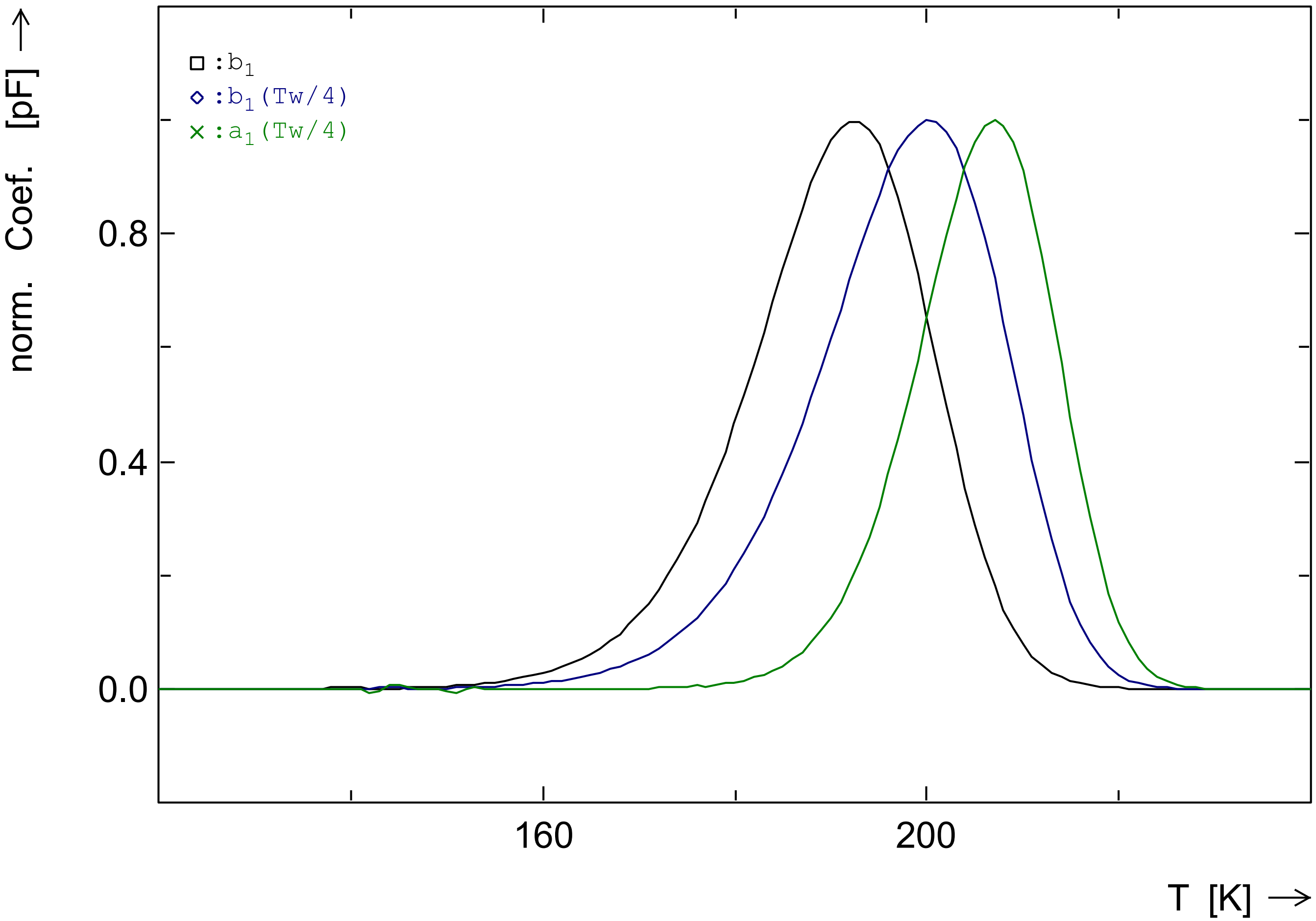




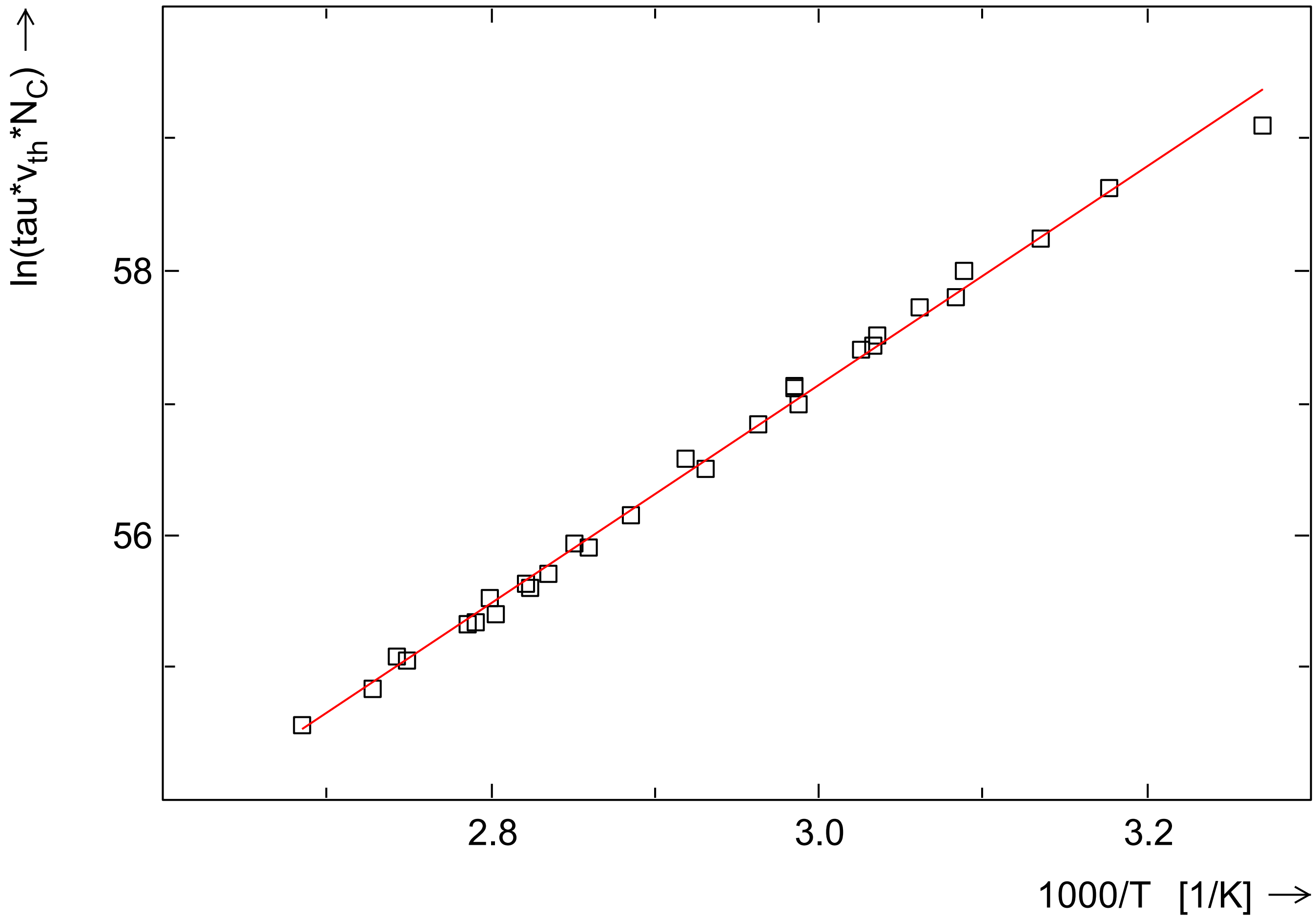
Name	= Double-Sqr		
ArNo.	= 16	Points	= 512
Tw	= 2.048E-01s	t0	= 2.800E-03s
Tw/t0-eff	= 7.314E+01		
AmpMax	= 4.463E-02	tauMax/Tw	= 1.232E-01
tauMax	= 2.523E-02s	TempMax	= 169.50 K
Integ	= 3.493E-02	<tau/Tw>	= 1.358E-01
Width	= 7.140E-01	WidthRat	= 1.063E+00
SNR	= 1.489E-01		



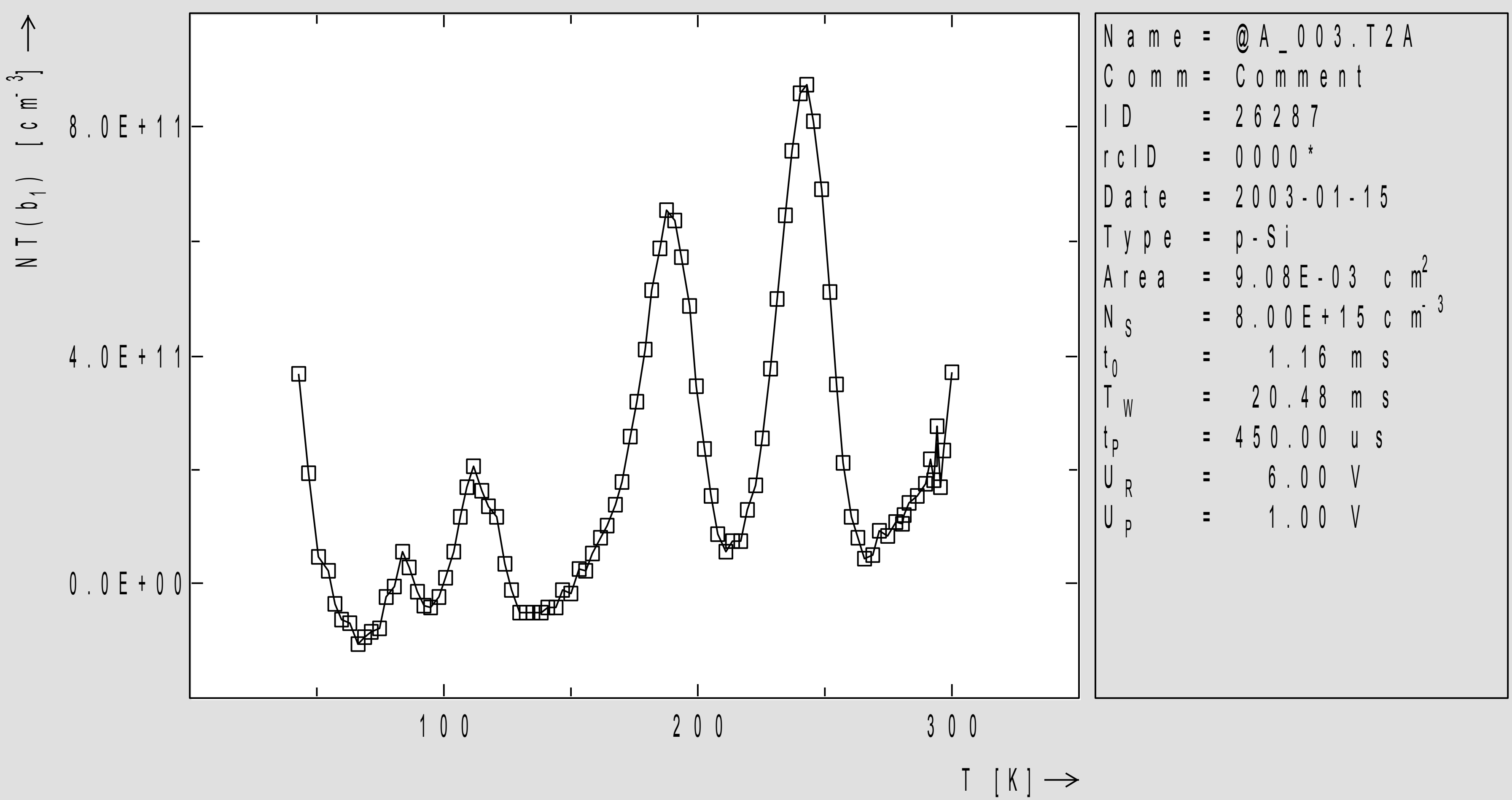




Name	=	@A_001.T1A
ID	=	ID
rcID	=	1A11
Date	=	2007-05-10
Type	=	n-Si
Area	=	8.00E-03 cm^2
N_S	=	2.00E+15 cm^{-3}
t_0	=	224.00 us
T_W	=	2.05 ms
t_P	=	100.00 us
U_R	=	-3.00 V
U_P	=	0.01 V

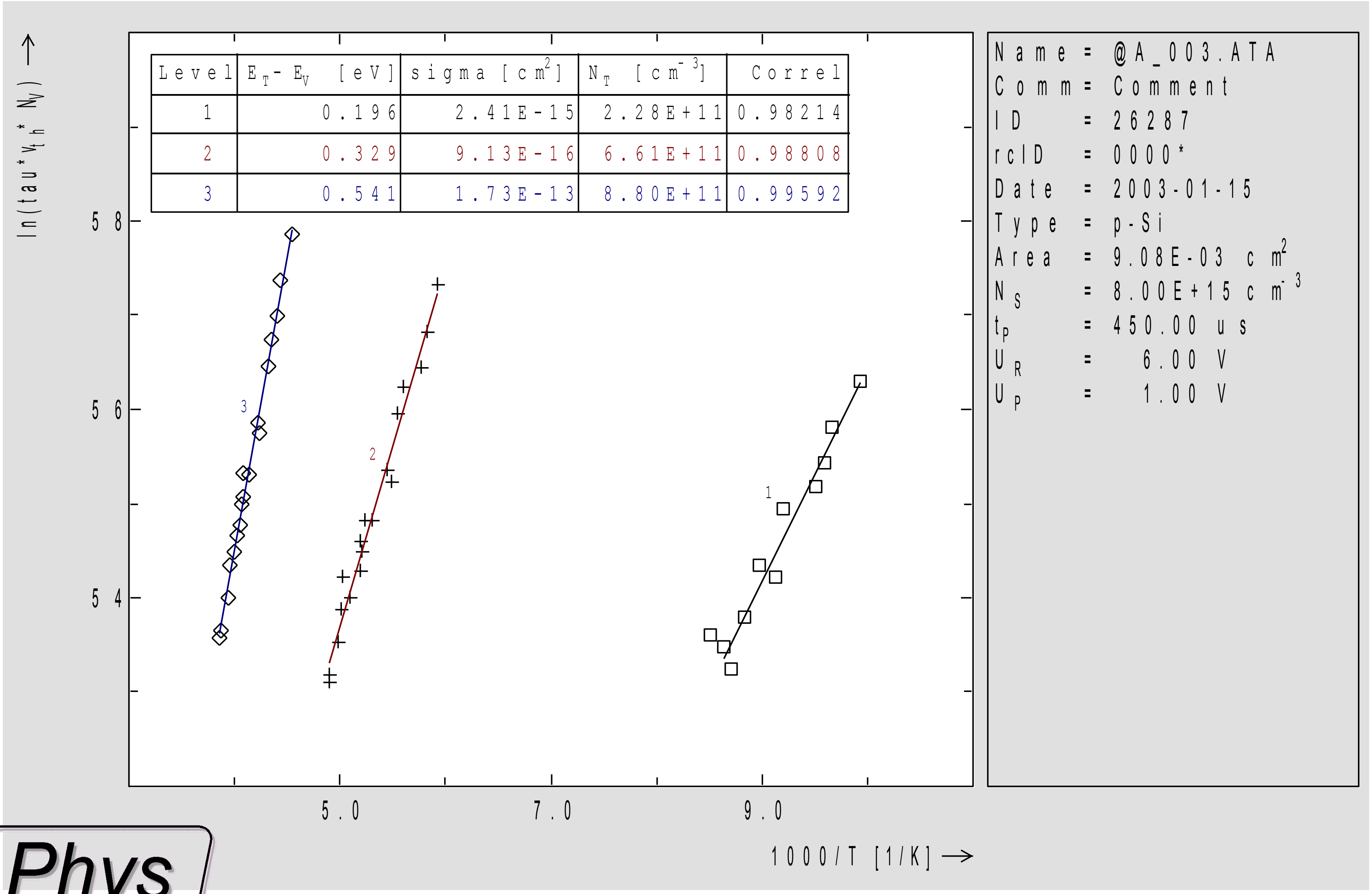


Name	=	@A_001.ATA	
ID	=	S1	
rcID	=	A001	
Date	=	2007-07-17	
Type	=	n-4HSiC	
Area	=	1.60E-03	cm^2
N_S	=	2.00E+16	cm^{-3}
t_P	=	1.00	ms
U_R	=	-8.00	V
U_P	=	0.10	V
Energy	=	0.713	eV
sigma	=	9.20E-15	cm^2
N_T	=	1.98E+13	cm^{-3}
N_{Ts}	=	6.11E+13	cm^{-3}
x_P	=	6.61E-01	um
x_R	=	8.93E-01	um
Correl	=	0.99762	

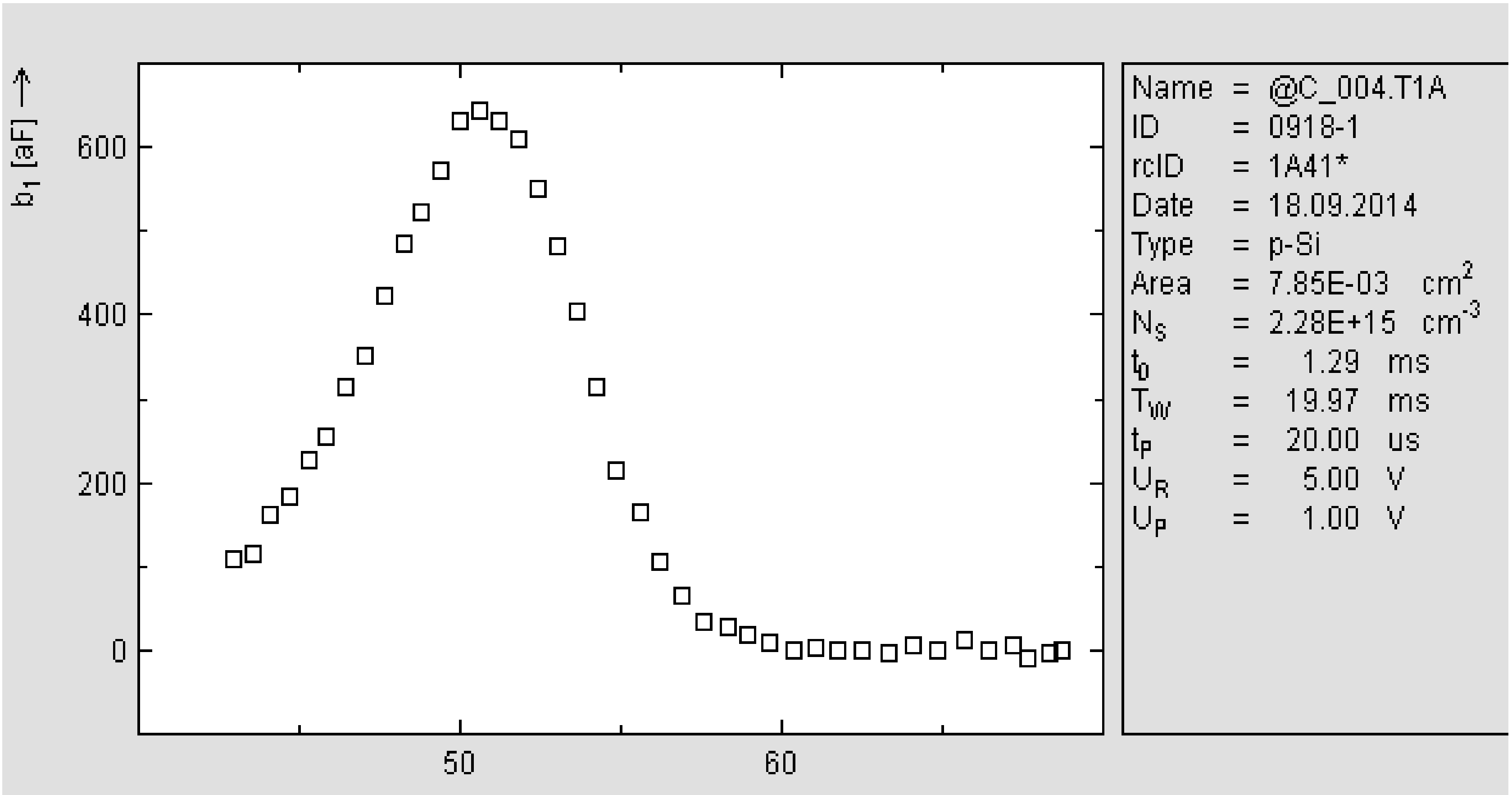


NT(b1) [cm-3] →
8.0E+11
4.0E+11
0.0E+00
100
200
300
T [K] →
Name = @A_003.T2A
Comm = Comment
ID = 26287
rcID = 0000*
Date = 2003-01-15
Type = p-Si
Area = 9.08E-03 cm2
NS = 8.00E+15 cm-3
t0 = 1.16 ms
TW = 20.48 ms
tP = 450.00 us
UR = 6.00 V
UP = 1.00 V

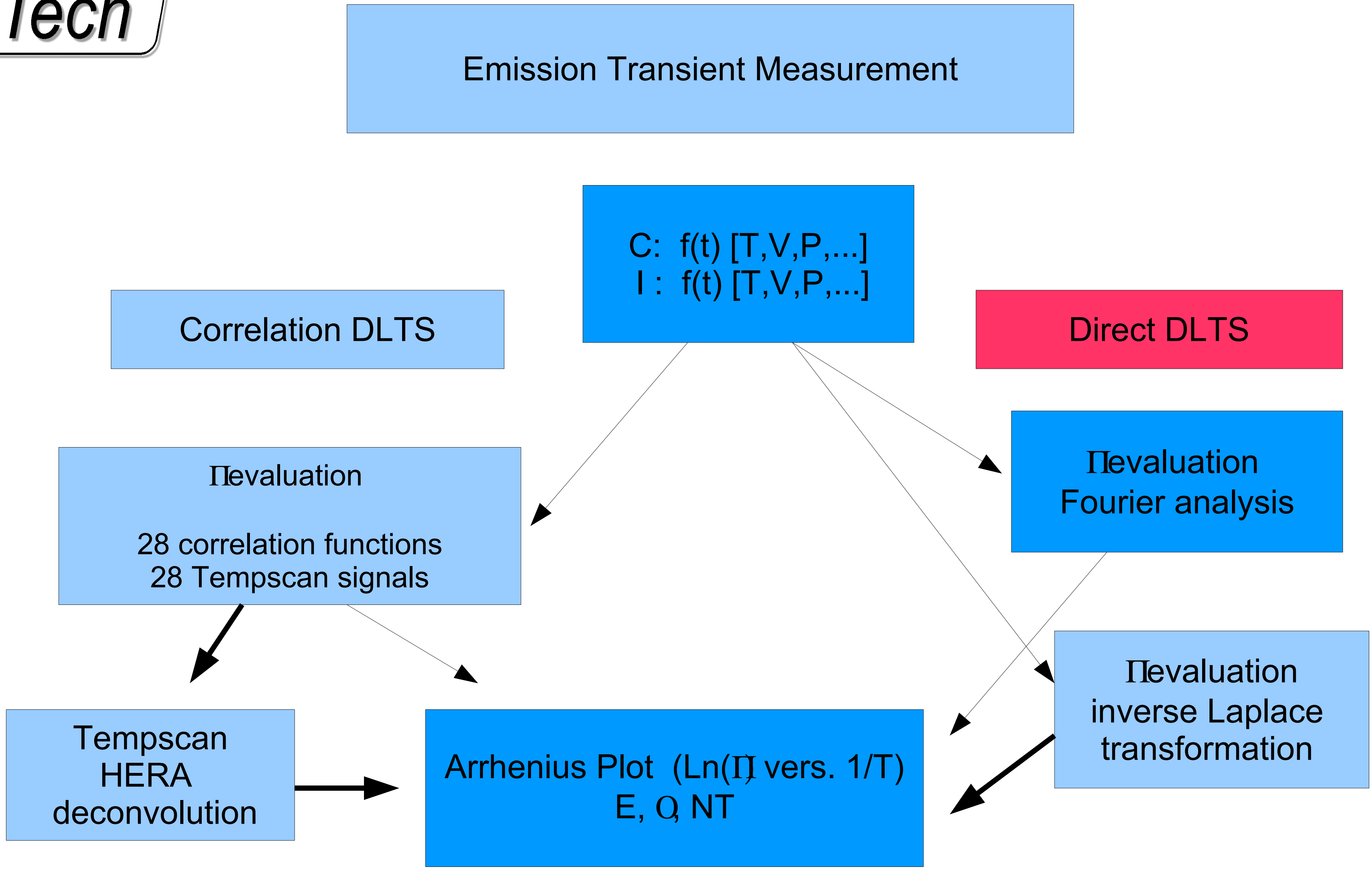
Phys Tech



Level	$E_T - E_V$ [eV]	sigma [cm^2]	N_T [cm^{-3}]	Correl
1	0.196	2.41E-15	2.28E+11	0.98214
2	0.329	9.13E-16	6.61E+11	0.98808
3	0.541	1.73E-13	8.80E+11	0.99592



b1 [aF] →
600
400
200
0
50
60
Name = @C_004.T1A
ID = 0918-1
rcID = 1A41*
Date = 18.09.2014
Type = p-Si
Area = 7.85E-03 cm2
NS = 2.28E+15 cm-3
t0 = 1.29 ms
TW = 19.97 ms
tP = 20.00 us
UR = 5.00 V
UP = 1.00 V


Emission Transient Measurement
C: f(t) [T,V,P,...]
I : f(t) [T,V,P,...]
Correlation DLTS
Direct DLTS
Πevaluation
28 correlation functions
28 Tempscan signals
Πevaluation
Fourier analysis
Πevaluation
inverse Laplace
transformation
Tempscan
HERA
deconvolution
Arrhenius Plot (Ln(Π vers. 1/T)
E, Q, NT

Exponential Time Dependence

$$f(t) = A \exp\left(-\frac{t+t_0}{\tau}\right) + B$$

A : amplitude, τ : time constant, B : offset

Fourier coefficients:

$$a_0 = \frac{2A}{T_W} \exp\left(-\frac{t_0}{\tau}\right) \left(1 - \exp(-\frac{T_W}{\tau})\right) \tau + 2B$$

$$a_n = \frac{2A}{T_W} \exp\left(-\frac{t_0}{\tau}\right) \left(1 - \exp(-\frac{T_W}{\tau})\right) \frac{\frac{1}{\tau}}{\frac{1}{\tau^2} + n^2\omega^2}$$

cosine coefficient

$$b_n = \frac{2A}{T_W} \exp\left(-\frac{t_0}{\tau}\right) \left(1 - \exp(-\frac{T_W}{\tau})\right) \frac{n\omega}{\frac{1}{\tau^2} + n^2\omega^2}$$

sine coefficient

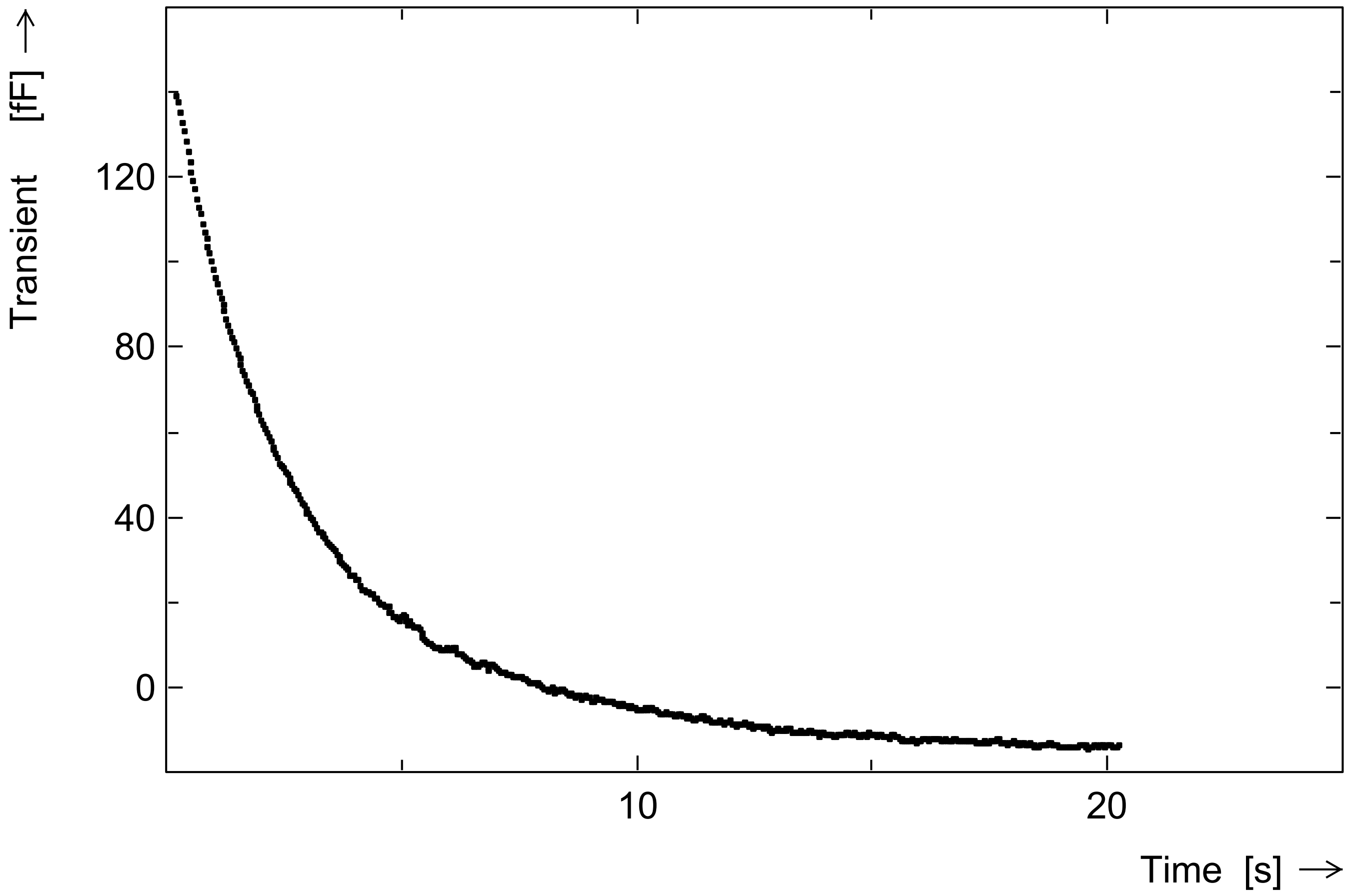
calculation of time constant:

a) $\tau(a_n, a_k) = \frac{1}{\omega}\sqrt{\frac{a_n - a_k}{k^2 a_k - n^2 a_n}}$ from cosine coefficient

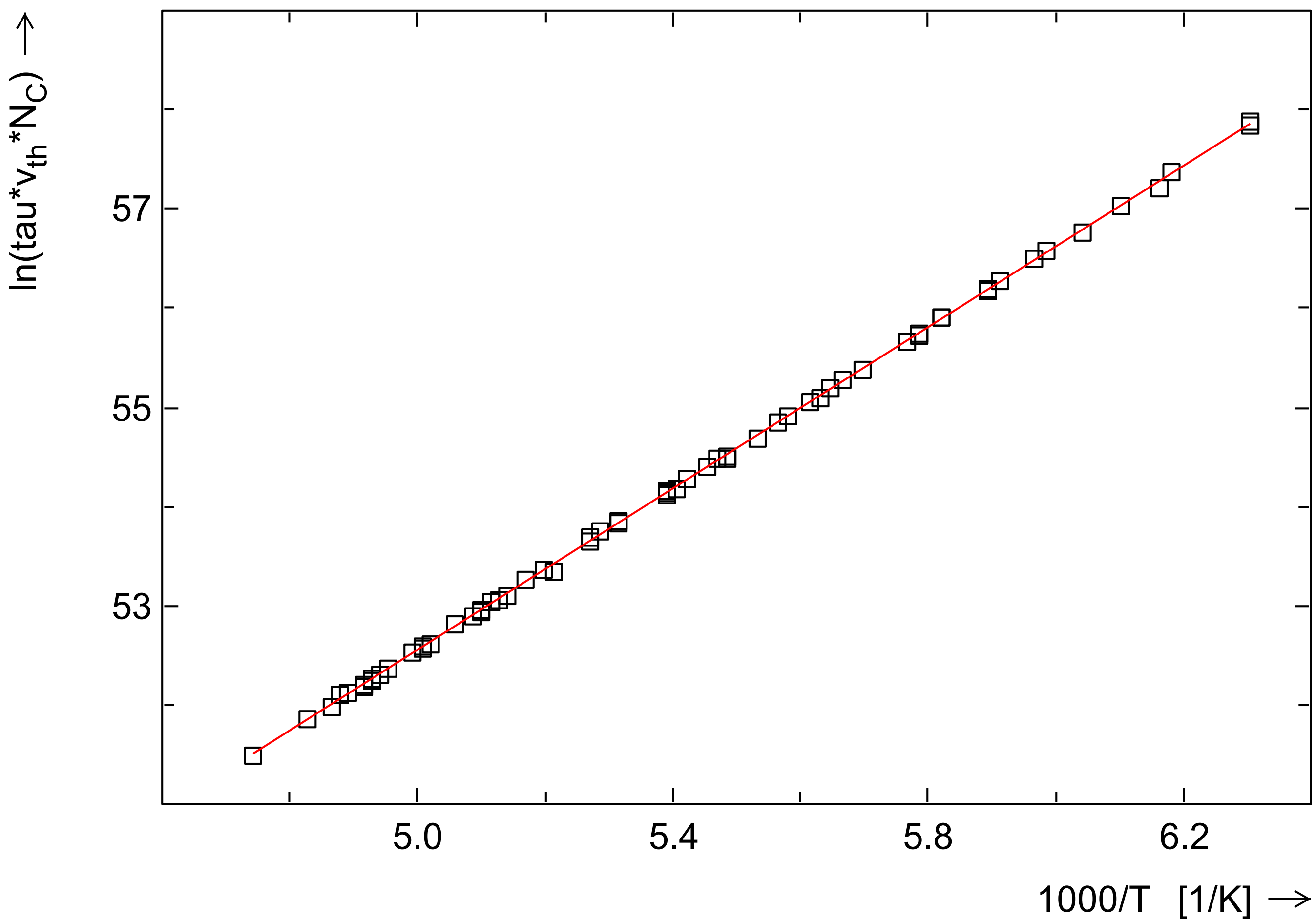
b) $\tau(b_n, b_k) = \frac{1}{\omega}\sqrt{\frac{k b_n - n b_k}{k^2 n b_k - n^2 k b_n}}$ from sine coefficient

c) $\tau(a_n, b_n) = \frac{1}{n\omega}\frac{b_n}{a_n}$ from cosine and sine coefficient

tau(a1,b1) =	3.206 s	Amplitude =	139.409 fF
tau(a2,b2) =	2.664 s	NT =	3.09E+15 cm^{-3}
tau(b1,b2) =	2.368 s	NTs =	7.44E+15 cm^{-3}
tau(a1,a2) =	3.163 s	Energy =	0.636 eV
tau(Tw/4) =	2.341 s	tau,ts/Tw =	0.16,1.31
tau(Tw'/2) =	2.860 s	ExpClass =	0.83
tau(a0,b1) =	4.641 s	TauClass =	44



Name	=	@A_003.YEA
Comm	=	J7
ID	=	GANA18
rcID	=	1020
Date	=	29.10.2004
Type	=	n-GaN*
Area	=	3.14E-04 cm^2
N_S	=	2.07E+17 cm^{-3}
Temp	=	250.00 K
T_W	=	20.00 s
t_P	=	100.00 us
U_R	=	-3.00 V
U_P	=	-0.10 V
C_R	=	18.67 pF
I_R	=	-1.61 nA



Name	=	@A_002.ATA	
ID	=	ID	
rcID	=	A001	
Date	=	2007-05-10	
Type	=	n-Si	
Area	=	8.00E-03	cm^2
N_S	=	2.00E+15	cm^{-3}
t_P	=	100.00	us
U_R	=	-3.00	V
U_P	=	0.01	V
Energy	=	0.350	eV
sigma	=	1.01E-14	cm^2
N_T	=	7.36E+13	cm^{-3}
N_{Ts}	=	1.35E+14	cm^{-3}
x_P	=	2.82E-01	um
x_R	=	1.18E+00	um
Correl	=	0.99991	

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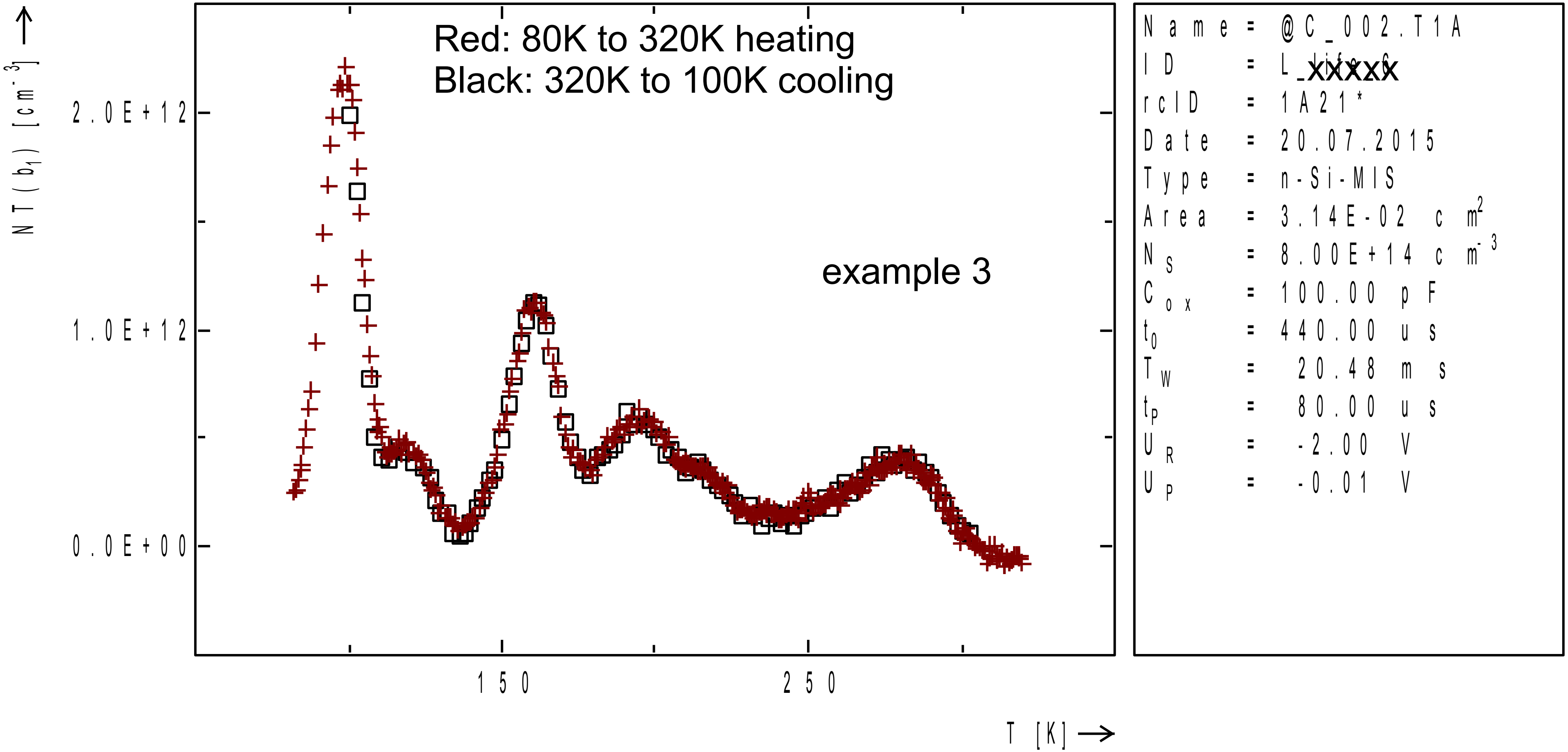
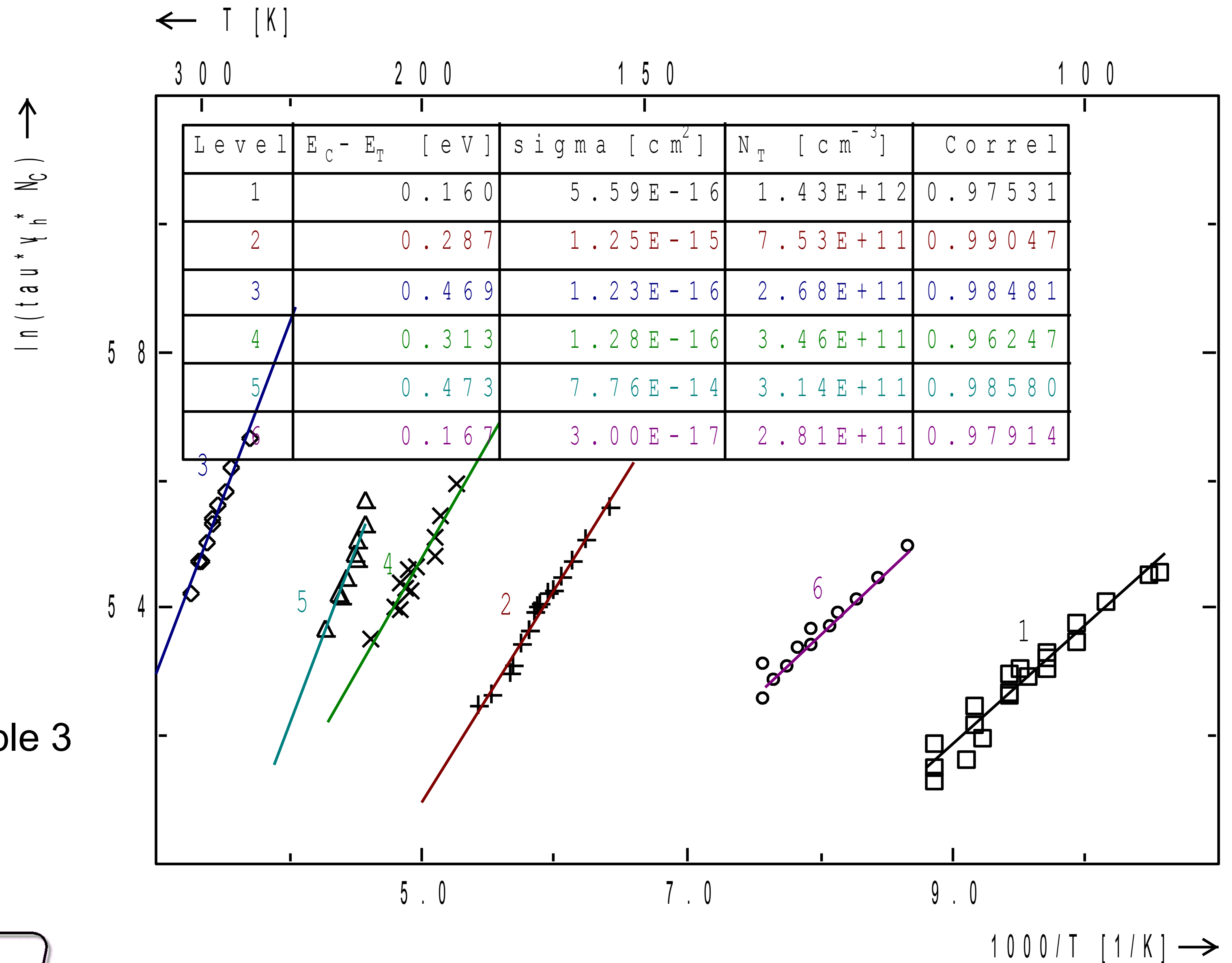
DLTS Simulation (SRH)
and
comarison with measurement results

(Physical emission process model check)



PhysTech

DLTS signal b1 normalized in Trapconcentration versus temperature measured during cooling down 320K – 100K (black squares) and during heating up 80K – 320K (red crosses)

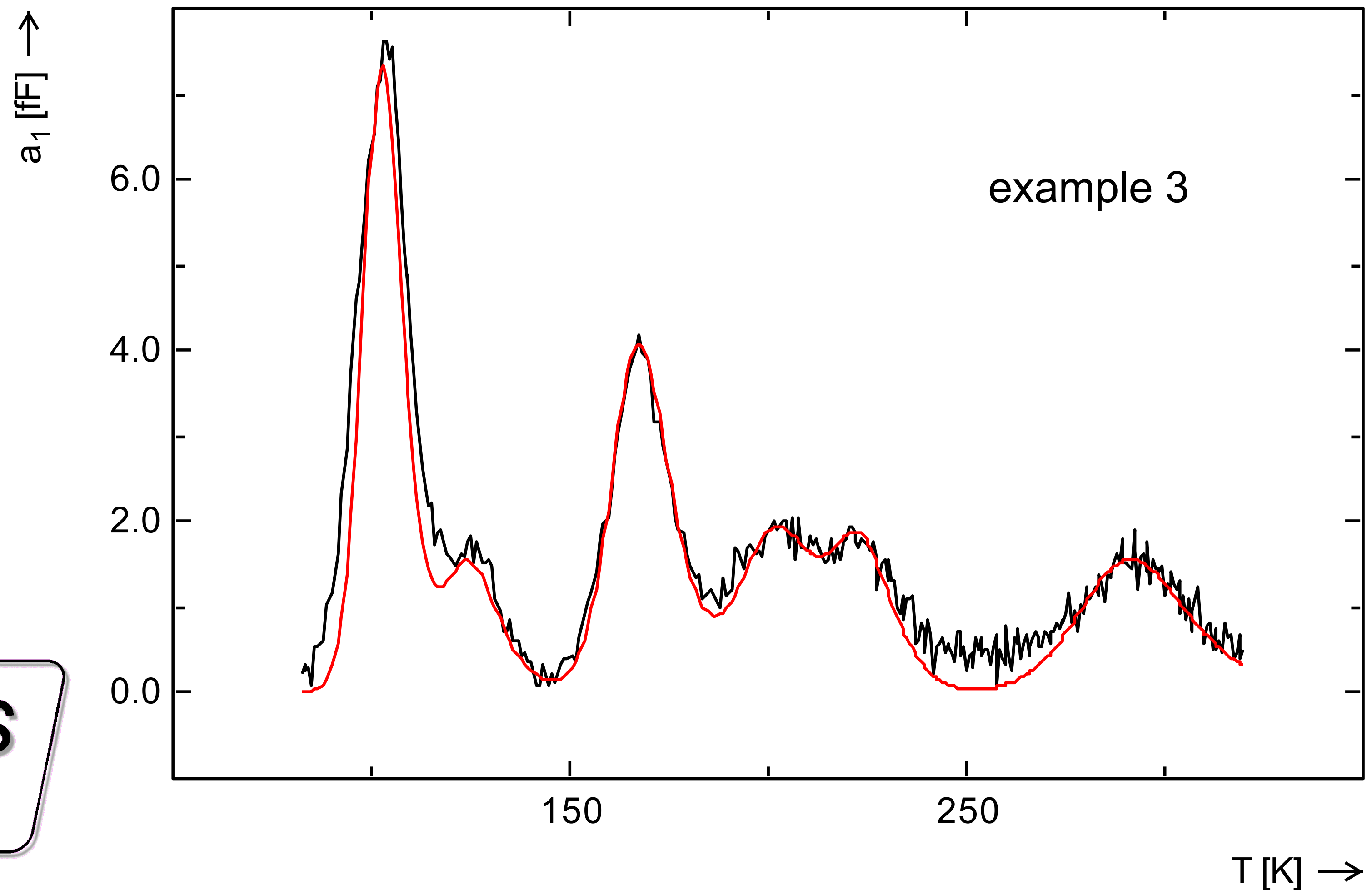


Level	$E_C - E_T$ [eV]	sigma [cm^2]	N_T [cm^{-3}]	Correl
1	0.160	5.59E-16	1.43E+12	0.97531
2	0.287	1.25E-15	7.53E+11	0.99047
3	0.469	1.23E-16	2.68E+11	0.98481
4	0.313	1.28E-16	3.46E+11	0.96247
5	0.473	7.76E-14	3.14E+11	0.98580
6	0.167	3.00E-17	2.81E+11	0.97914

example 3

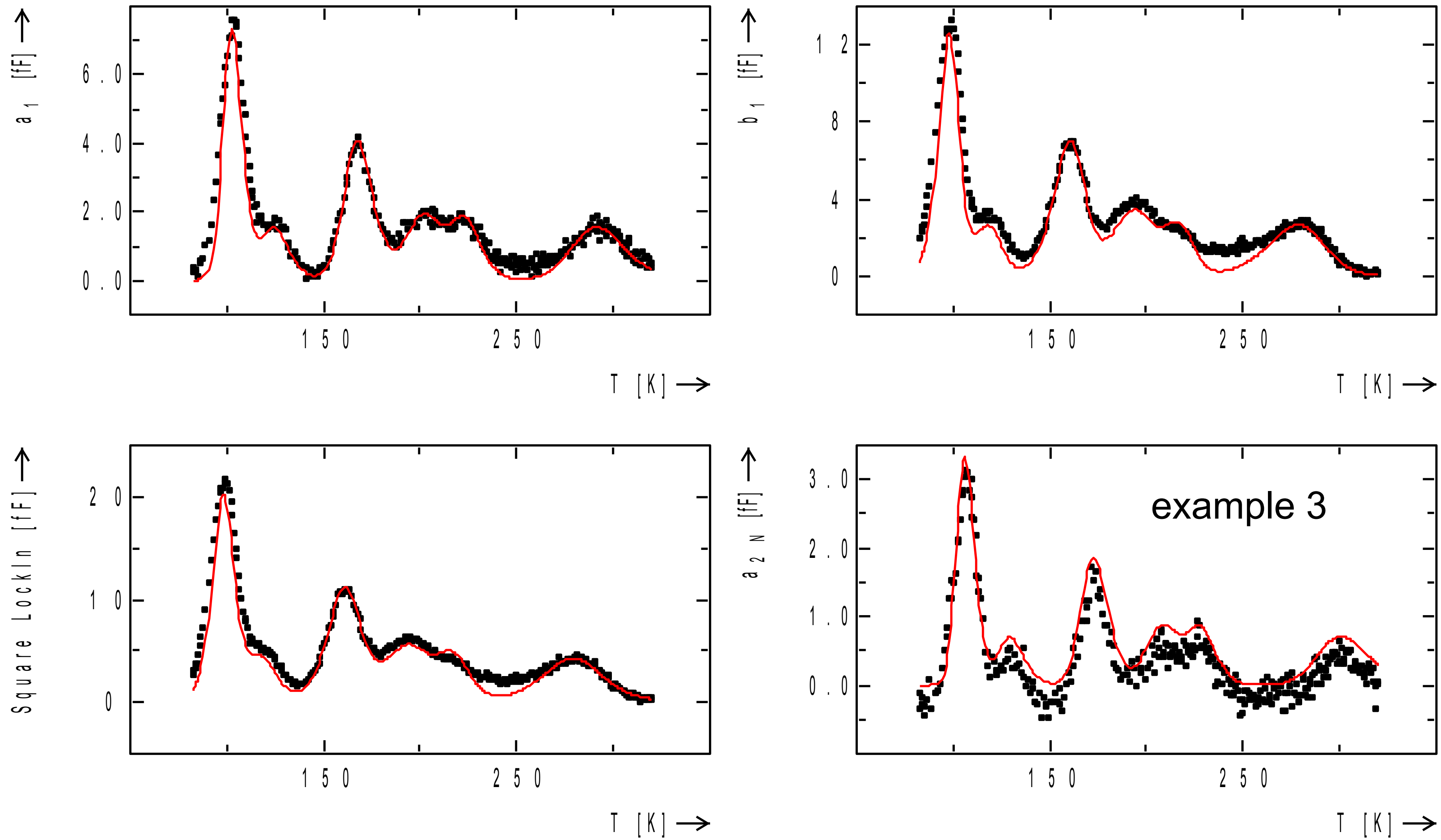
Phys Tech

Arrhenius plot of the measurements of above plot

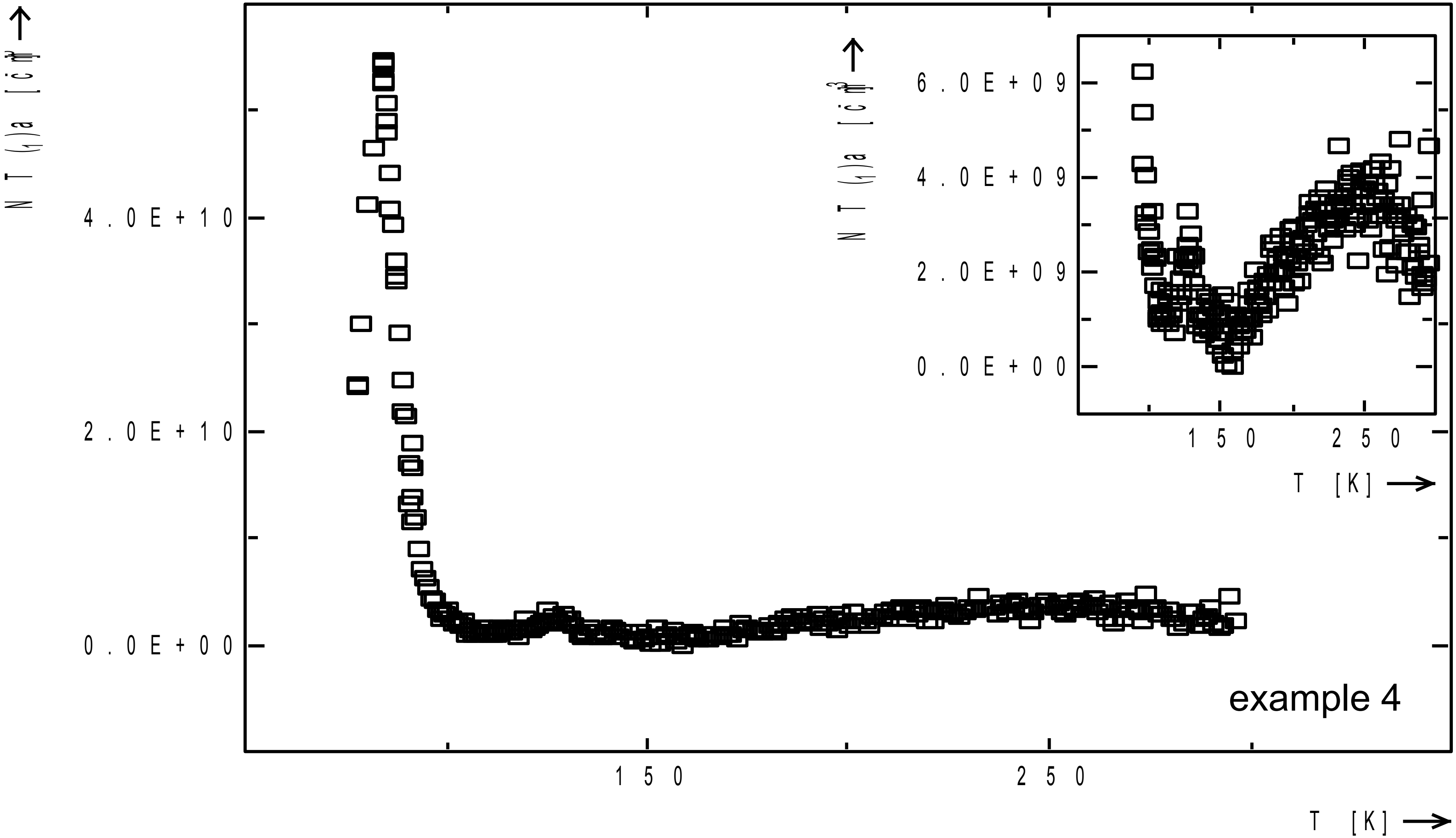


DLTS signal a1 vers. temperature:
black: measured data, red: simulated data (SRH) using the Arrhenius data above.

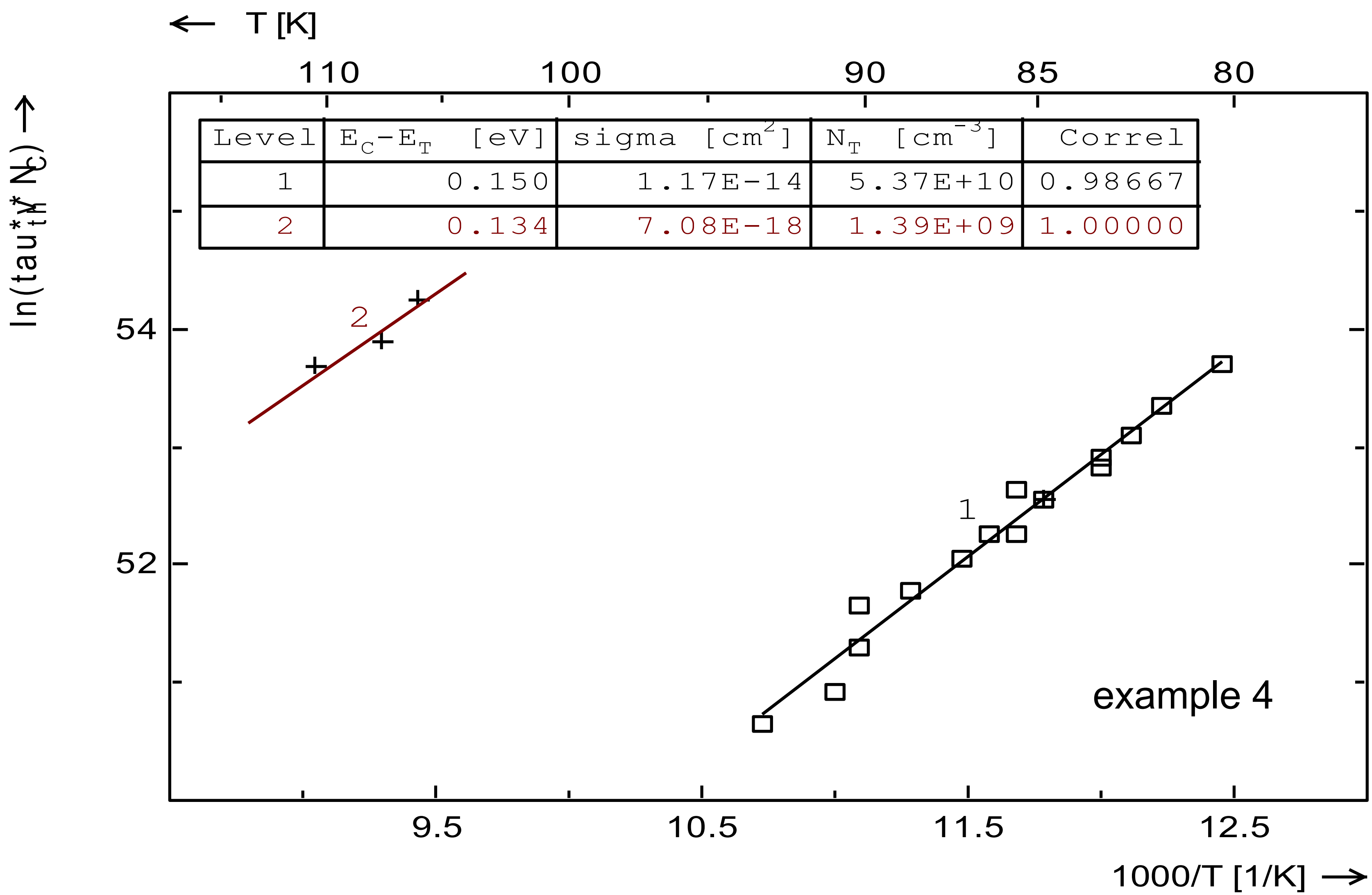
Plot 5



Different DLTS signals (DC values of different correlation functions) of the measurement (black dots) compared to the simulation of the measurements with the results of the Arrhenius plot above (red line).



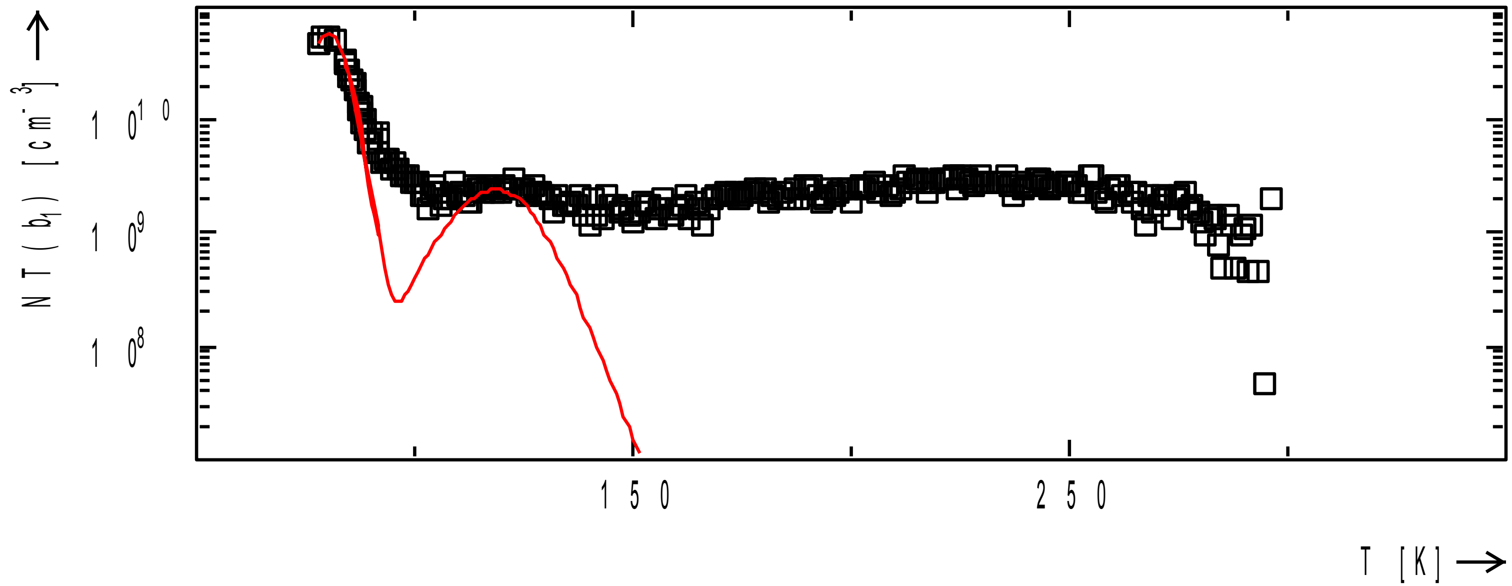
DLTS signal a1 vers. temperature (tempscan) of a Si sample
inlet zoomed without main peak

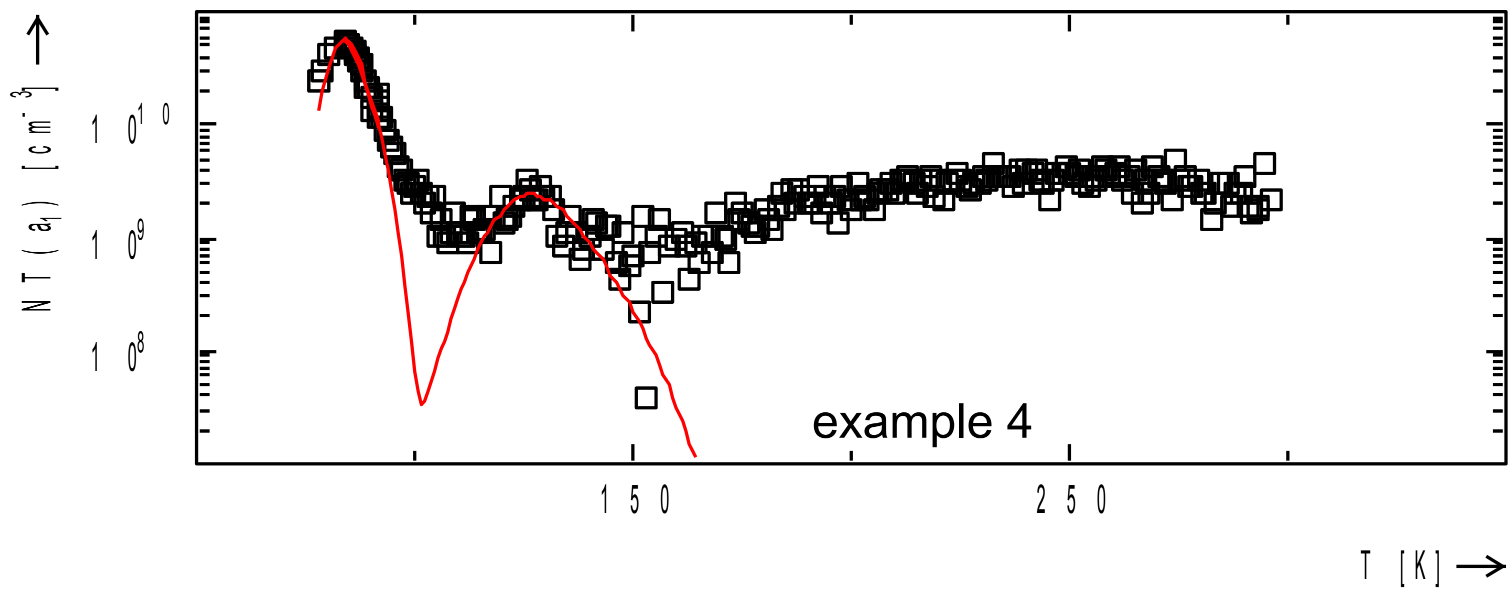


Level	E_C-E_T [eV]	sigma [cm^2]	N_T [cm^{-3}]	Correl
1	0.150	1.17E-14	5.37E+10	0.98667
2	0.134	7.08E-18	1.39E+09	1.00000

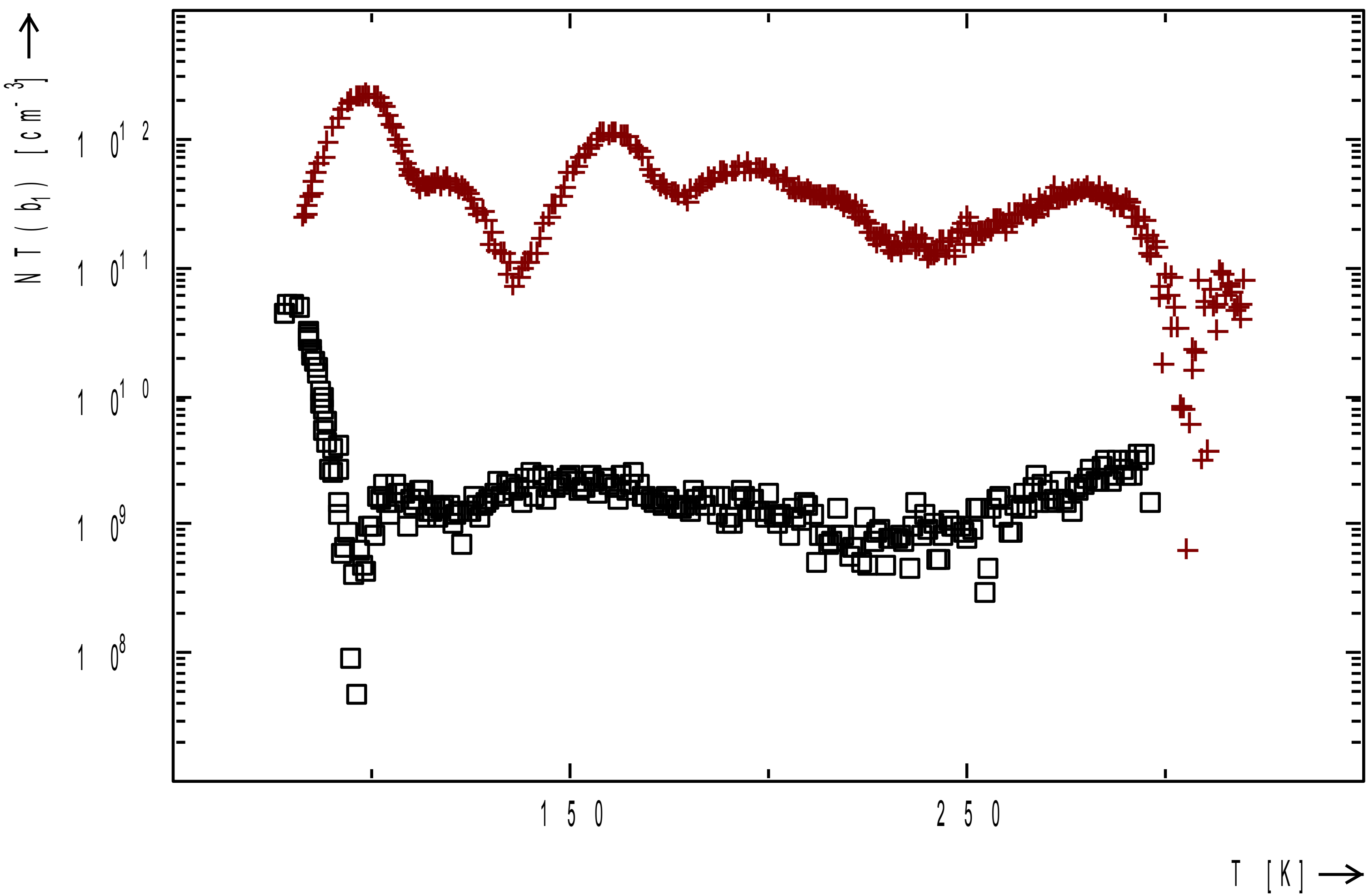
Arrhenius plot of the data above
Two paeks have been evaluated

Two tempscans (a1, b1) log scale of above measurement compared with simulated data (SRH) using the results from the above Arrhenius plot





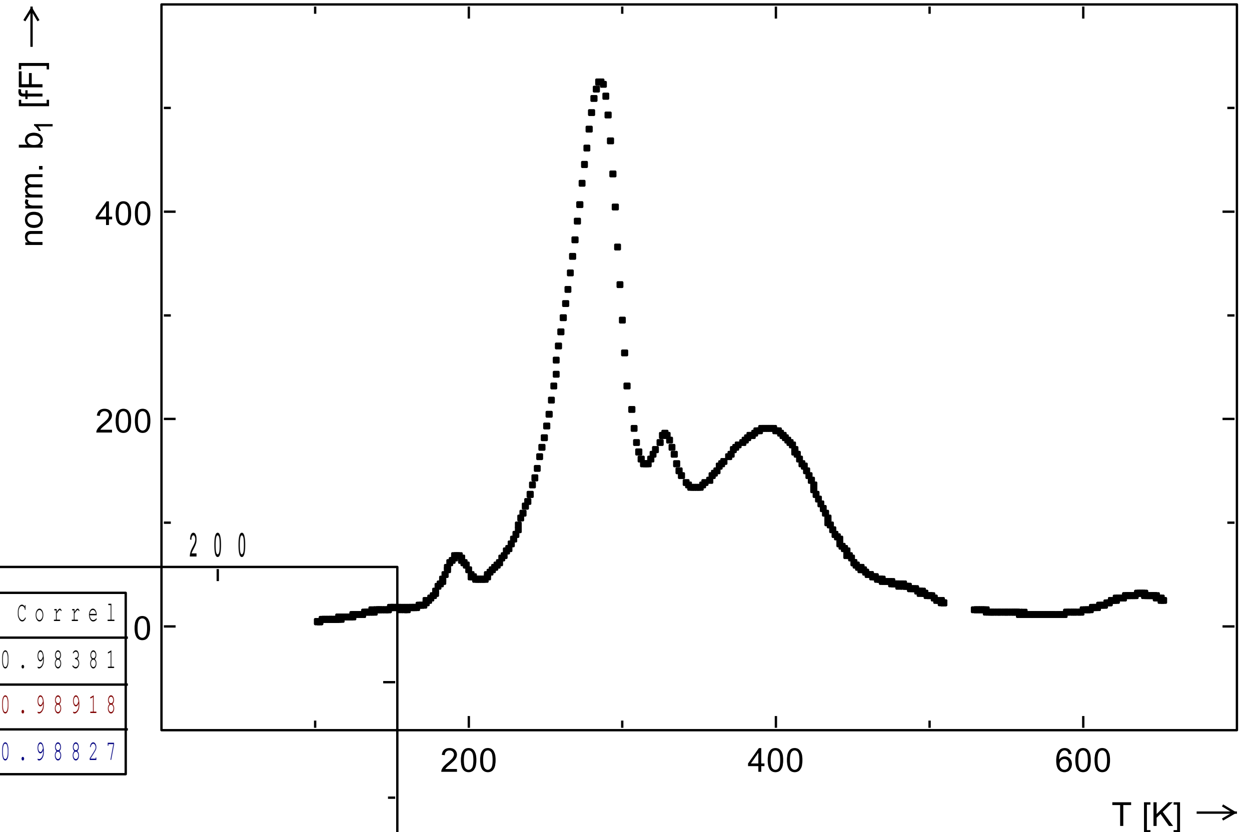
Phys Tech

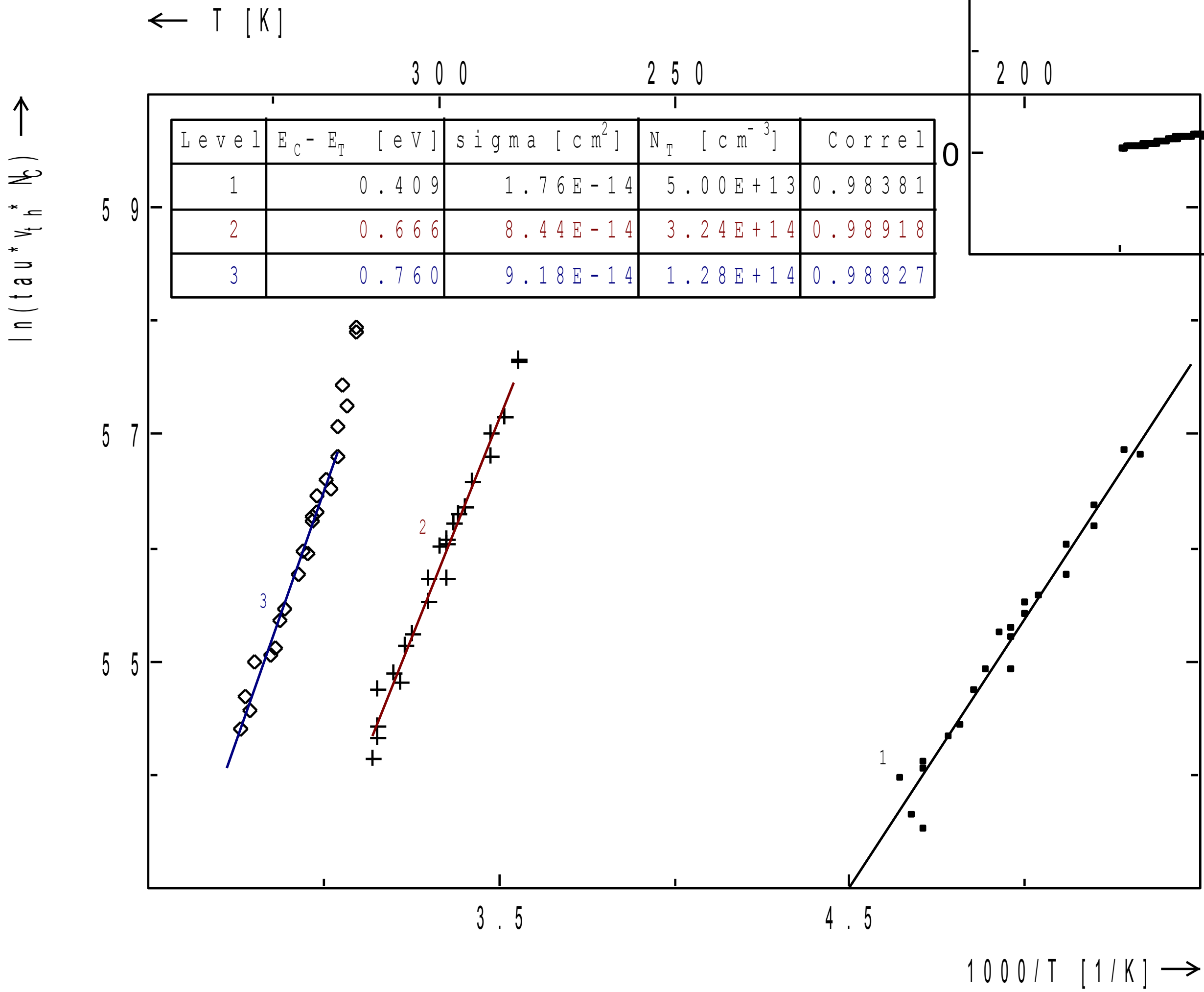


DLTS signal b1 for example 4 (blacksquares) and example 3 (red crosses) in a logarithmic scale.

SiC sample

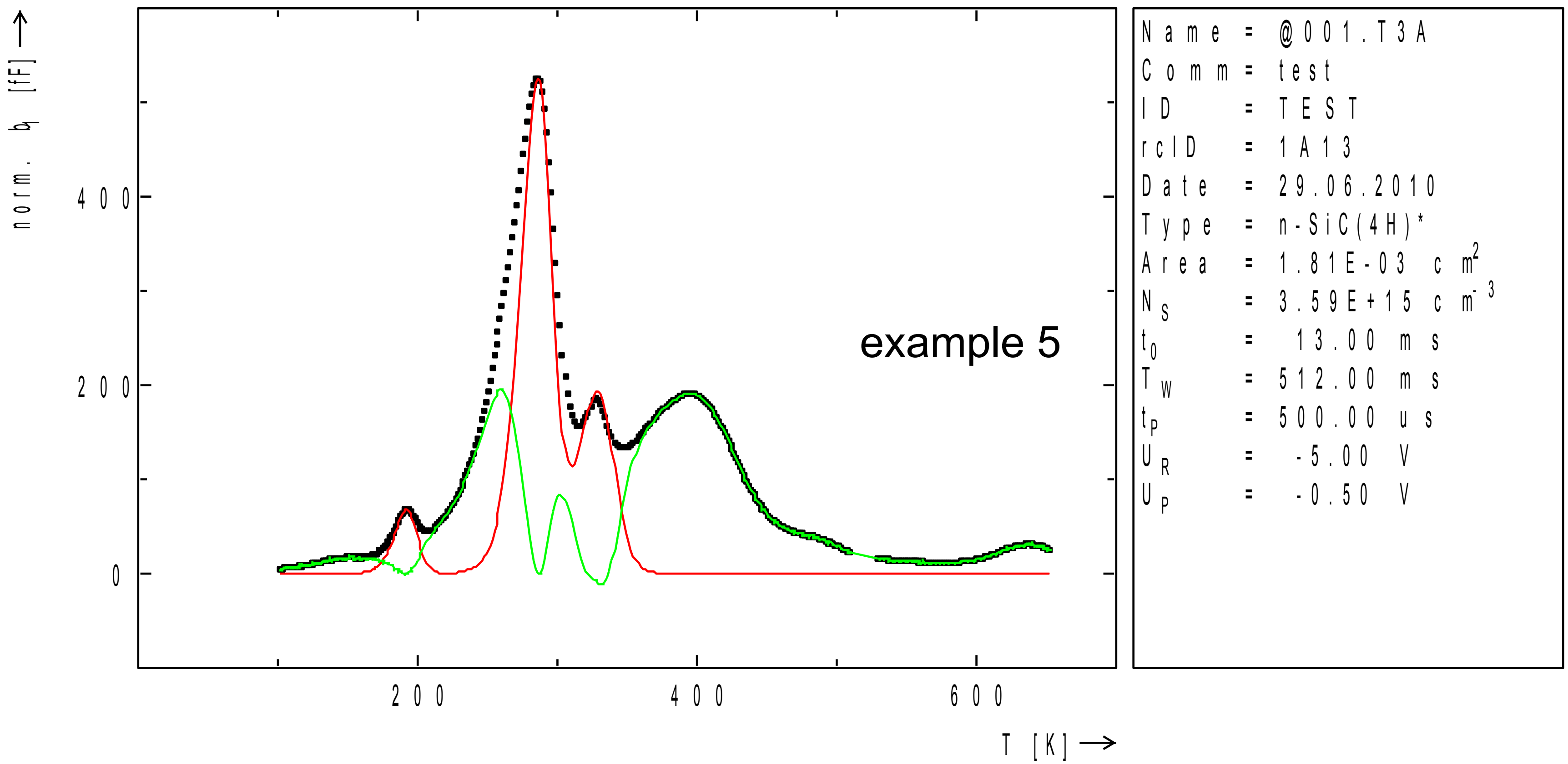
Tempscan (b1)
and
Arrhenius plot for
the first 3
maxima



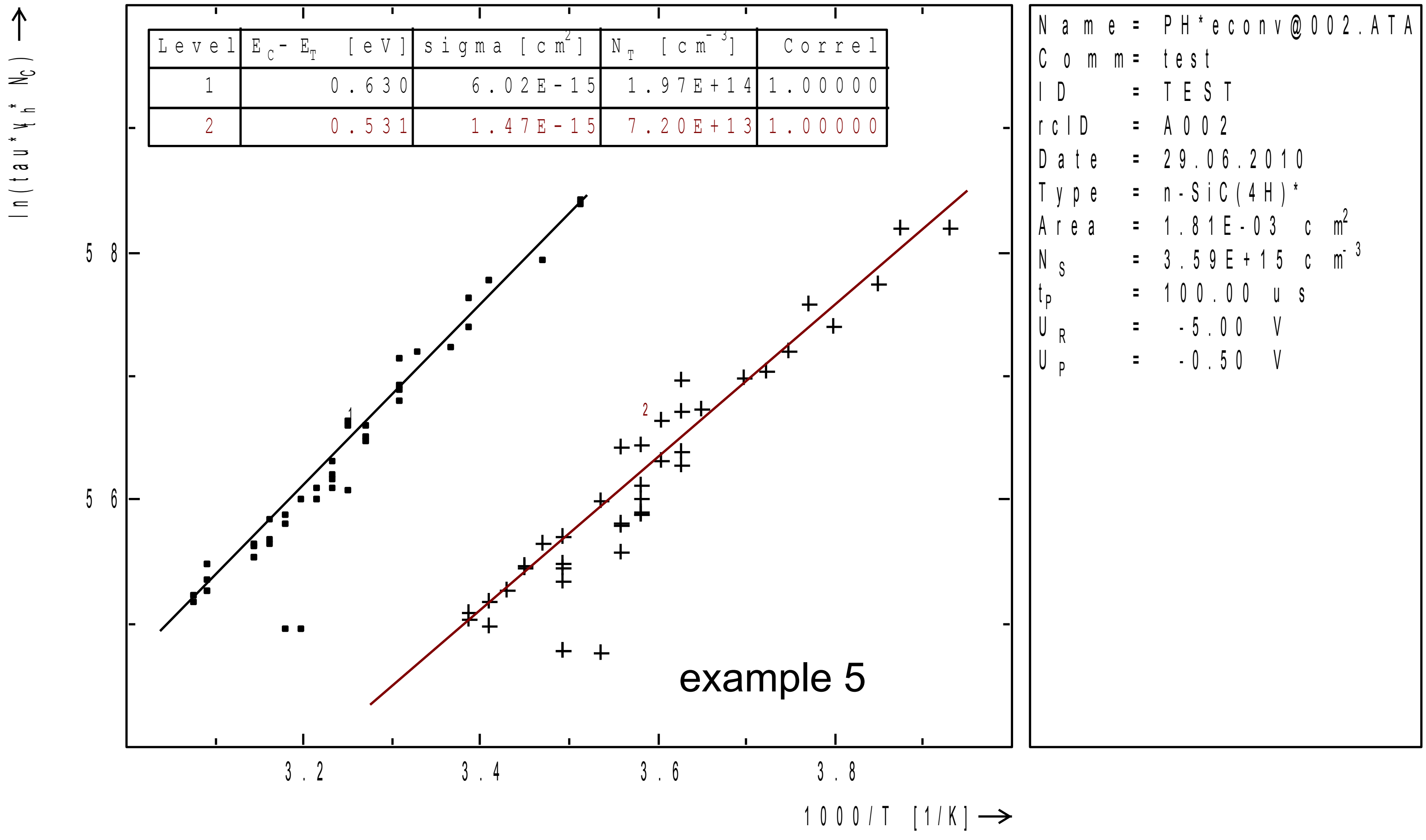


Level	$E_C - E_T$ [eV]	sigma [cm^2]	N_T [cm^{-3}]	Correl
1	0.409	1.76E-14	5.00E+13	0.98381
2	0.666	8.44E-14	3.24E+14	0.98918
3	0.760	9.18E-14	1.28E+14	0.98827

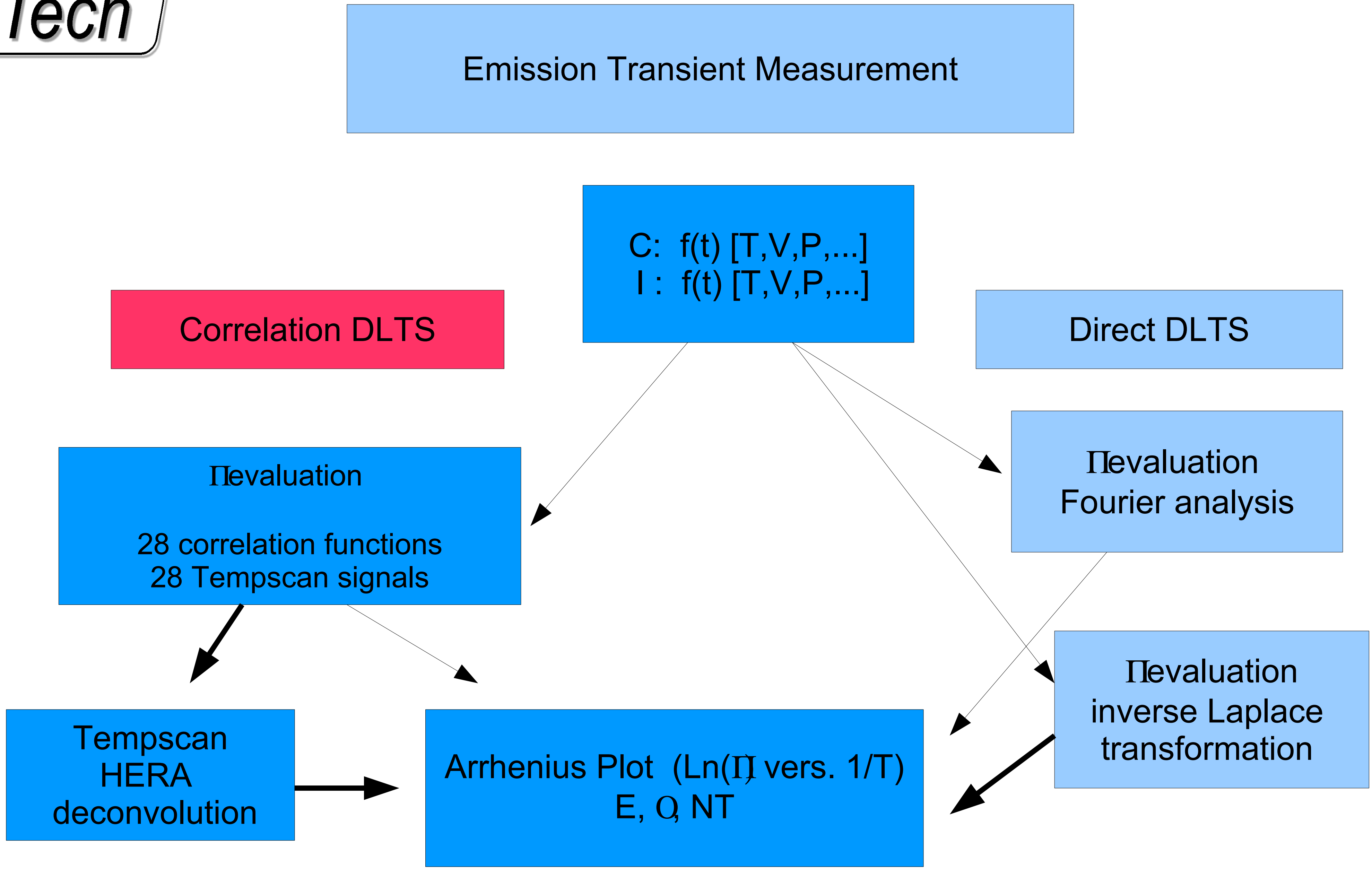
first 3 peaks seem to be single processes, the broad peak around 400K is definitly an overlapping signal.



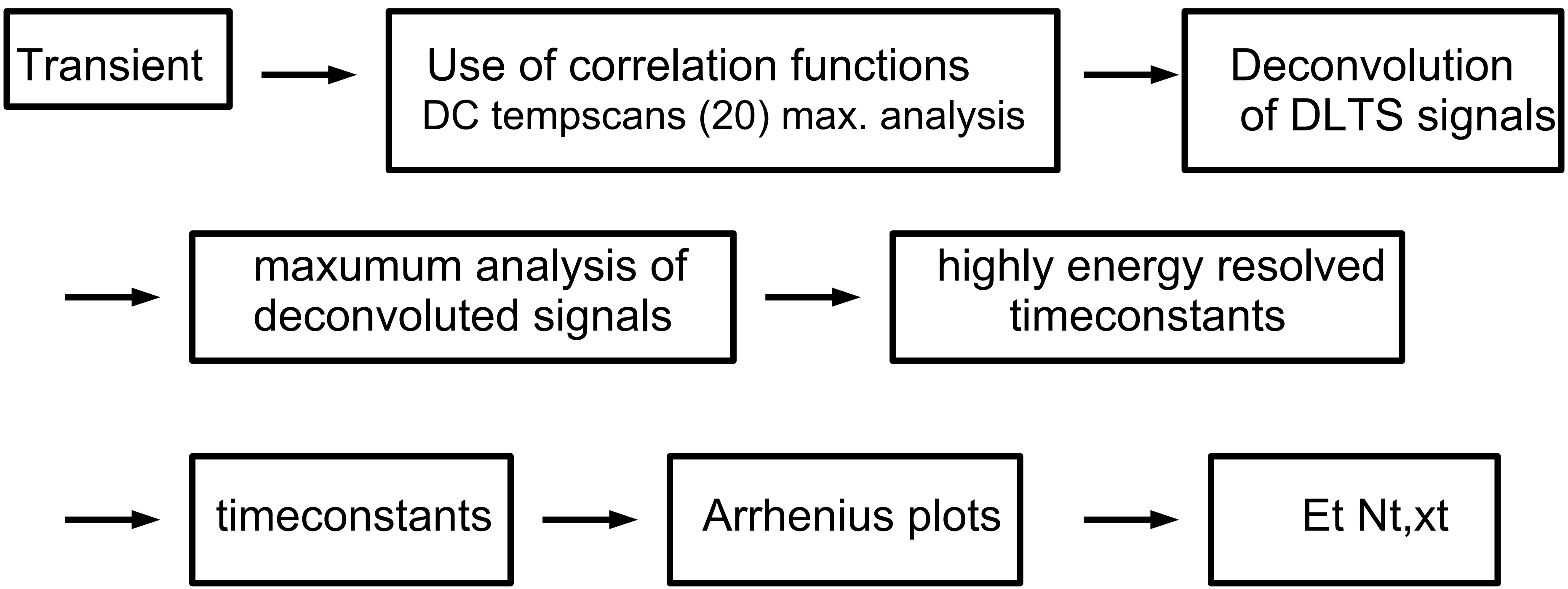
DLTS signal a1 vers. temperature:
black: measured data, red: simulated data (SRH) using the Arrhenius data above
green: difference between black and red data.
the difference curve is used for detecting onother 2 levels hidden in the main peak
the Arrhrenius plot for these peaks is shown on the next page



Arrhenius plot of the evaluation of the above plot
(green curve)

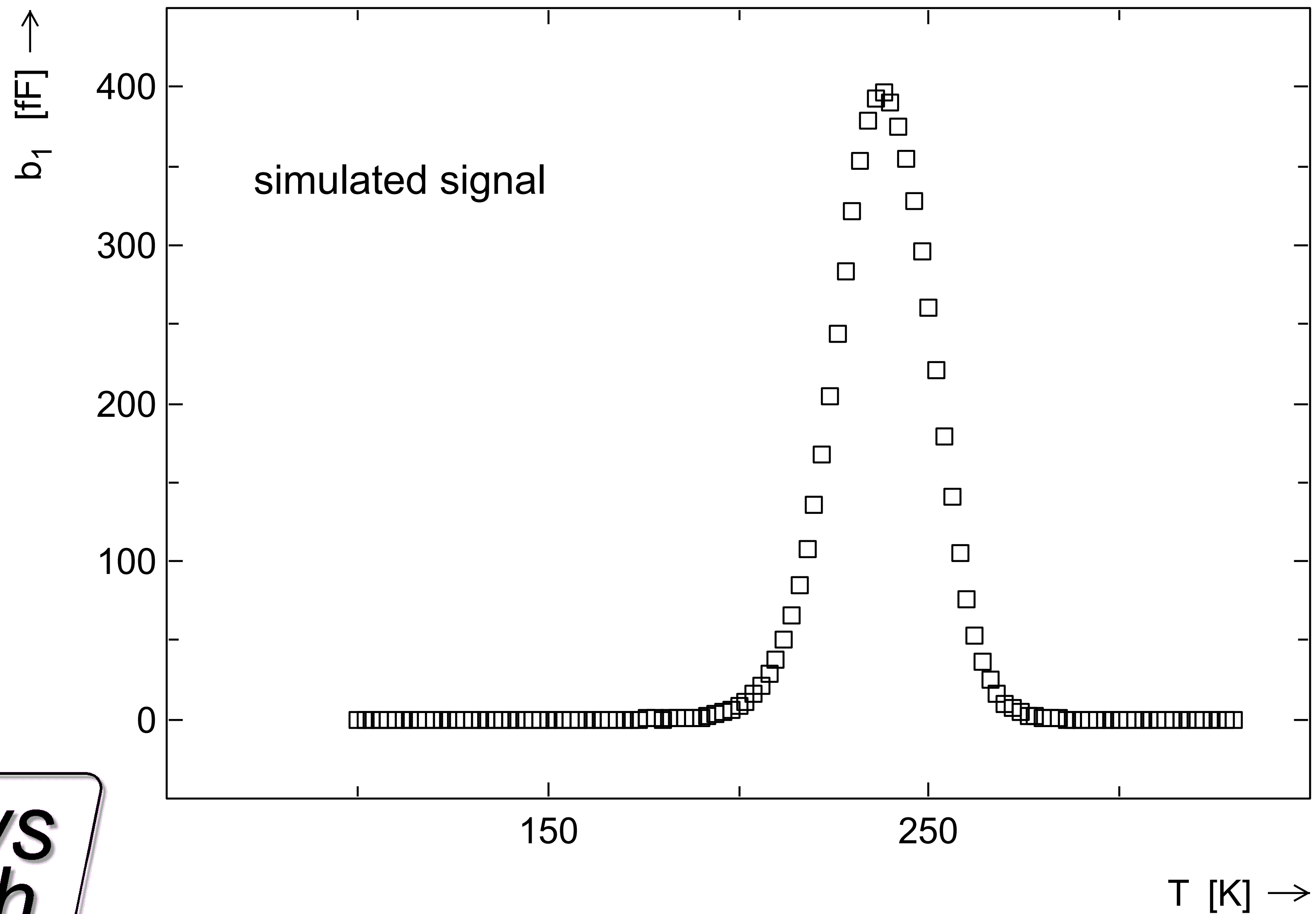

Emission Transient Measurement
C: f(t) [T,V,P,...]
I : f(t) [T,V,P,...]
Correlation DLTS
Direct DLTS
Πevaluation
28 correlation functions
28 Tempscan signals
Πevaluation
Fourier analysis
Πevaluation
inverse Laplace
transformation
Tempscan
HERA
deconvolution
Arrhenius Plot (Ln(Π vers. 1/T)
E, Q, NT

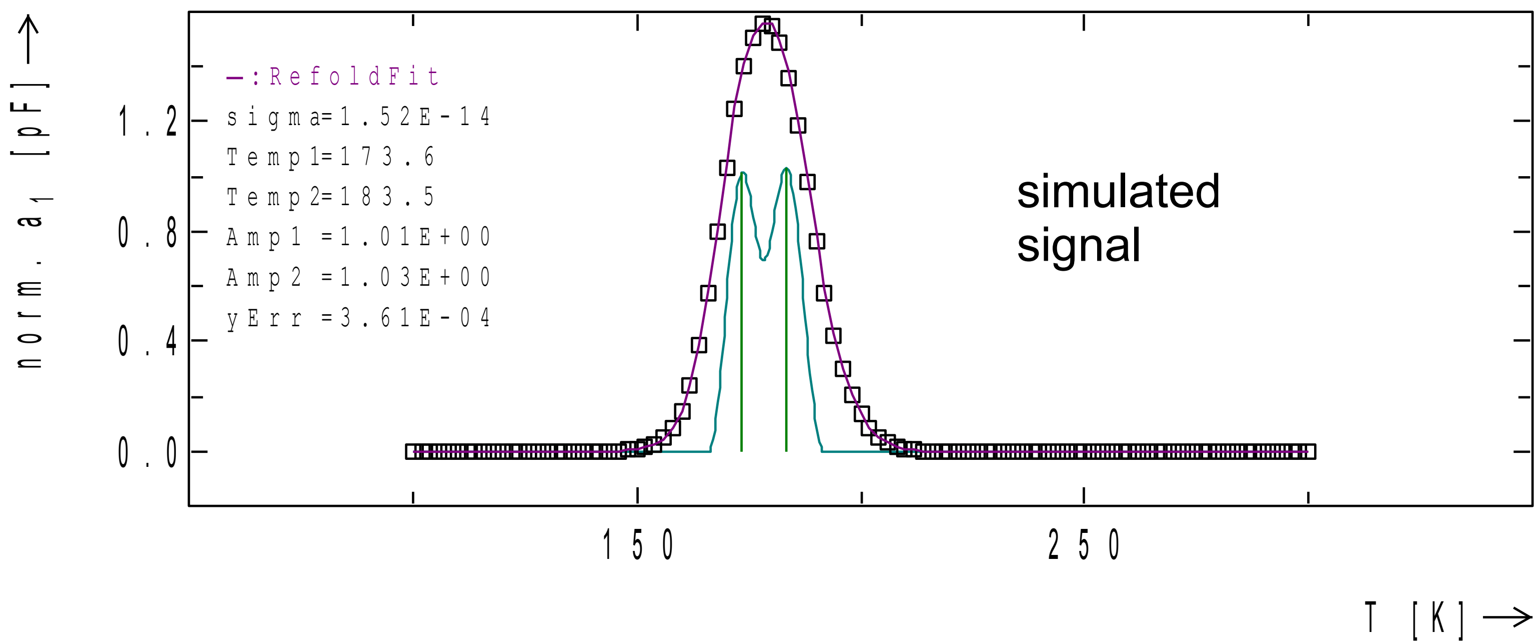
High Energy Resolution Correlation DLTS

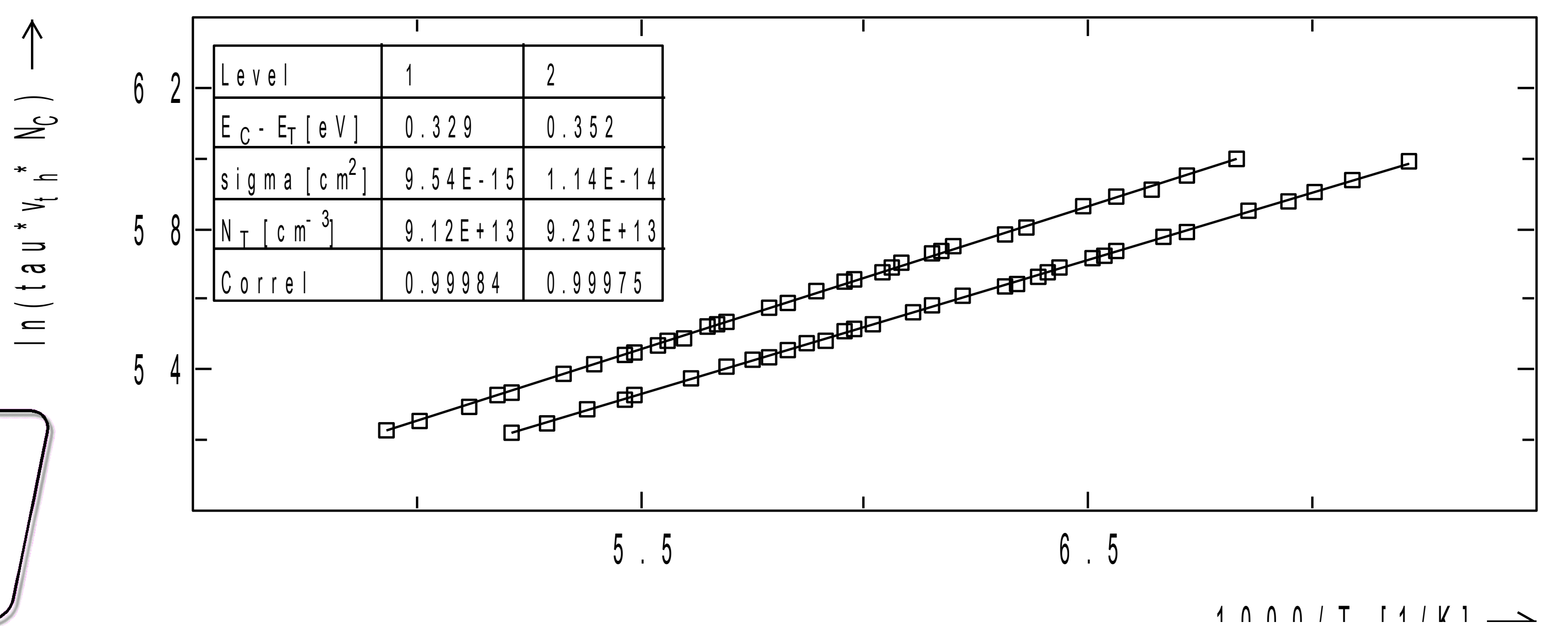


Phys
Tech

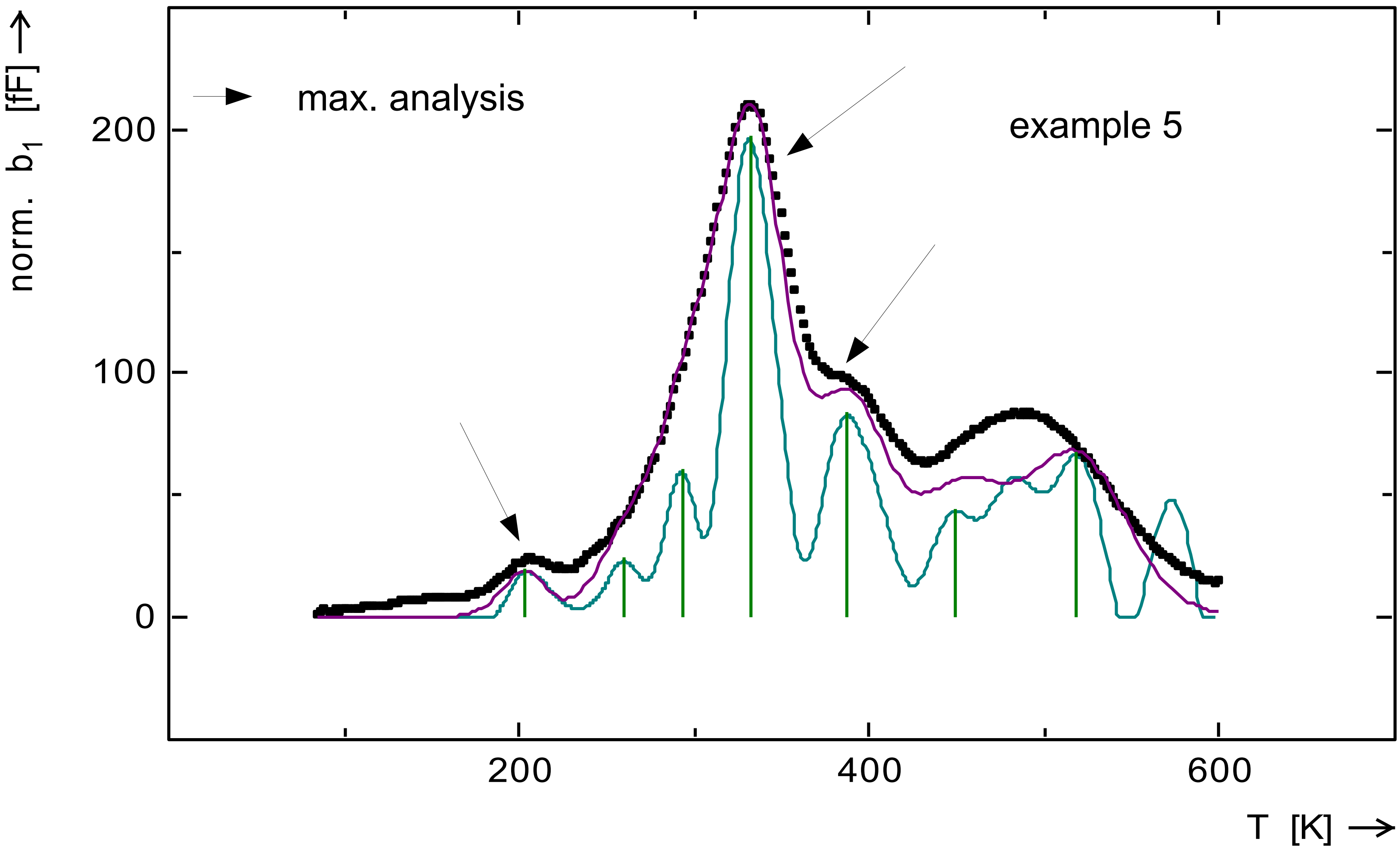
Deconvolution of correlation DLTS signal



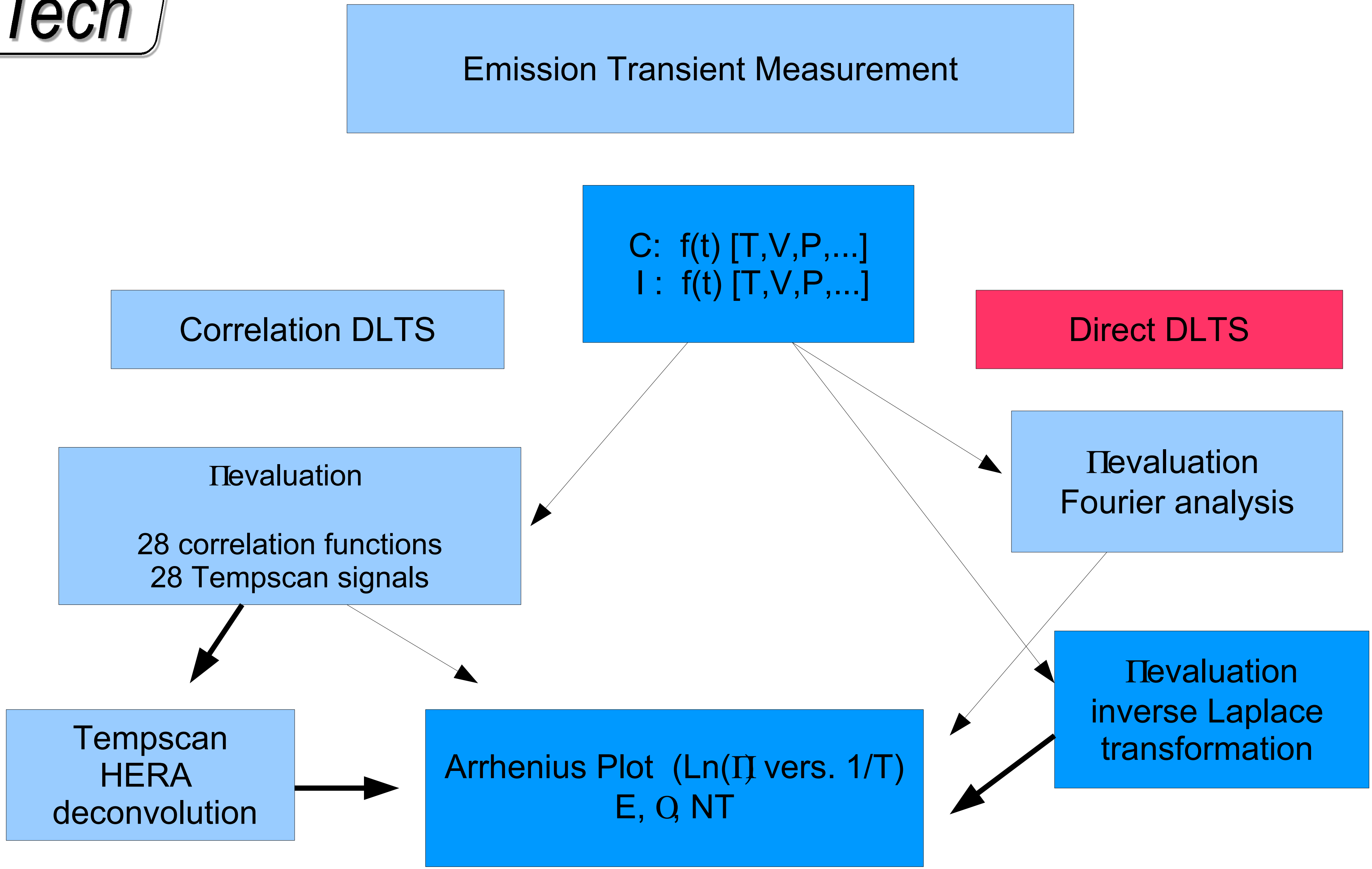




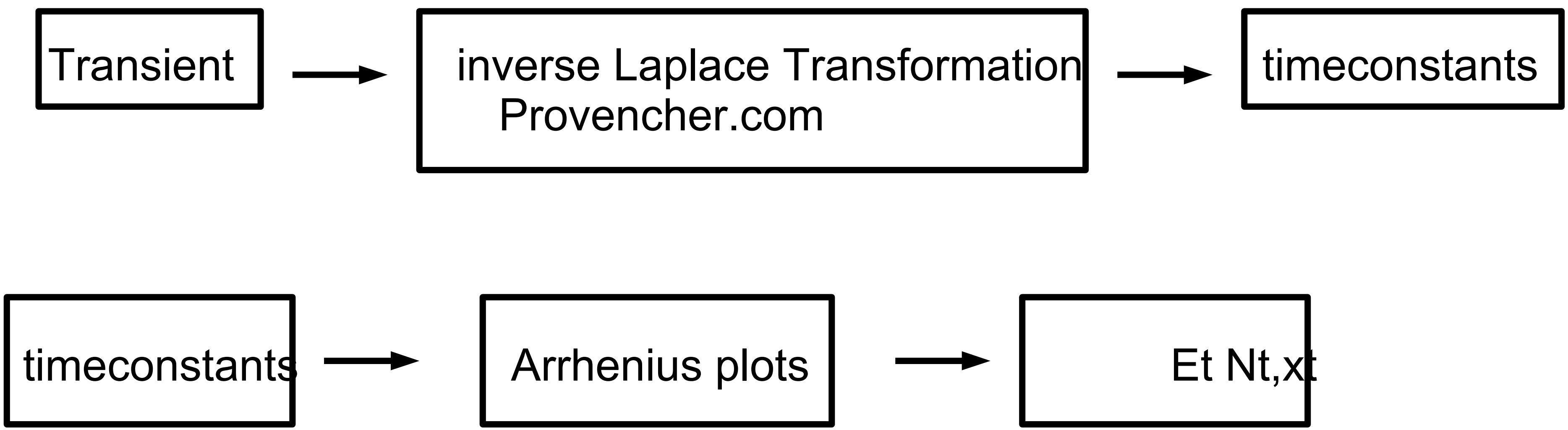
Level	1	2
$E_C - E_T$ [eV]	0.329	0.352
sigma [cm^2]	9.54E-15	1.14E-14
N_T [cm^{-3}]	9.12E+13	9.23E+13
Correl	0.99984	0.99975



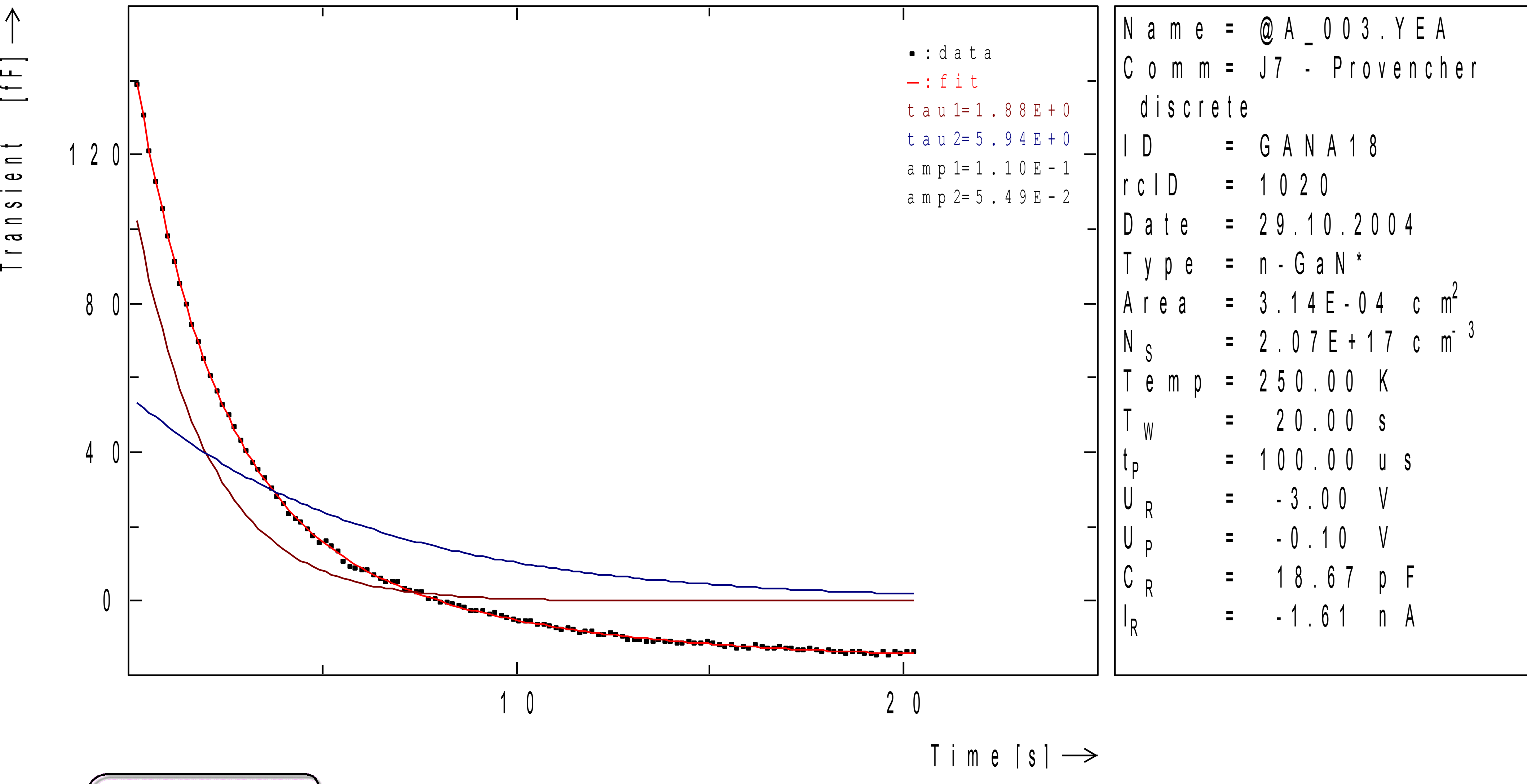
DC DLTS signal (b1): black dots
the deconvolution results of it: blue line
marked maxima: green vertical lines
calculated (SRH) DLTS signal (b1): purple line


Emission Transient Measurement
C: f(t) [T,V,P,...]
I : f(t) [T,V,P,...]
Correlation DLTS
Direct DLTS
Πevaluation
28 correlation functions
28 Tempscan signals
Πevaluation
Fourier analysis
Πevaluation
inverse Laplace
transformation
Tempscan
HERA
deconvolution
Arrhenius Plot (Ln(Π vers. 1/T)
E, Ω, NT

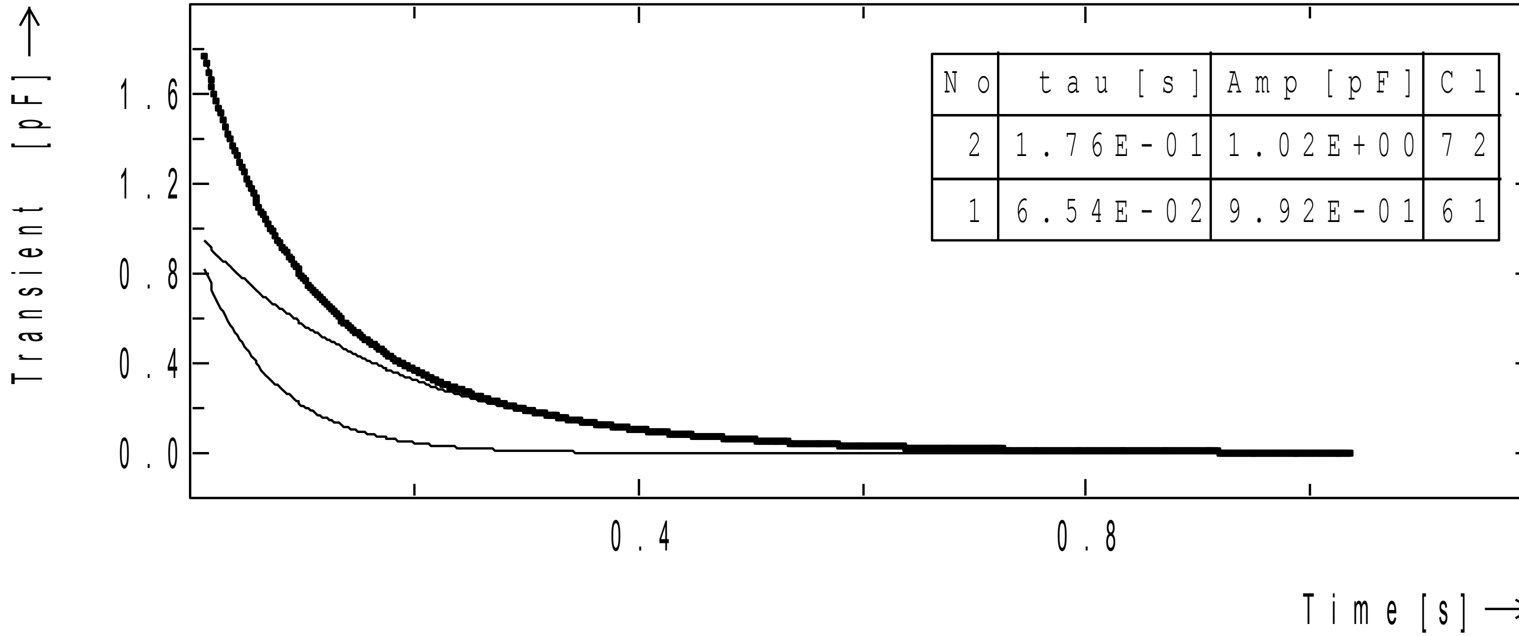
Laplace DLTS (Direct Transient Analysis)

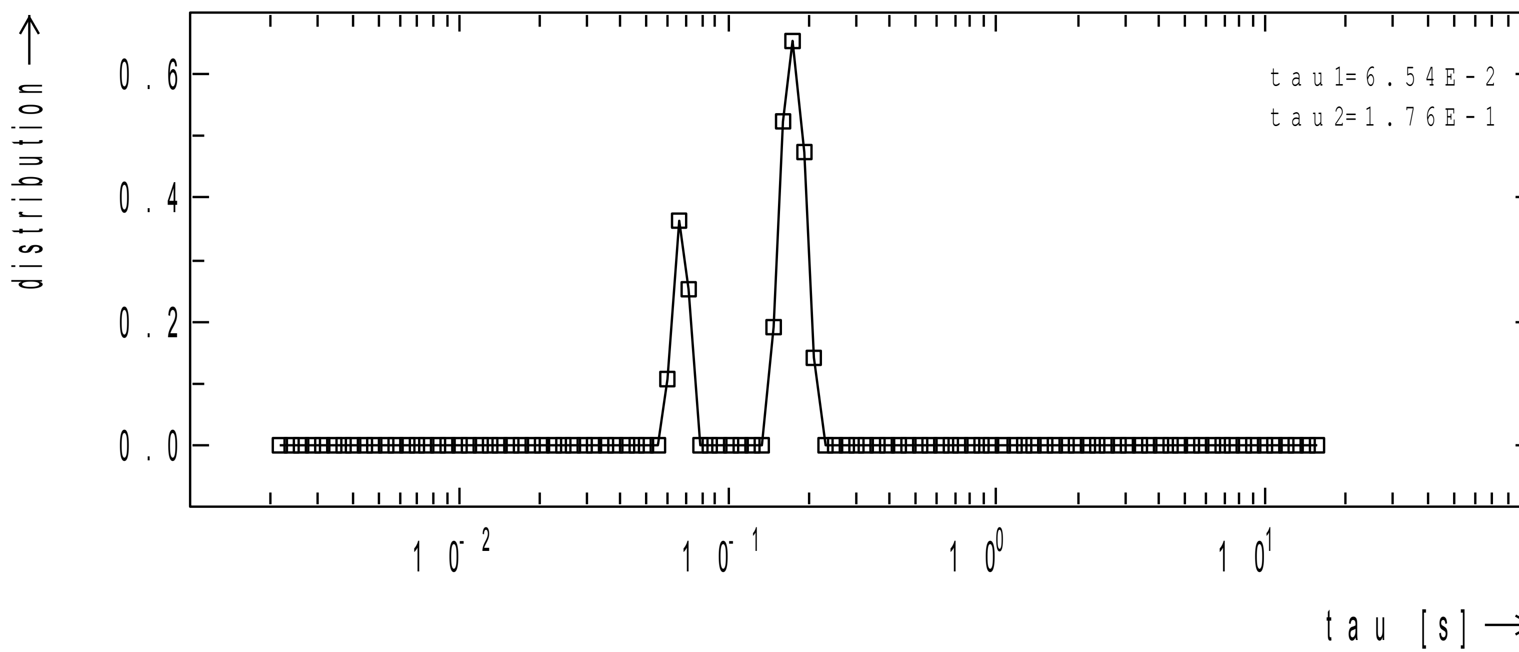


Phys Tech

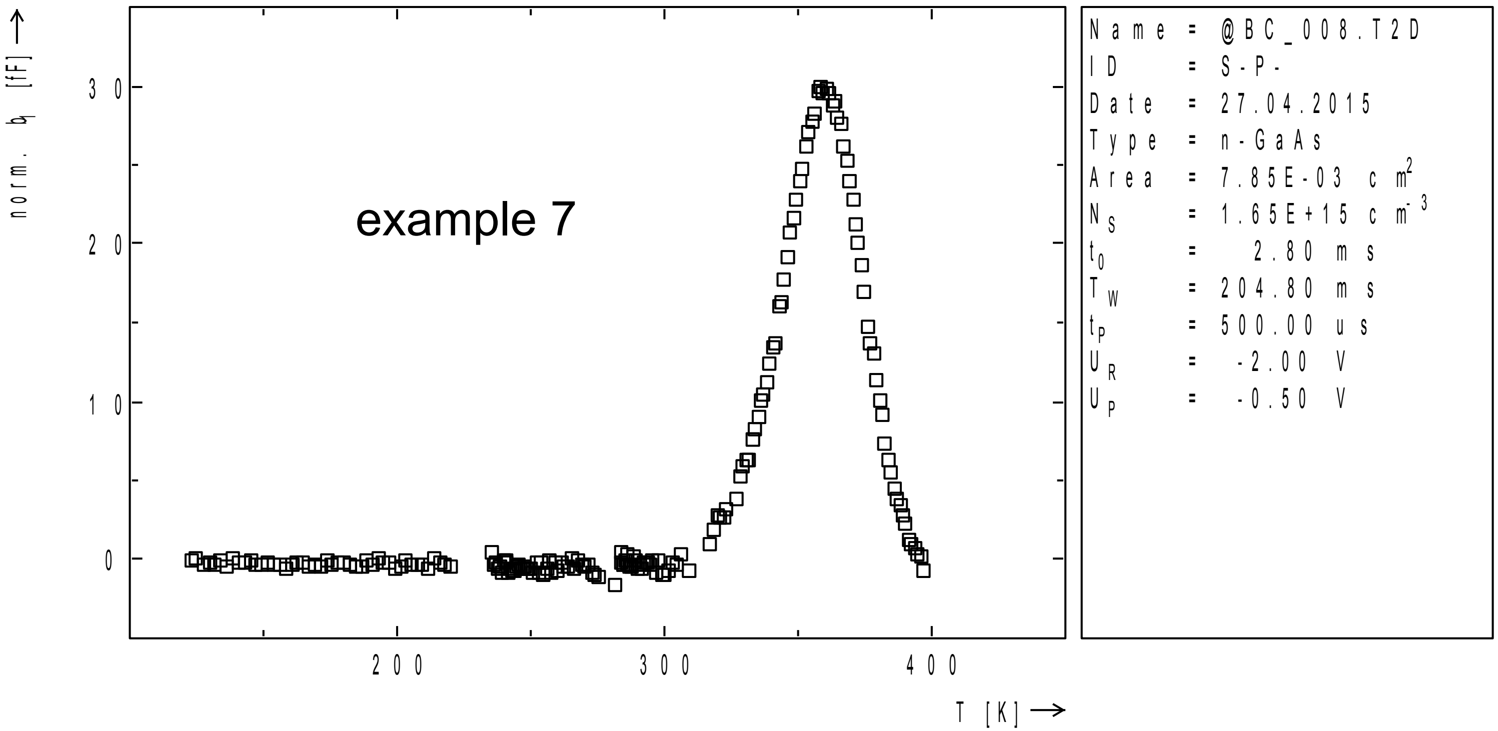


Transient [fF] →
120
80
40
0
10
20
Time [s] →
▪ : data
— : fit
tau1=1.88E+0
tau2=5.94E+0
amp1=1.10E-1
amp2=5.49E-2
Name = @A_003.YEA
Comm = J7 - Provencher discrete
ID = GANA18
rcID = 1020
Date = 29.10.2004
Type = n-GaN*
Area = 3.14E-04 cm²
N_S = 2.07E+17 cm⁻³
Temp = 250.00 K
T_W = 20.00 s
t_P = 100.00 us
U_R = -3.00 V
U_P = -0.10 V
C_R = 18.67 pF
I_R = -1.61 nA

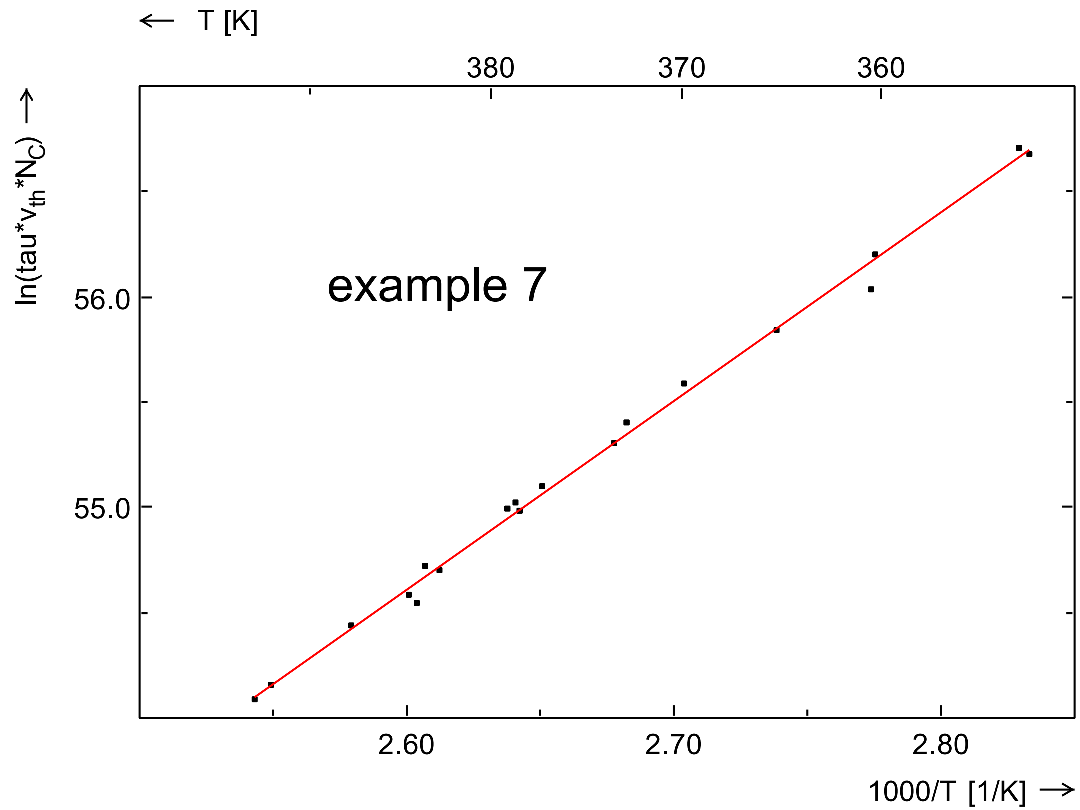

Transient [pF]
1.6
1.2
0.8
0.4
0.0
0.4
0.8
Time [s]
No | tau [s] | Amp [pF] | Cl
2 | 1.76E-01 | 1.02E+00 | 72
1 | 6.54E-02 | 9.92E-01 | 61


distribution
0.6
0.4
0.2
0.0
tau1=6.54E-2
tau2=1.76E-1
10^{-2}
10^{-1}
10^{0}
10^{1}
tau [s]

Phys
Tech

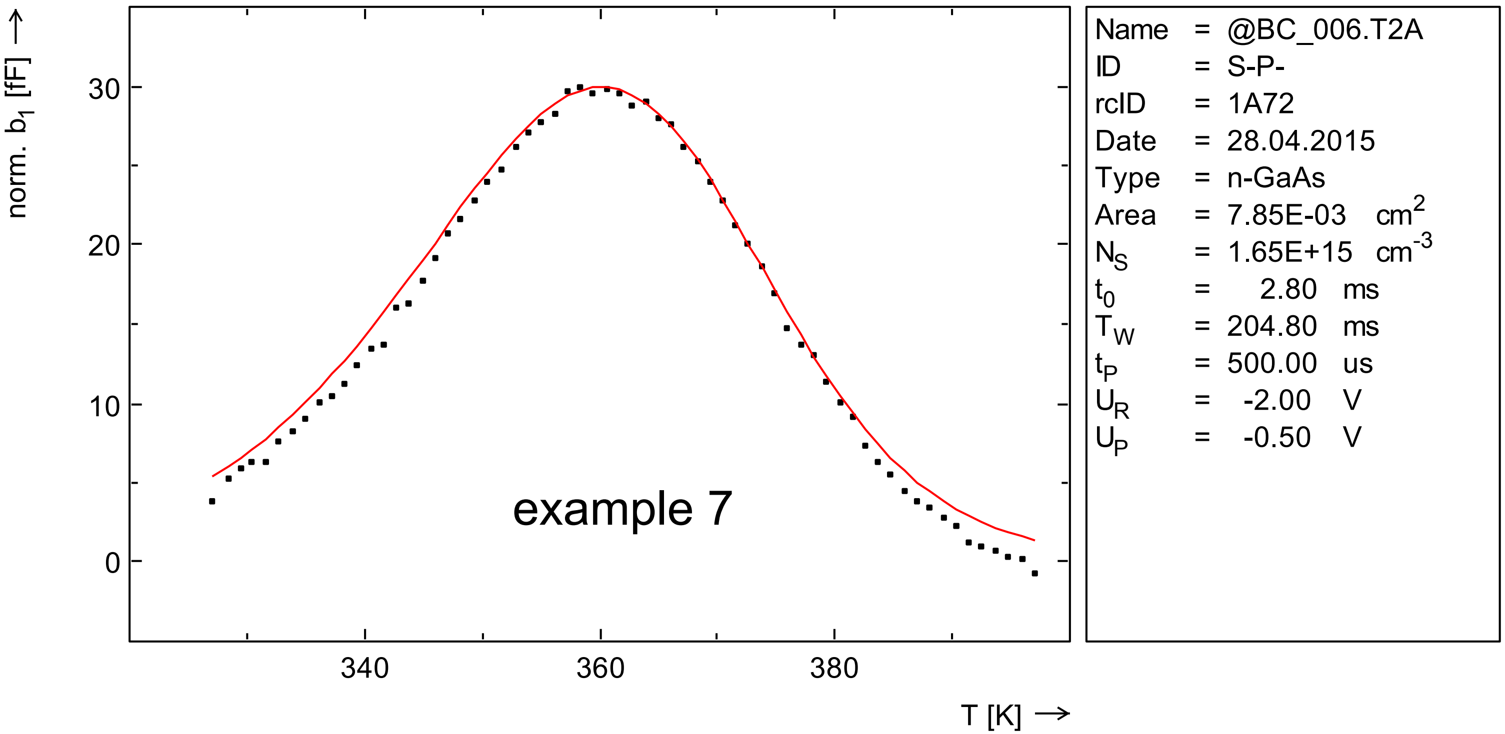


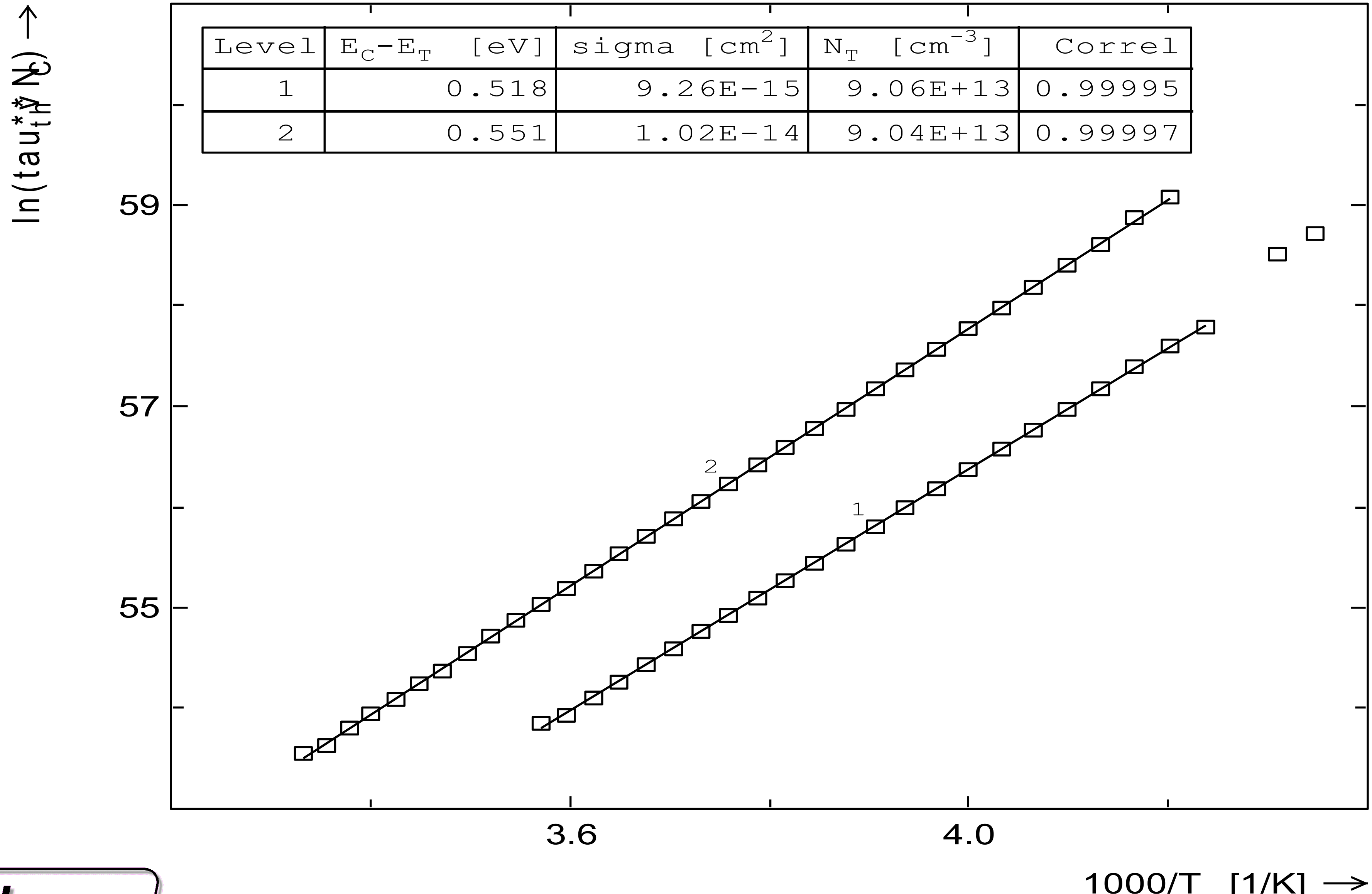
DLTS measurement (DLTS signal b1 versus temperature. Both measurements have been combined to a total temperature range DLTS measurement



Name	=	@BC_006.ATA	
ID	=	S-P-	
rcID	=	A034	
Date	=	28.04.2015	
Type	=	n-GaAs	
Area	=	7.85E-03	cm^2
N_S	=	1.65E+15	cm^{-3}
t_P	=	500.00	us
U_R	=	-2.00	V
U_P	=	-0.50	V
Energy	=	0.772	eV
sigma	=	2.49E-14	cm^2
N_T	=	1.30E+12	cm^{-3}
N_{Ts}	=	1.55E+13	cm^{-3}
Correl	=	0.99745	

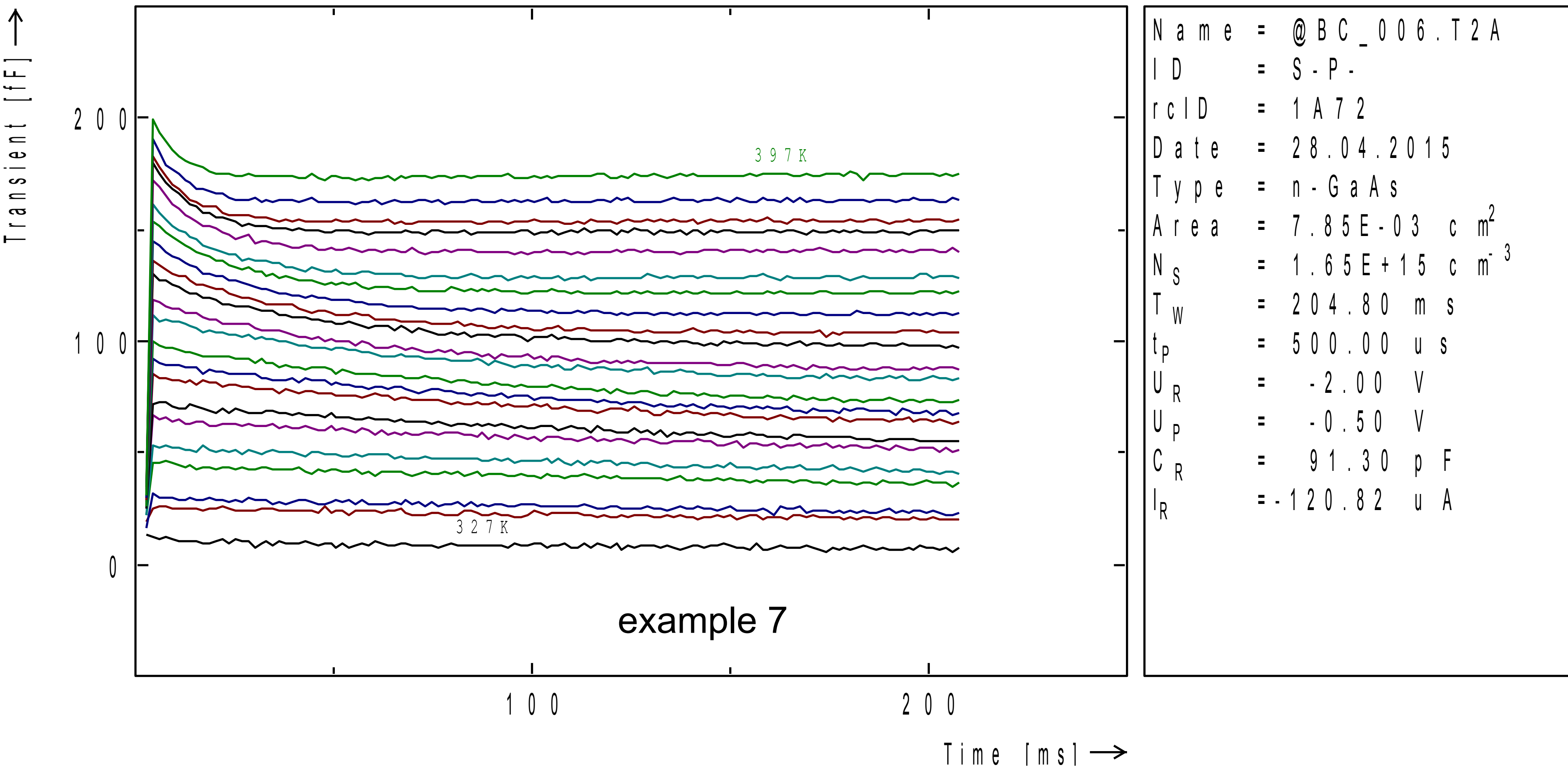
Arrhenius plot of the above measurement using the maximum analysis.
Energy:0.77eV, capture cross section: 2.5 E-14cm2
See also last page


norm. b_1 [fF] →
30
20
10
0
340
360
380
T [K] →
example 7
Name = @BC_006.T2A
ID = S-P-
rcID = 1A72
Date = 28.04.2015
Type = n-GaAs
Area = 7.85E-03 cm^2
N_S = 1.65E+15 cm^{-3}
t_0 = 2.80 ms
T_W = 204.80 ms
t_P = 500.00 us
U_R = -2.00 V
U_P = -0.50 V



Level	E_C-E_T [eV]	sigma [cm^2]	N_T [cm^{-3}]	Correl
1	0.518	9.26E-15	9.06E+13	0.99995
2	0.551	1.02E-14	9.04E+13	0.99997

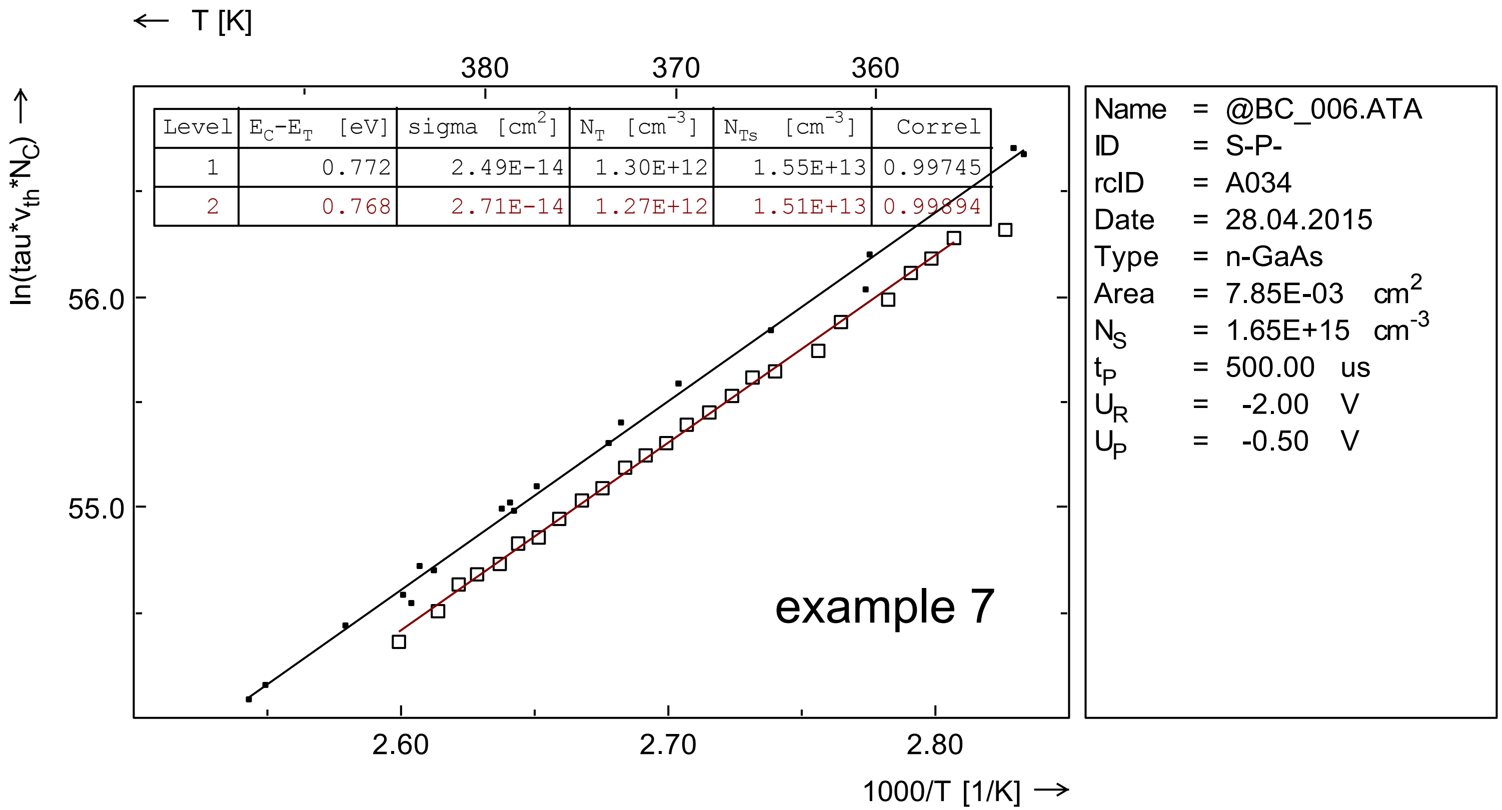
Phys Tech



Some of the measured transients of the high temperature DLTS measurement

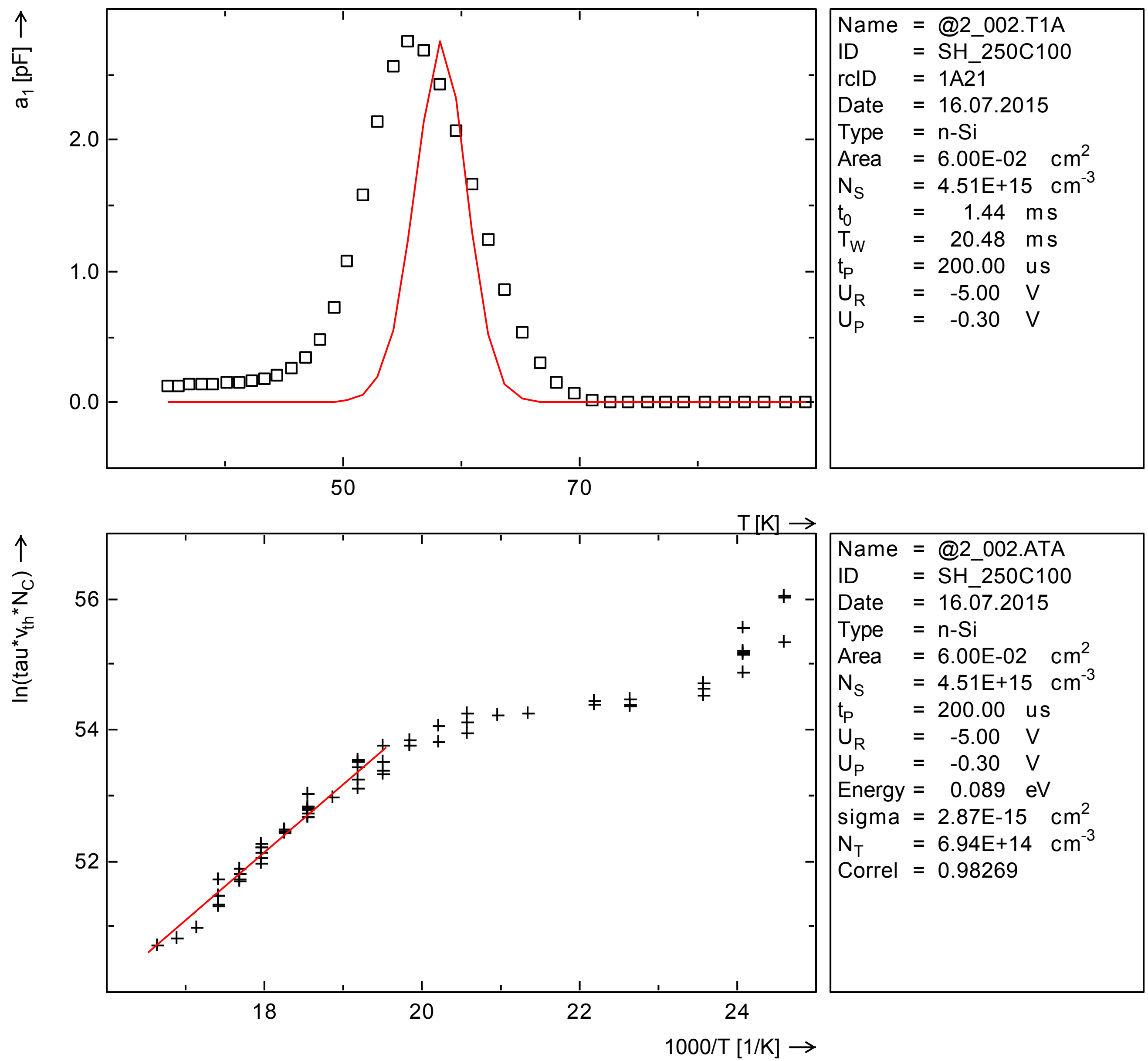
It is nice to see the temperature depending change of the timeconstant.
These transients can (and are in the next page) used for the so called Laplace evaluation (direct transient timeconstant evaluation)

Phys Tech



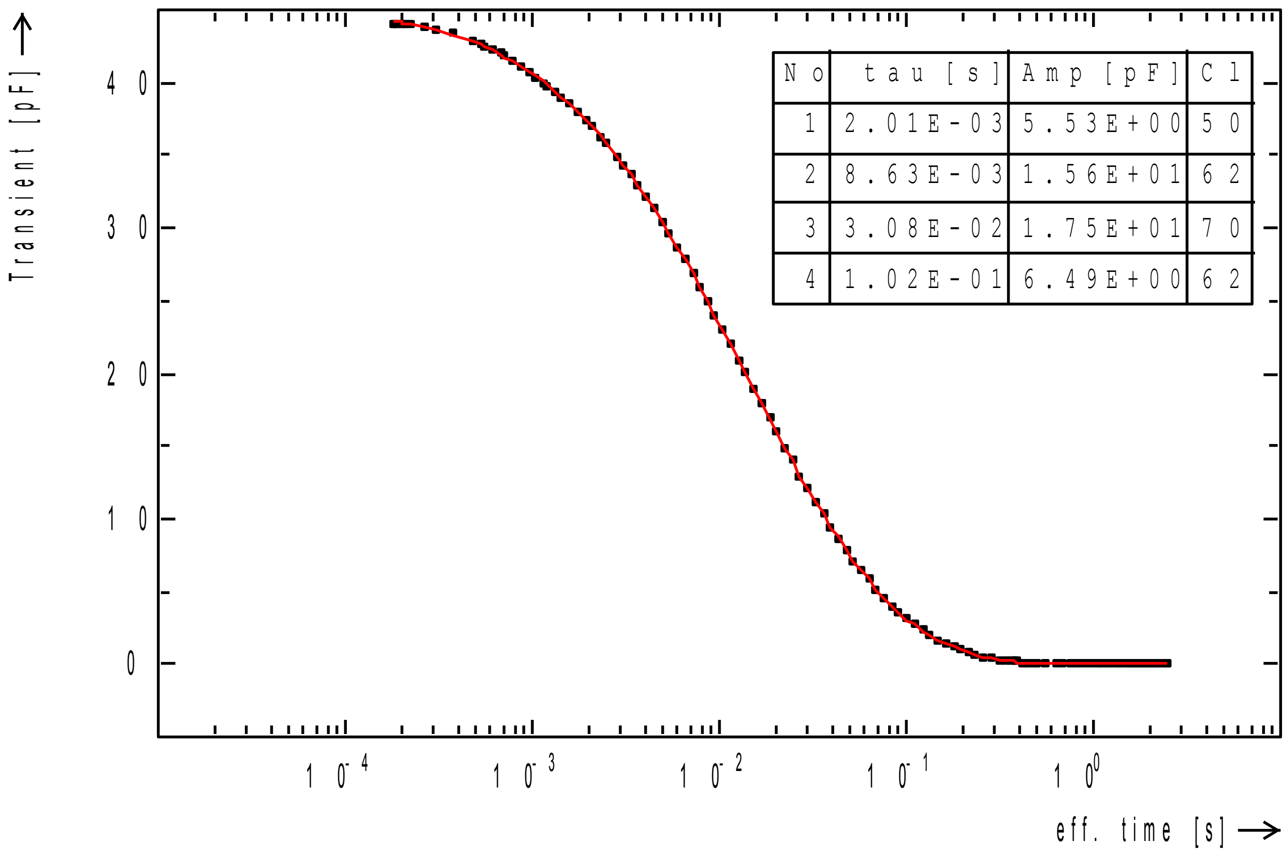
Level	E_C-E_T [eV]	sigma [cm^2]	N_T [cm^{-3}]	N_{Ts} [cm^{-3}]	Correl
1	0.772	2.49E-14	1.30E+12	1.55E+13	0.99745
2	0.768	2.71E-14	1.27E+12	1.51E+13	0.99894

Arrhenius plot of the above measurement comparing the maximum analysis with the direct Laplace analysis.
Level1: maximum analysis, Level2: Laplace analysis



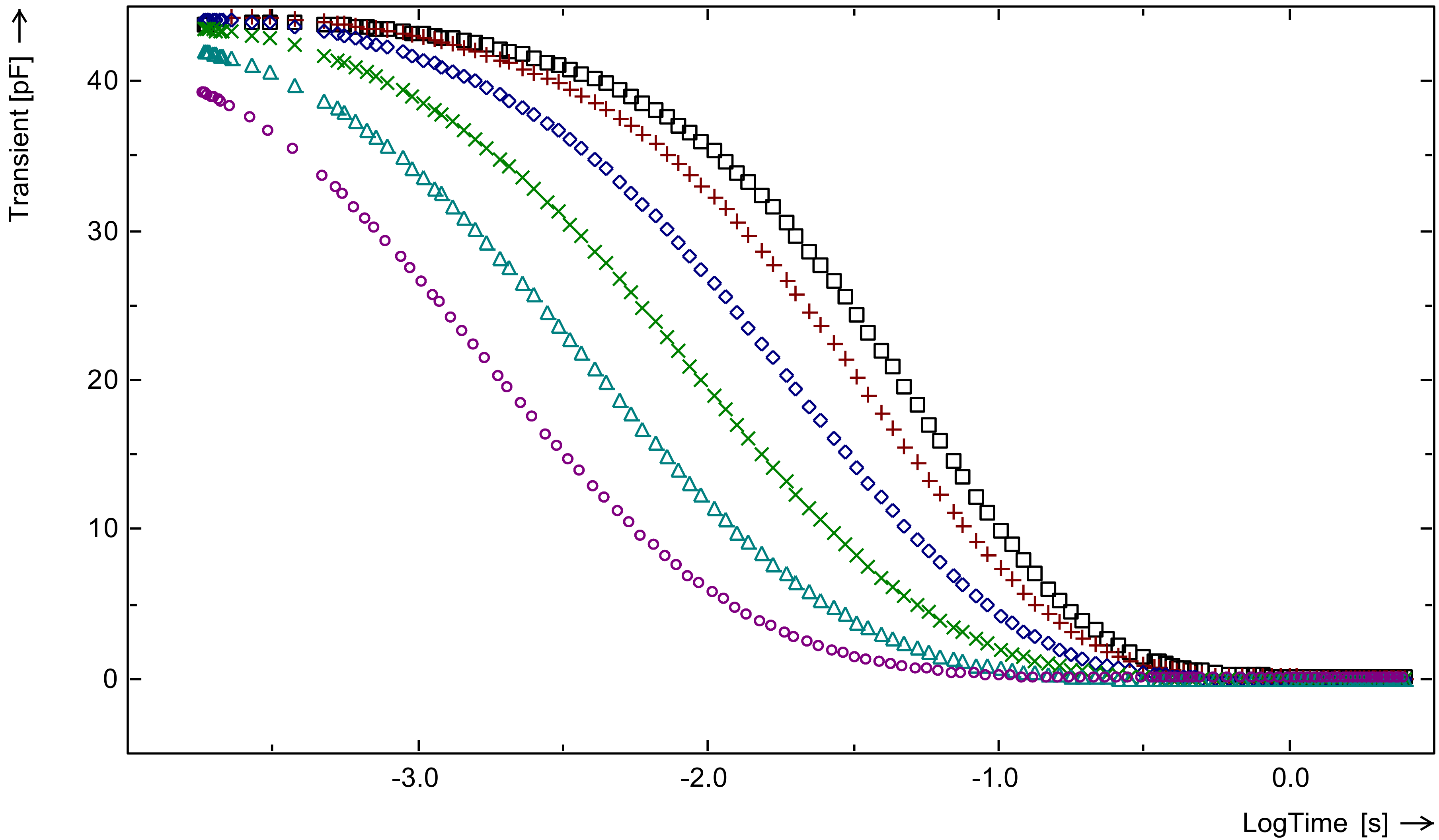
a1 [pF]
2.0
1.0
0.0
50
70
T [K]
Name = @2_002.T1A
ID = SH_250C100
rcID = 1A21
Date = 16.07.2015
Type = n-Si
Area = 6.00E-02 cm2
NS = 4.51E+15 cm-3
t0 = 1.44 ms
TW = 20.48 ms
tP = 200.00 us
UR = -5.00 V
UP = -0.30 V
ln(tau*vth*NC)
56
54
52
18
20
22
24
1000/T [1/K]
Name = @2_002.ATA
ID = SH_250C100
Date = 16.07.2015
Type = n-Si
Area = 6.00E-02 cm2
NS = 4.51E+15 cm-3
tP = 200.00 us
UR = -5.00 V
UP = -0.30 V
Energy = 0.089 eV
sigma = 2.87E-15 cm2
NT = 6.94E+14 cm-3
Correl = 0.98269

treated Si sample



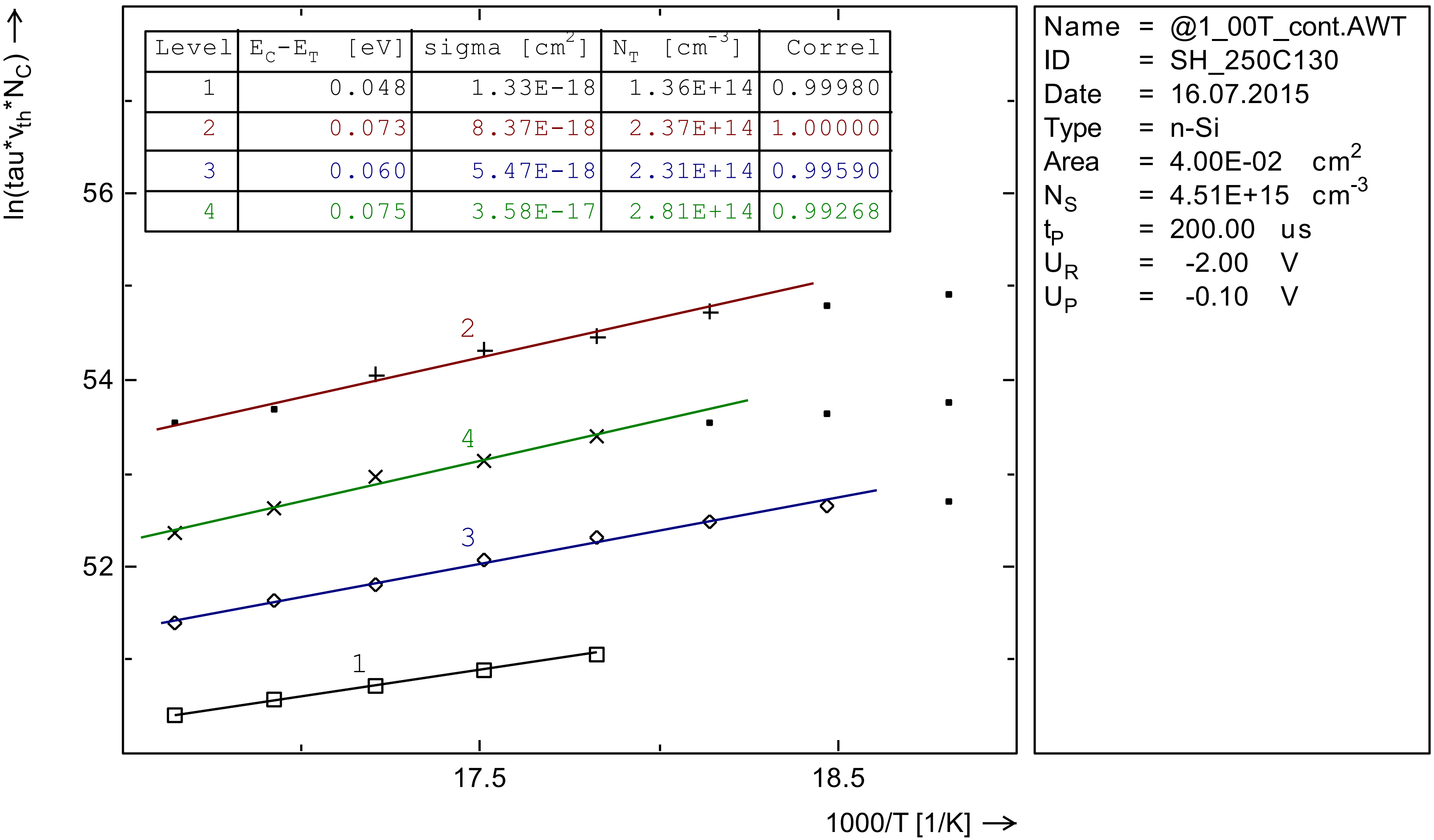
No	tau [s]	Amp [pF]	Cl
1	2.01E-03	5.53E+00	50
2	8.63E-03	1.56E+01	62
3	3.08E-02	1.75E+01	70
4	1.02E-01	6.49E+00	62

Name = @1_00T006.PWA
ID = SH_250C130
rcID = 2015*
Date = 16.07.2015
Type = n-Si
Area = 4.00E-02 cm^2
N_S = 4.51E+15 cm^{-3}
Temp = 55.08 K
TempX = 0.11 K
t_P = 200.00 us
U_R = -2.00 V
U_P = -0.10 V
C_R = 472.52 pF
I_R = -4.34 uA
Dif-T = 0.11 K
Class = 64

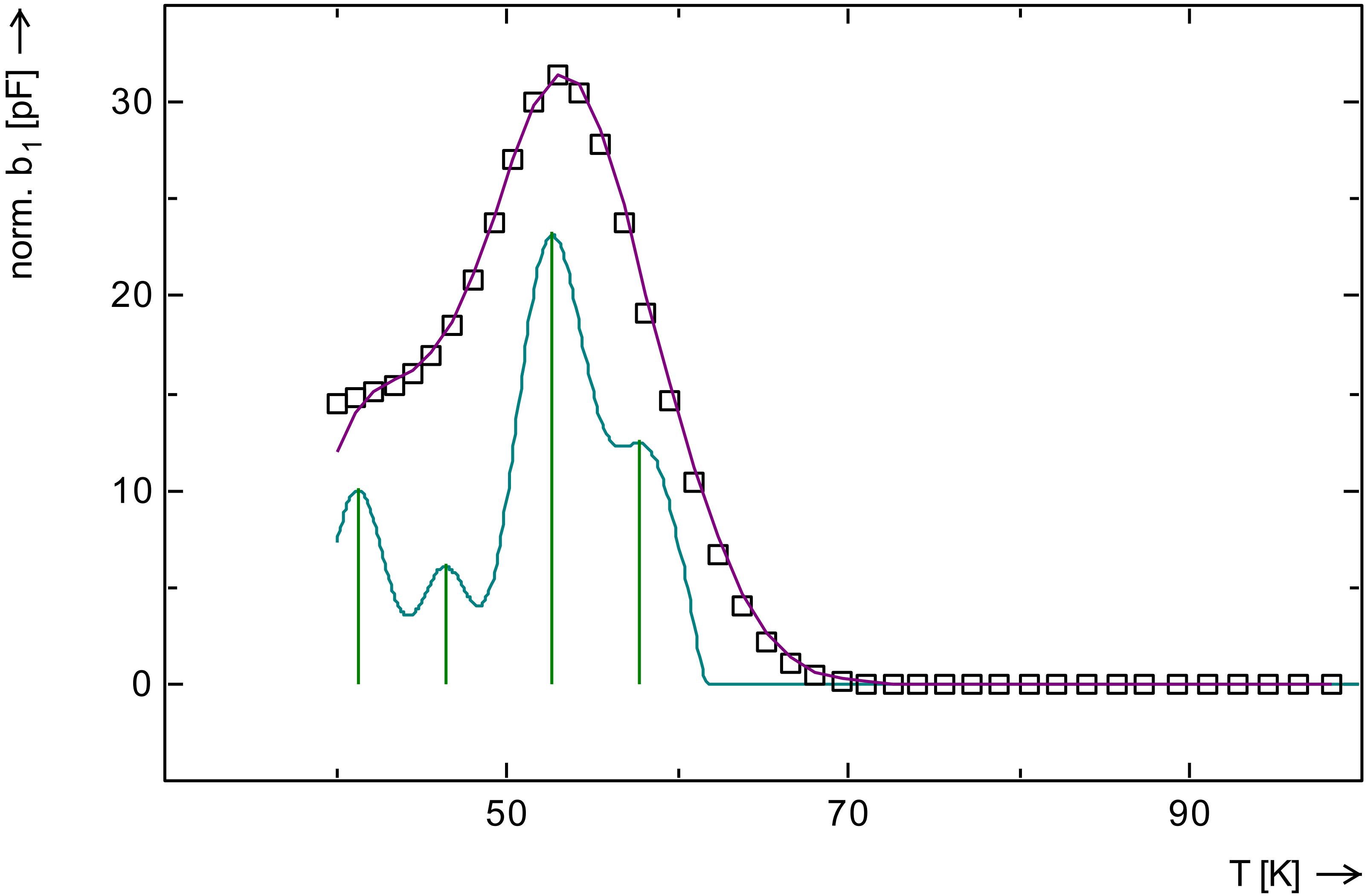


Log sampled transients measured from 50K to 65 K

3 measurements with linear sampling using 65000 data points each and constructing a log sampled transient



Level	E_C-E_T [eV]	sigma [cm^2]	N_T [cm^{-3}]	Correl
1	0.048	1.33E-18	1.36E+14	0.99980
2	0.073	8.37E-18	2.37E+14	1.00000
3	0.060	5.47E-18	2.31E+14	0.99590
4	0.075	3.58E-17	2.81E+14	0.99268



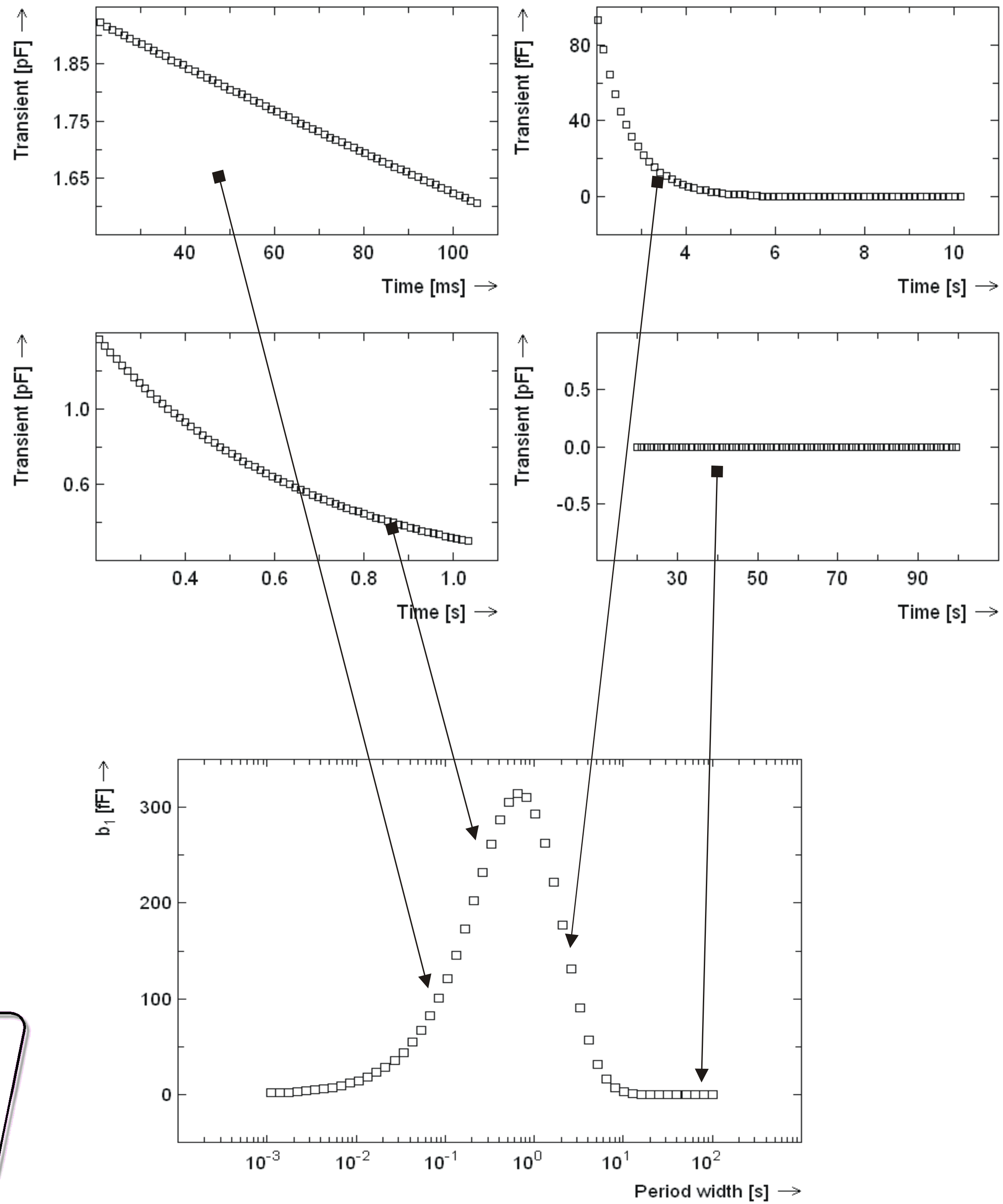
norm. b_1 [pF]
30
20
10
0
50
70
90
T [K]

ITS, ICTS, Periodwidthscan

ITS : Isothermal Transient Spectroscopy

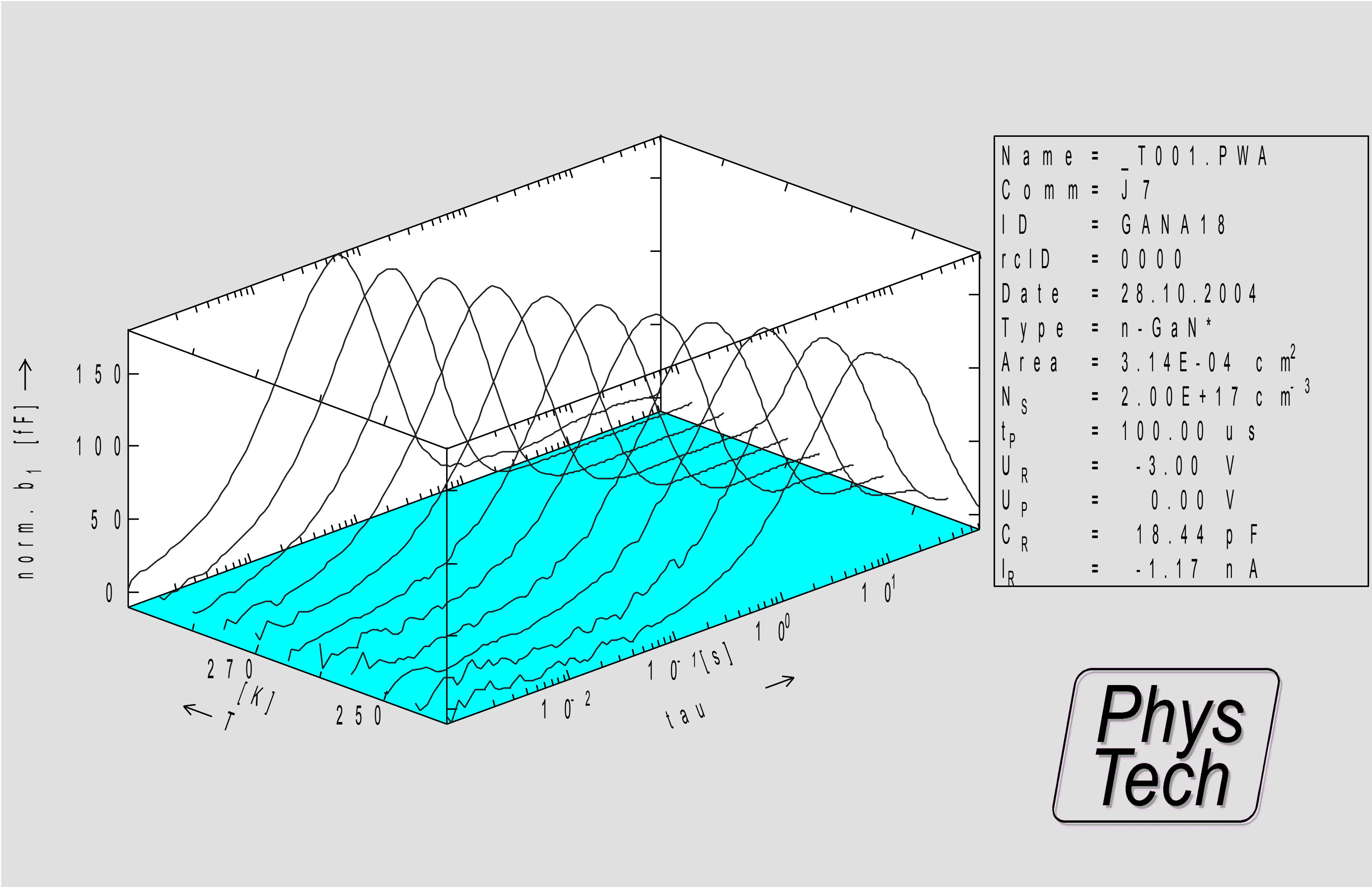
ICTS:Isothermal Current Transient Spectroscopy

Phys
Tech

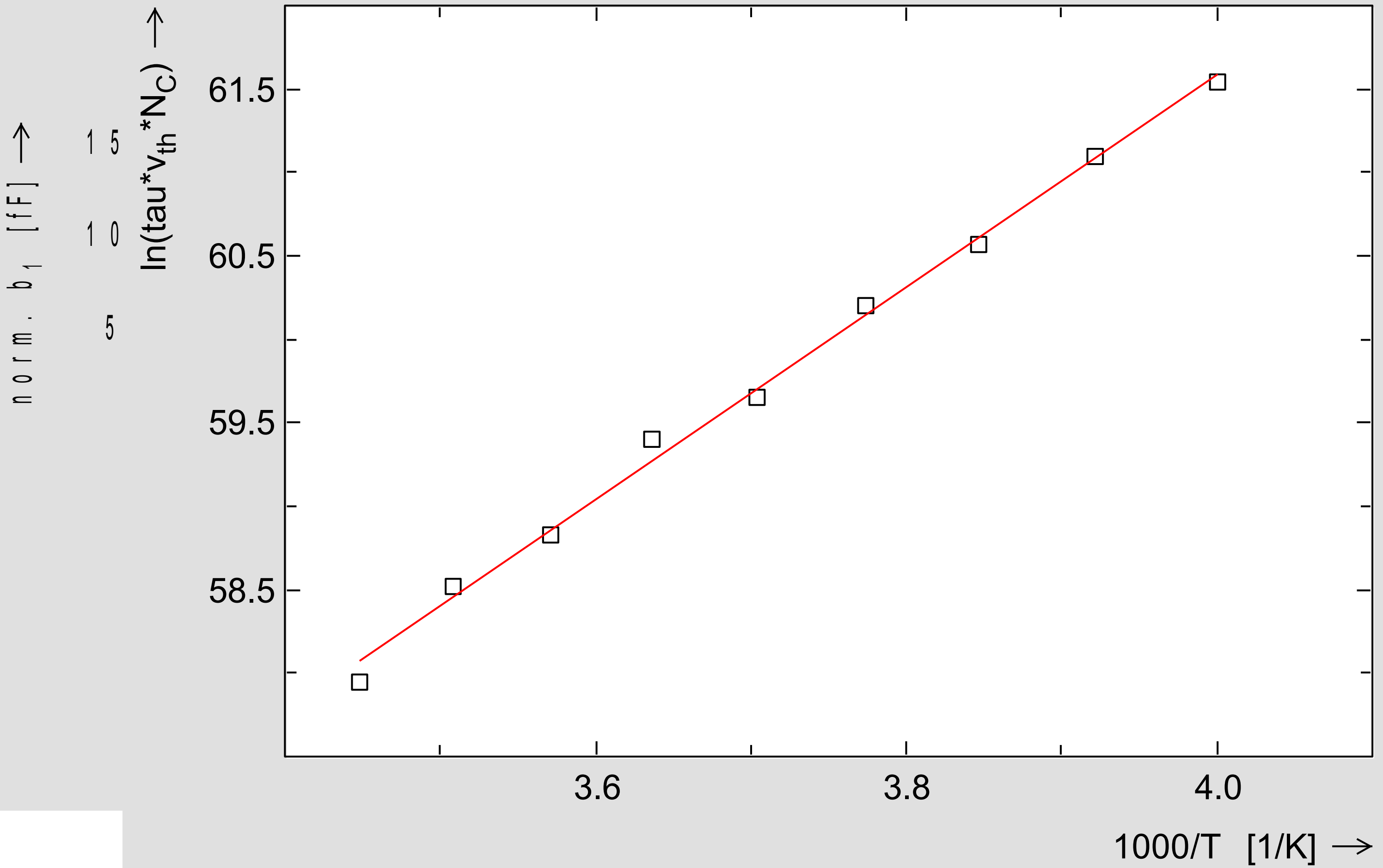


Transient [pF]
1.85
1.75
1.65
40
60
80
100
Time [ms]
Transient [fF]
80
40
0
4
6
8
10
Time [s]
Transient [pF]
1.0
0.6
0.4
0.6
0.8
1.0
Time [s]
Transient [pF]
0.5
0.0
-0.5
30
50
70
90
Time [s]
b_1 [fF]
300
200
100
0
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Period width [s]

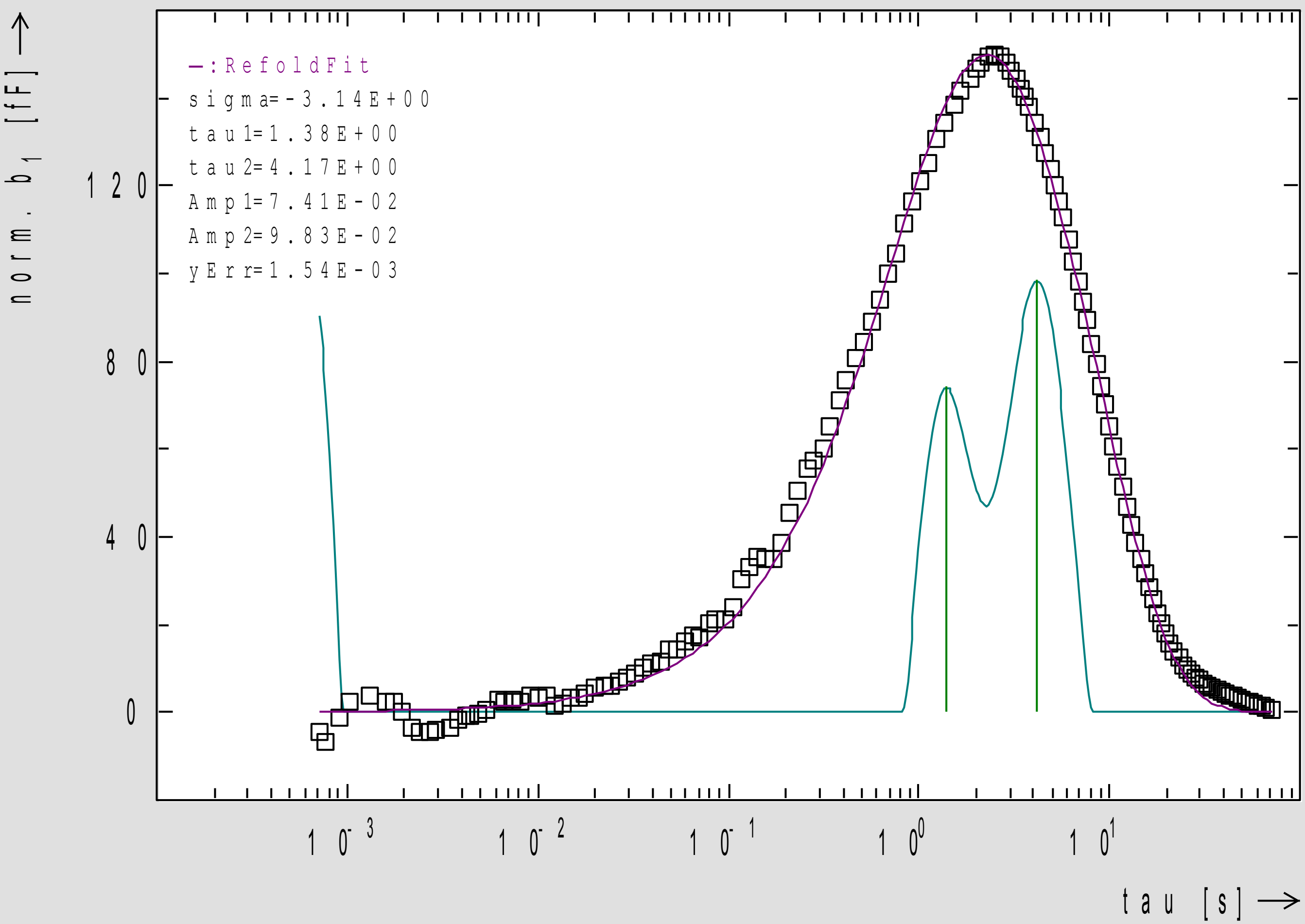
Phys
Tech



Name = _T001.PWA
Comm = J7
ID = GANA18
rcID = 0000
Date = 28.10.2004
Type = n-GaN*
Area = 3.14E-04 cm²
N_S = 2.00E+17 cm⁻³
t_P = 100.00 us
U_R = -3.00 V
U_P = 0.00 V
C_R = 18.44 pF
I_R = -1.17 nA
norm. b1 [fF]
150
100
50
0
270
250
T [K]
10⁻²
10⁻¹ [s]
10⁰
10¹
tau
Phys Tech

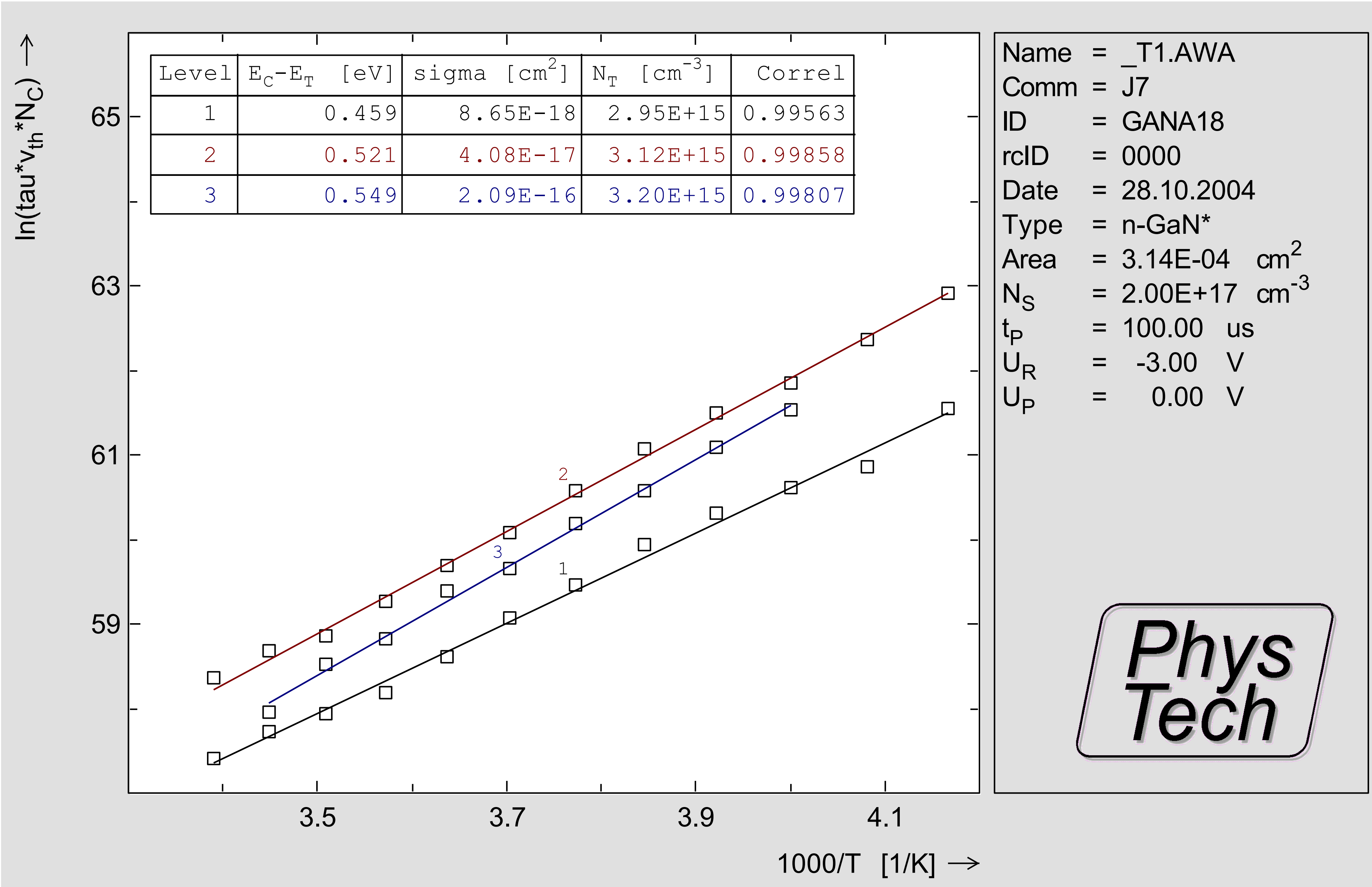


Name	=	_T1.AWA	
Comm	=	J7	
ID	=	GANA18	
rcID	=	0000	
Date	=	28.10.2004	
Type	=	n-GaN*	
Area	=	3.14E-04	cm^2
N_S	=	2.00E+17	cm^{-3}
t_P	=	100.00	us
U_R	=	-3.00	V
U_P	=	0.00	V
Energy	=	0.549	eV
sigma	=	2.09E-16	cm^2
N_T	=	3.20E+15	cm^{-3}
Correl	=	0.99807	



—: RefoldFit
sigma=-3.14E+00
tau1=1.38E+00
tau2=4.17E+00
Amp1=7.41E-02
Amp2=9.83E-02
yErr=1.54E-03
norm. b_1 [fF] →
120
80
40
0
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
tau [s] →

PhysTech



Level | Ec-ET [eV] | sigma [cm2] | NT [cm-3] | Correl
1 | 0.459 | 8.65E-18 | 2.95E+15 | 0.99563
2 | 0.521 | 4.08E-17 | 3.12E+15 | 0.99858
3 | 0.549 | 2.09E-16 | 3.20E+15 | 0.99807
ln(tau*vth*NC) →
65
63
61
59
3.5
3.7
3.9
4.1
1000/T [1/K] →
1
2
3
Name = _T1.AWA
Comm = J7
ID = GANA18
rcID = 0000
Date = 28.10.2004
Type = n-GaN*
Area = 3.14E-04 cm2
NS = 2.00E+17 cm-3
tP = 100.00 us
UR = -3.00 V
UP = 0.00 V
Phys Tech

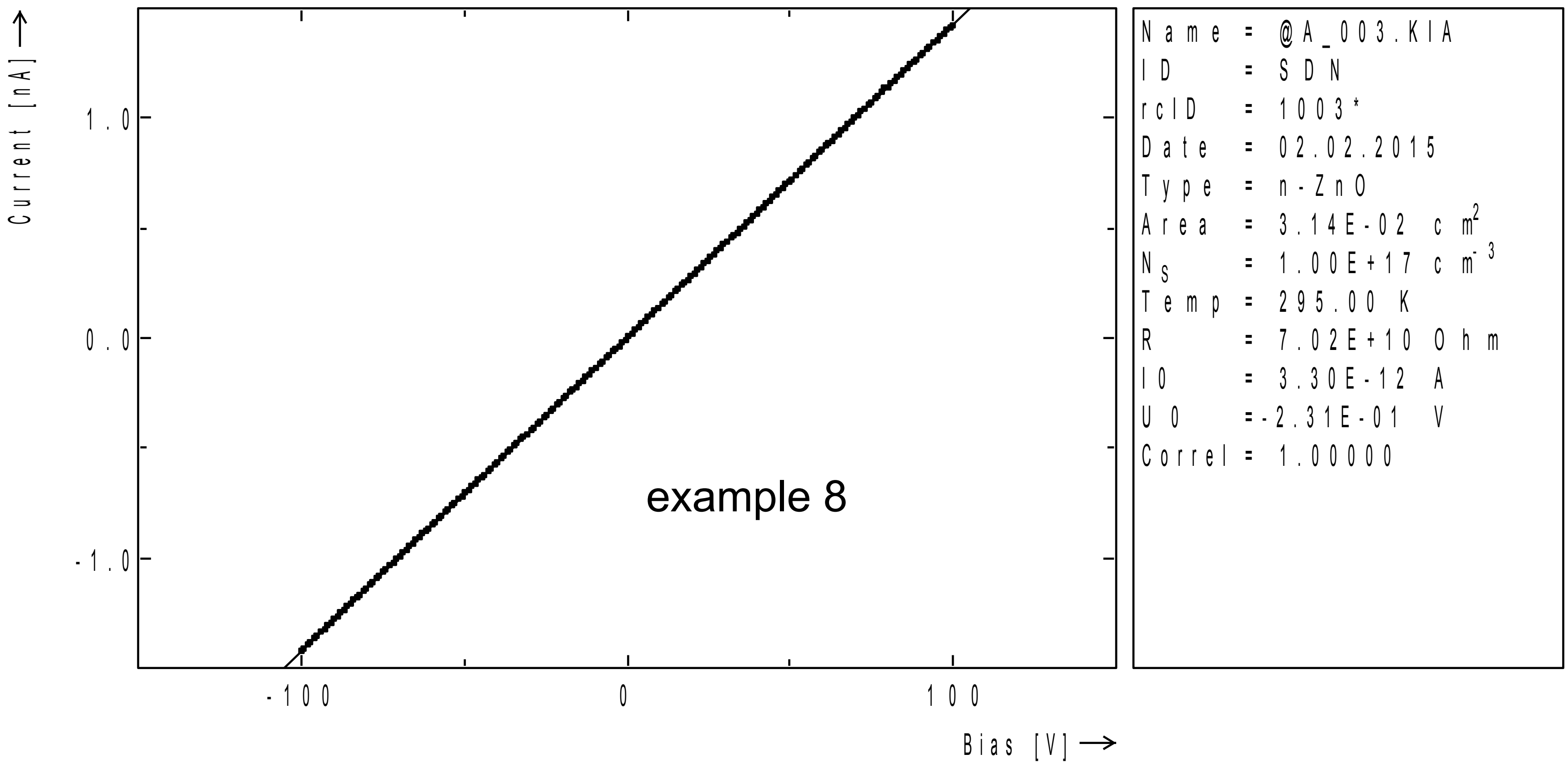
Current - DLTS

Resistivity sample

example 8

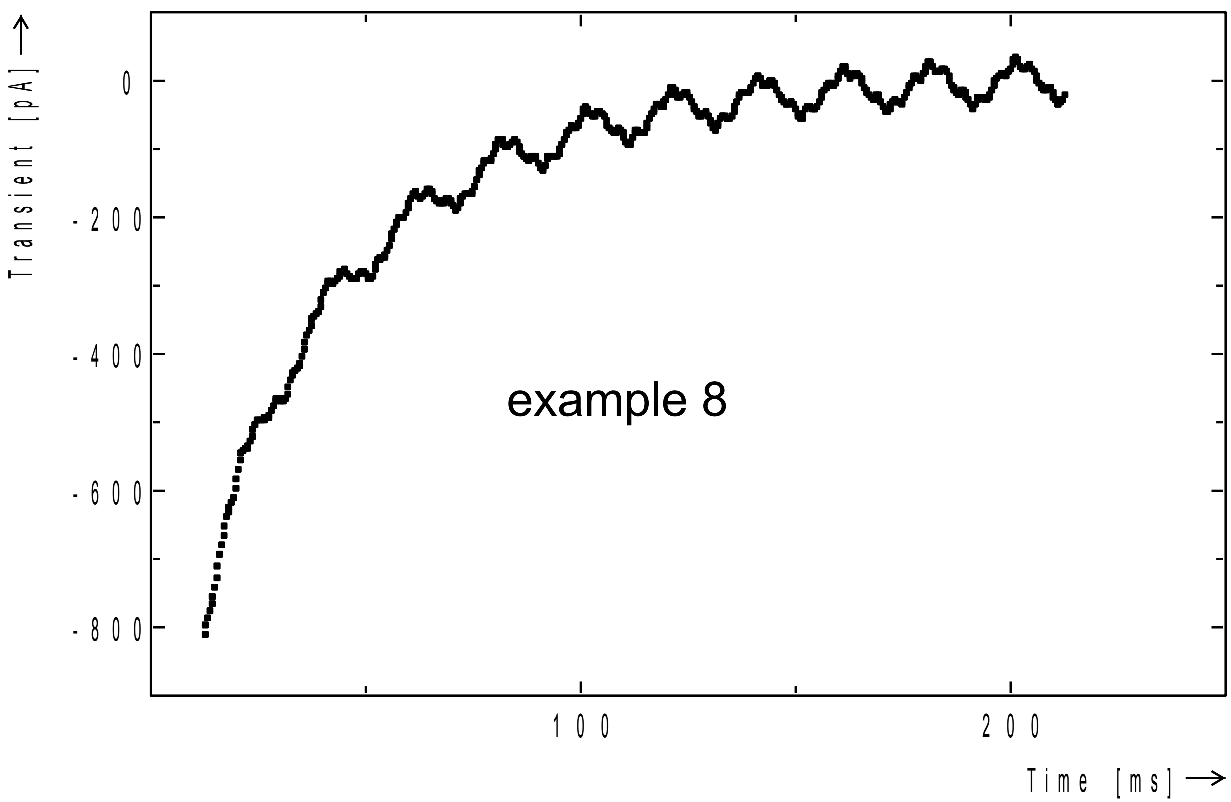
Deconvolution DLTS example

1

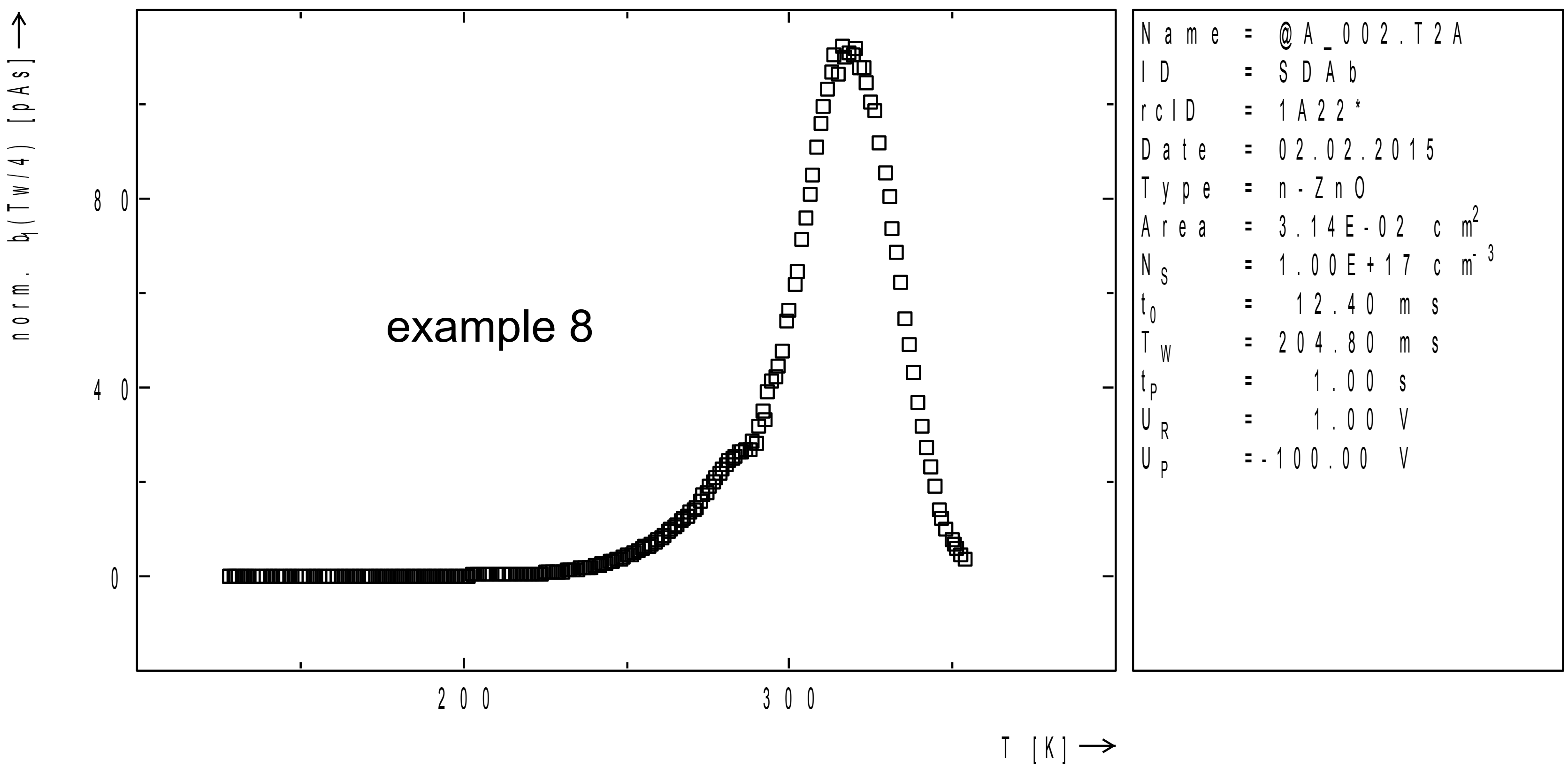

Current [nA] →
1.0
0.0
-1.0
-100
0
100
Bias [V] →
example 8
Name = @A_003.KIA
ID = SDN
rcID = 1003*
Date = 02.02.2015
Type = n-ZnO
Area = 3.14E-02 cm2
NS = 1.00E+17 cm-3
Temp = 295.00 K
R = 7.02E+10 Ohm
I0 = 3.30E-12 A
U0 =-2.31E-01 V
Correl = 1.00000

2

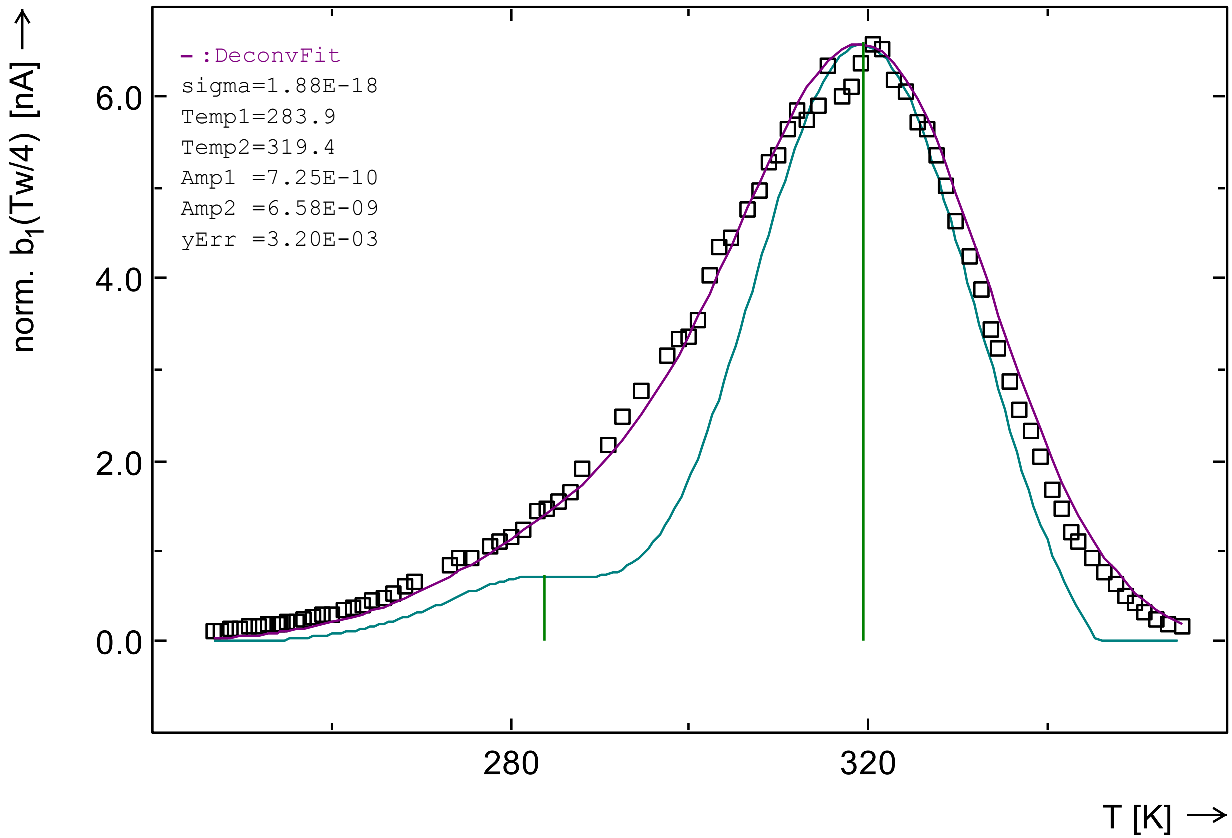
tau(a1,b1) = 38.079 ms	Amplitude = -966.235 pA, -36.793 pAs
tau(a2,b2) = 34.466 ms	NT = 3.09E+08 cm^{-3}
tau(b1,b2) = 31.868 ms	NTs = 0.00E+00 cm^{-3}
tau(a1,a2) = 38.029 ms	Energy = 0.615 eV
tau(Tw/4) = 27.997 ms	tau,ts/Tw = 0.19,1.47
tau(Tw'/2) = 37.583 ms	ExpClass = 0.91
tau(a0,b1) = 48.355 ms	TauClass = 55



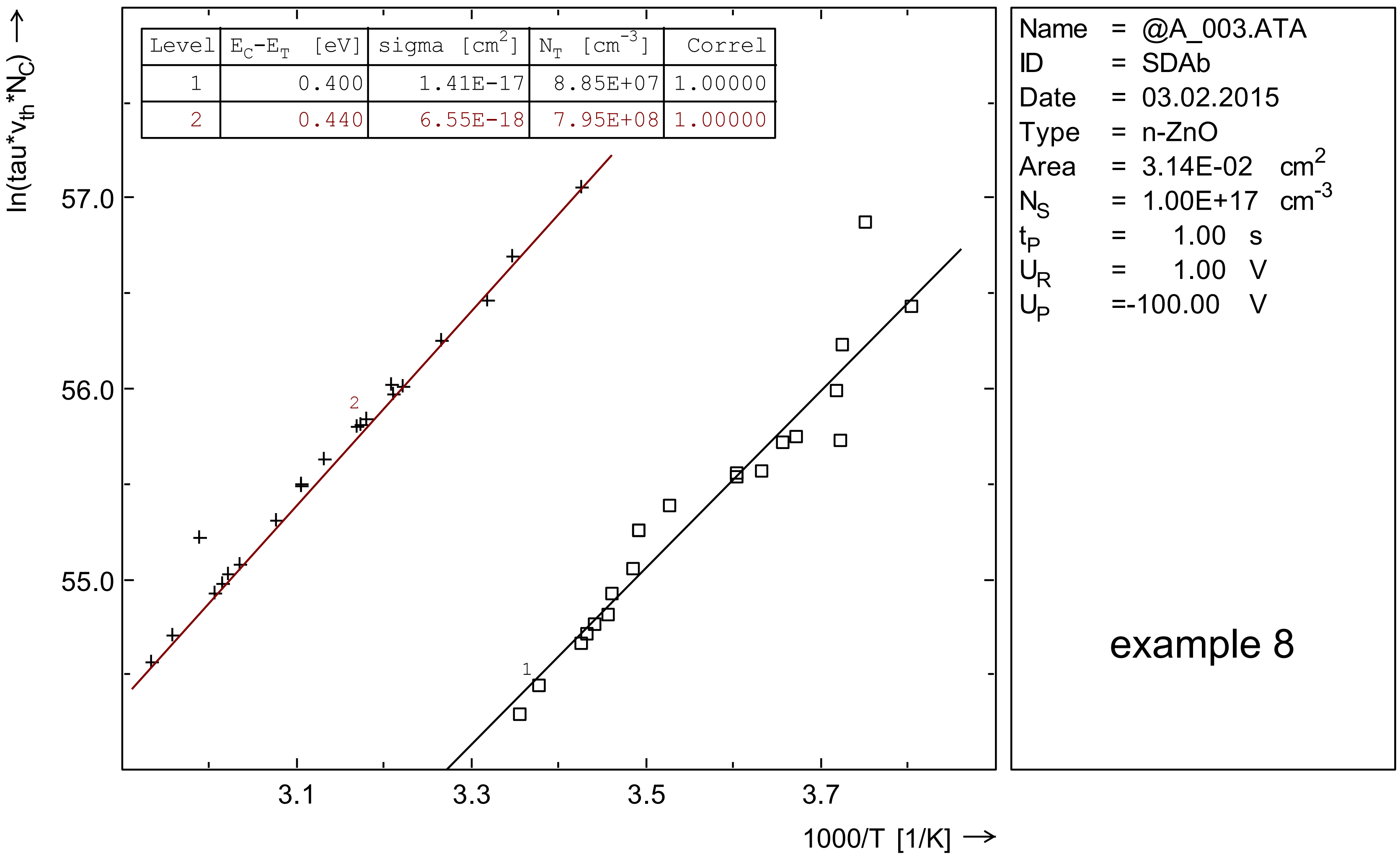
Name = @A_003.YCA
ID = SDN
rcID = 1015*
Date = 02.02.2015
Type = n-ZnO
Area = 3.14E-02 cm^2
N_S = 1.00E+17 cm^{-3}
Temp = 295.90 K
T_W = 199.94 ms
t_P = 1.00 s
U_R = 1.00 V
U_P = -100.00 V
I_R = 3.62 pA



norm. b_1(Tw/4) [pAs]
0
40
80
200
300
T [K]
example 8
Name = @A_002.T2A
ID = SDAb
rcID = 1A22*
Date = 02.02.2015
Type = n-ZnO
Area = 3.14E-02 cm^2
N_S = 1.00E+17 cm^{-3}
t_0 = 12.40 ms
T_W = 204.80 ms
t_P = 1.00 s
U_R = 1.00 V
U_P =-100.00 V

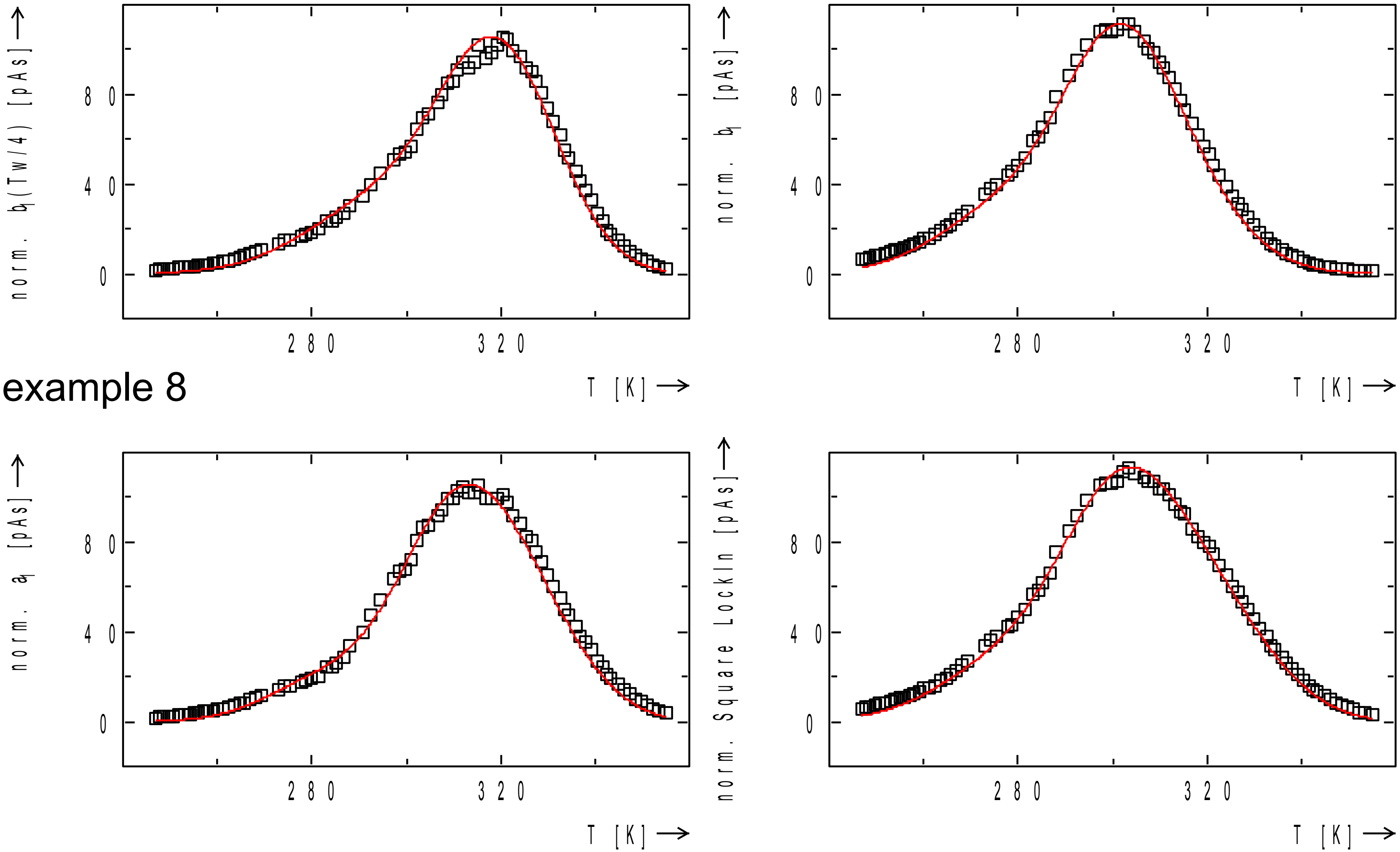


- :DeconvFit
sigma=1.88E-18
Temp1=283.9
Temp2=319.4
Amp1 =7.25E-10
Amp2 =6.58E-09
yErr =3.20E-03
norm. b1(Tw/4) [nA] →
6.0
4.0
2.0
0.0
280
320
T [K] →

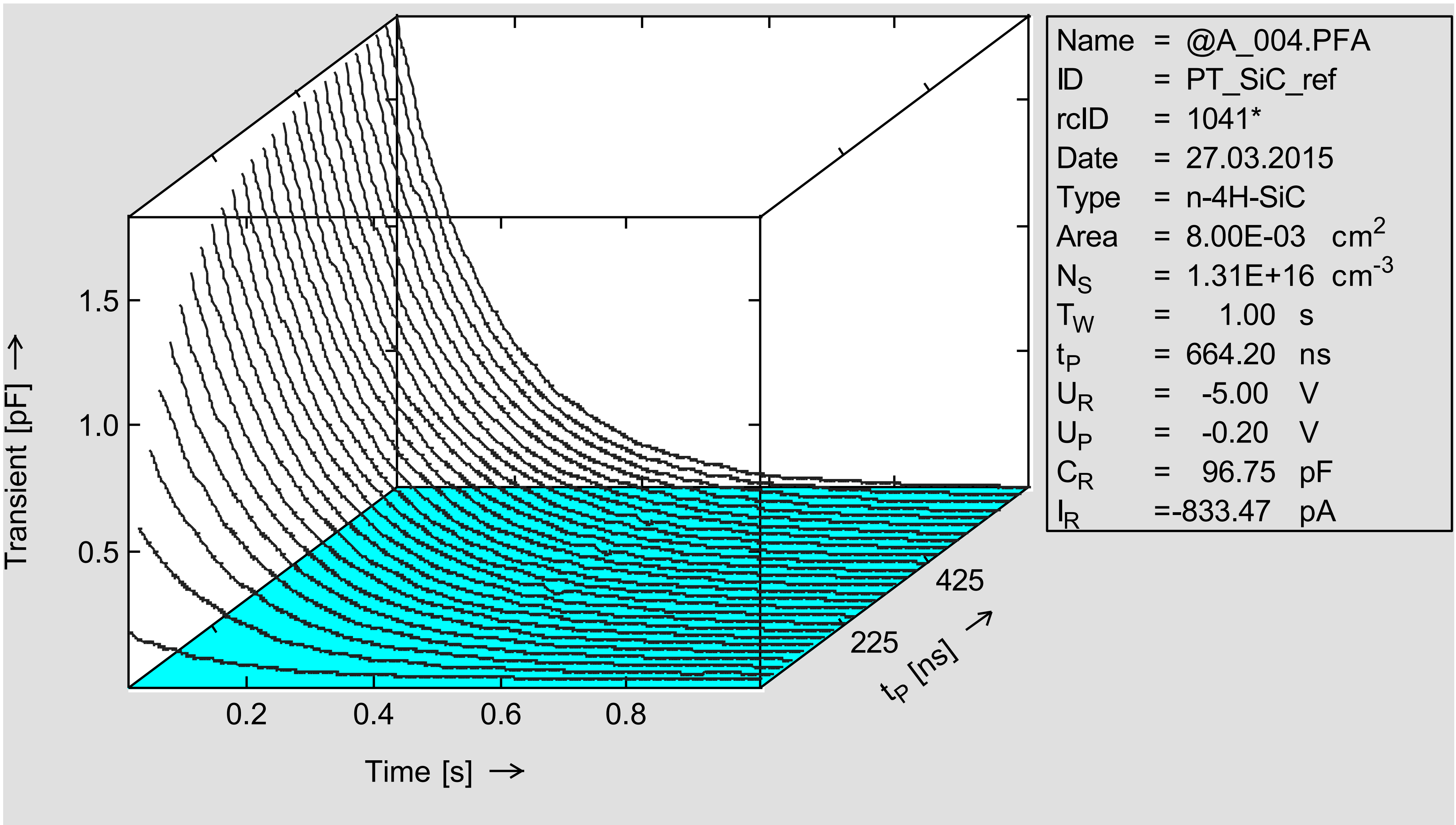


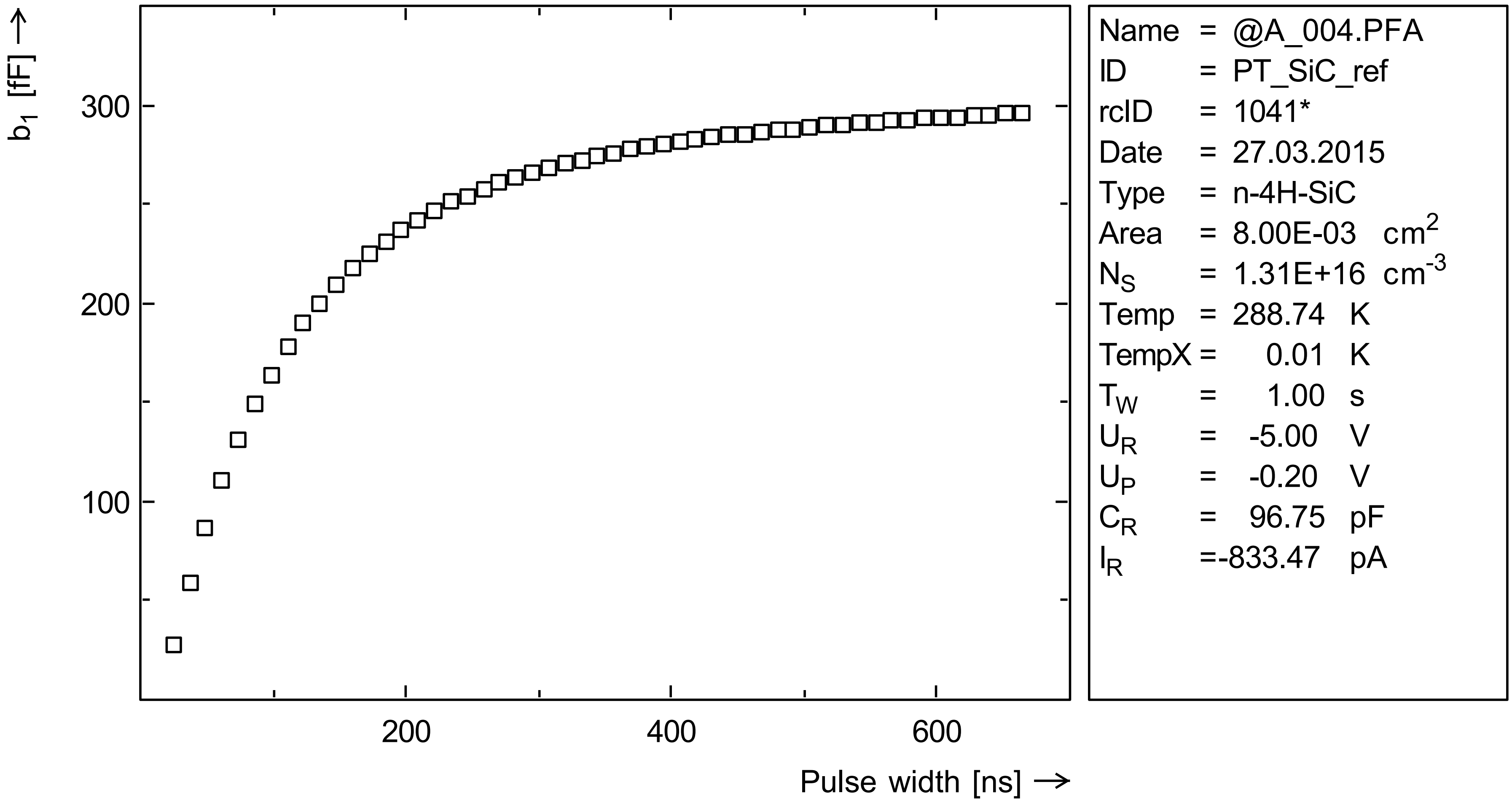
Level	E_C-E_T [eV]	sigma [cm^2]	N_T [cm^{-3}]	Correl
1	0.400	1.41E-17	8.85E+07	1.00000
2	0.440	6.55E-18	7.95E+08	1.00000

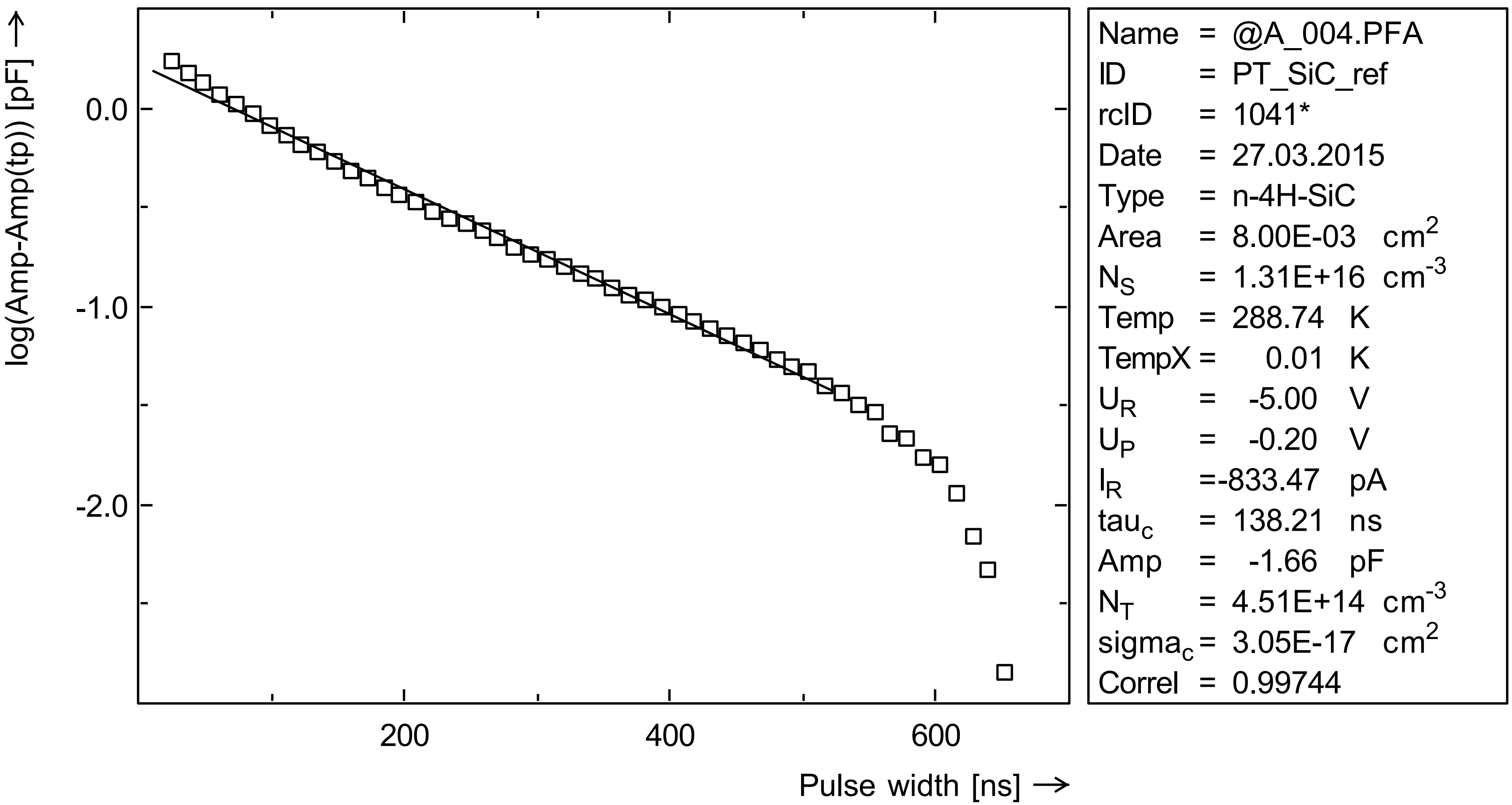
example 8


norm. b1(Tw/4) [pAs]
norm. b1 [pAs]
norm. a1 [pAs]
norm. Square LockIn [pAs]
0
40
80
280
320
T [K]

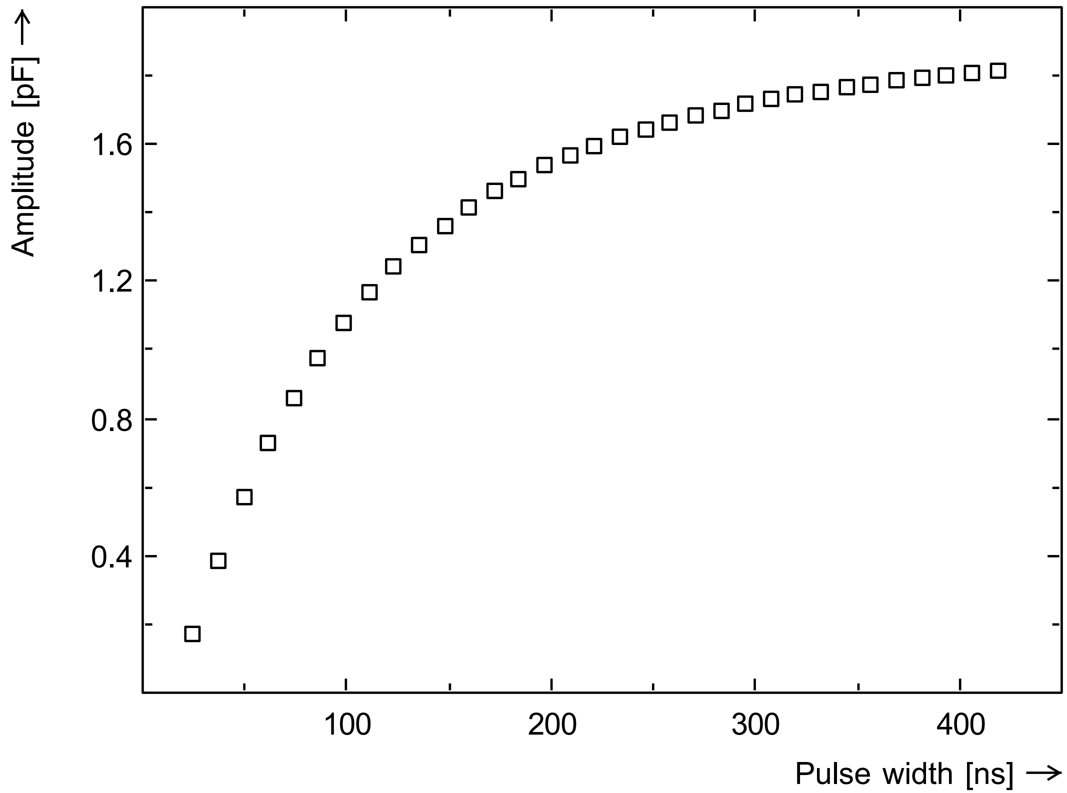
Capture Cross Section Measurements


Name = @A_004.PFA
ID = PT_SiC_ref
rcID = 1041*
Date = 27.03.2015
Type = n-4H-SiC
Area = 8.00E-03 cm2
NS = 1.31E+16 cm-3
TW = 1.00 s
tP = 664.20 ns
UR = -5.00 V
UP = -0.20 V
CR = 96.75 pF
IR =-833.47 pA
Transient [pF] →
1.5
1.0
0.5
0.2
0.4
0.6
0.8
Time [s] →
225
425
tP [ns] →

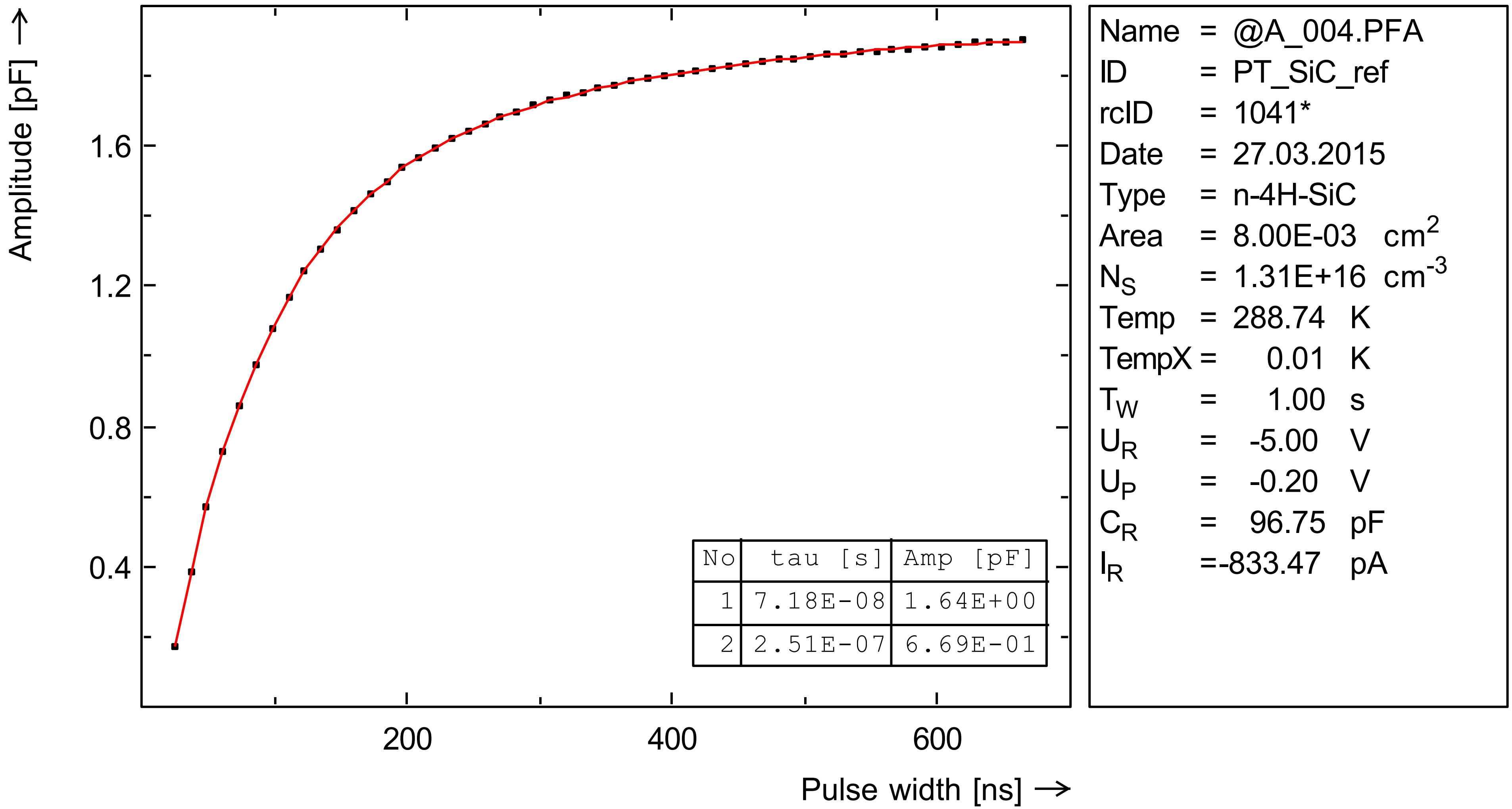

b1 [fF] →
300
200
100
200
400
600
Pulse width [ns] →
Name = @A_004.PFA
ID = PT_SiC_ref
rcID = 1041*
Date = 27.03.2015
Type = n-4H-SiC
Area = 8.00E-03 cm2
NS = 1.31E+16 cm-3
Temp = 288.74 K
TempX = 0.01 K
TW = 1.00 s
UR = -5.00 V
UP = -0.20 V
CR = 96.75 pF
IR =-833.47 pA

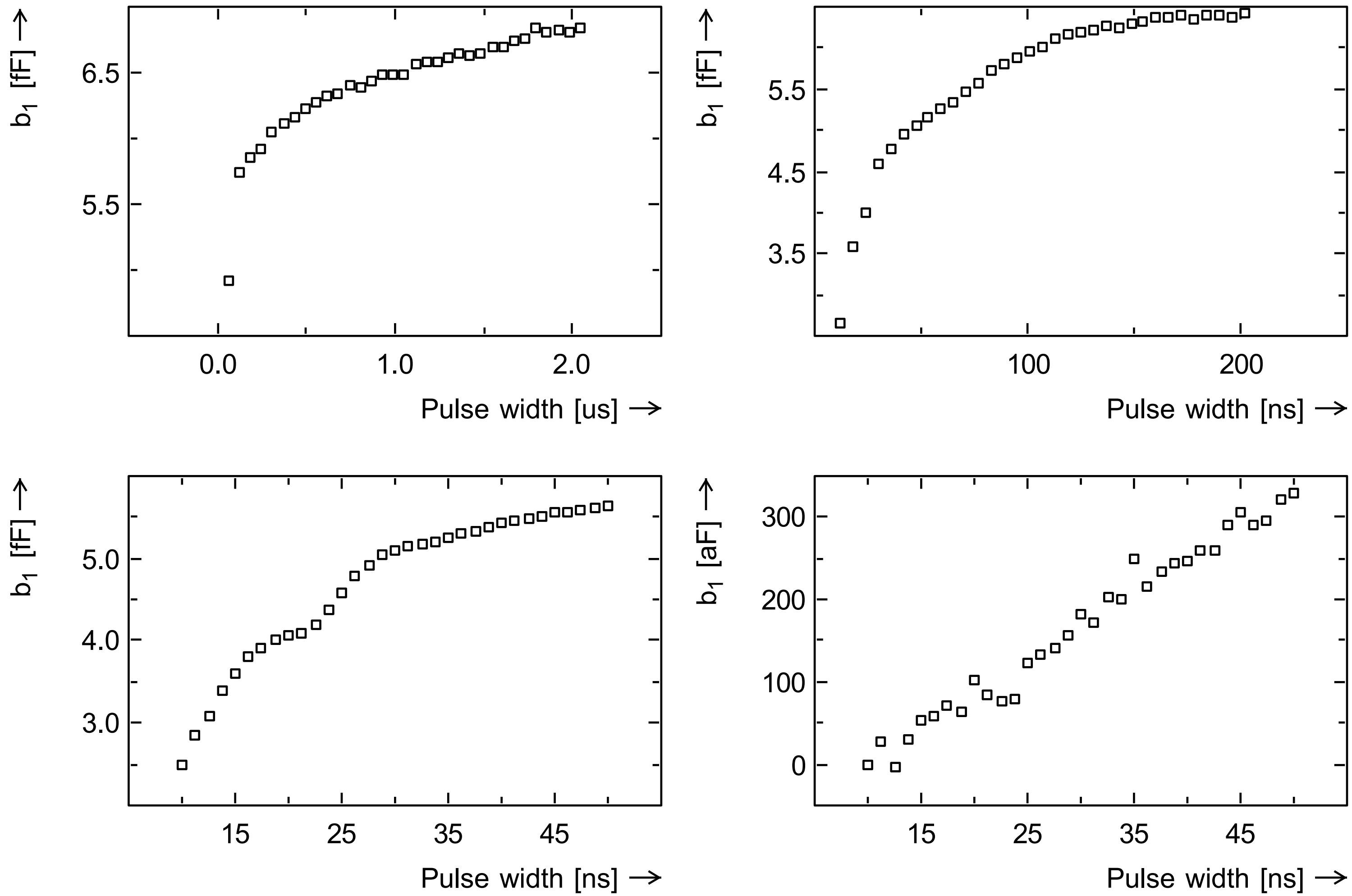

log(Amp-Amp(tp)) [pF] →
0.0
-1.0
-2.0
200
400
600
Pulse width [ns] →
Name = @A_004.PFA
ID = PT_SiC_ref
rcID = 1041*
Date = 27.03.2015
Type = n-4H-SiC
Area = 8.00E-03 cm^2
N_S = 1.31E+16 cm^{-3}
Temp = 288.74 K
TempX = 0.01 K
U_R = -5.00 V
U_P = -0.20 V
I_R =-833.47 pA
tau$_c$ = 138.21 ns
Amp = -1.66 pF
N_T = 4.51E+14 cm^{-3}
sigma$_c$ = 3.05E-17 cm^2
Correl = 0.99744

Name = PT_SiC_ref@A_004.PFA

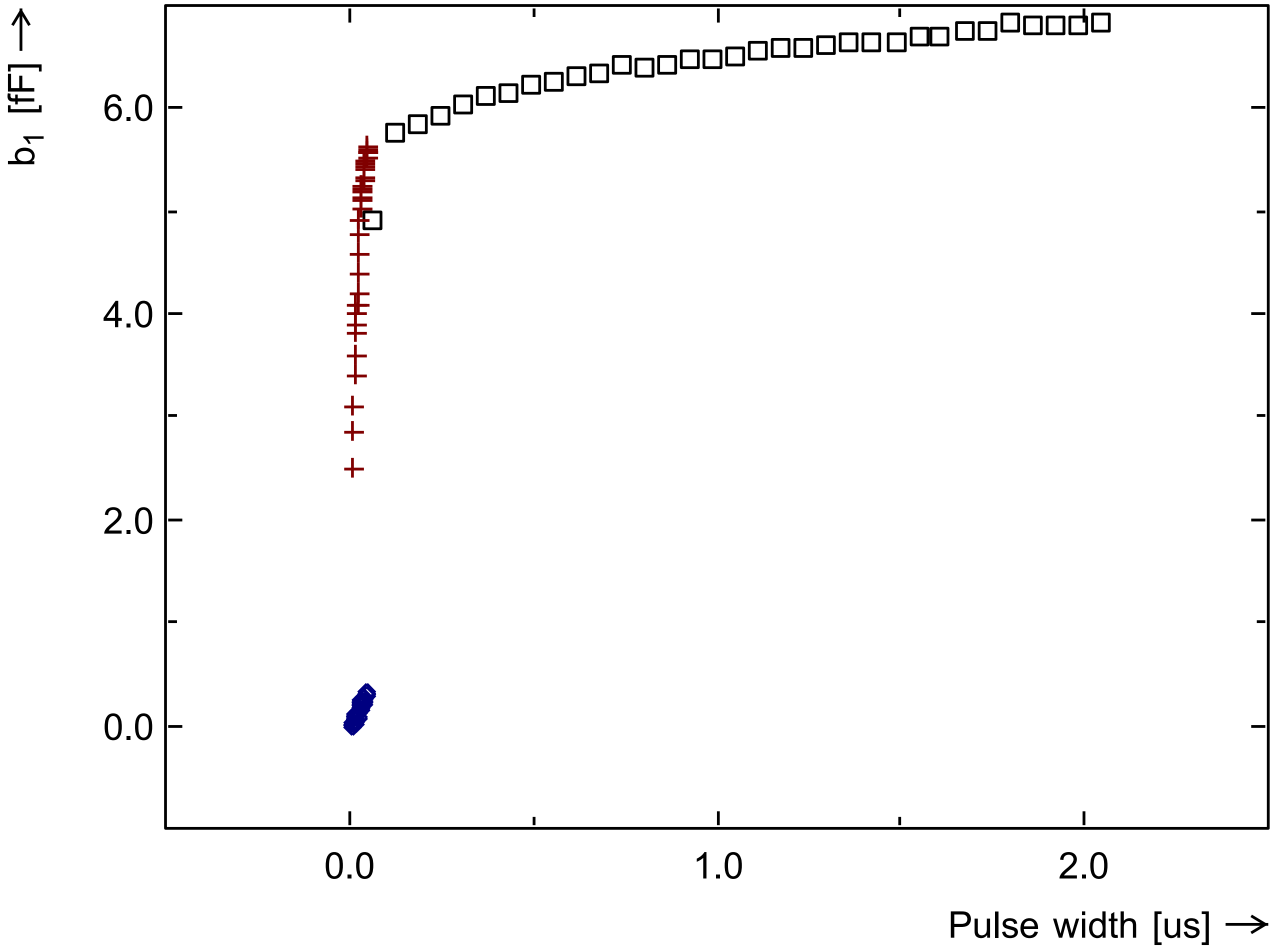


ID	=	PT_SiC_ref	
rcID	=	1041*	
Date	=	27.03.2015	
Type	=	n-4H-SiC	
Area	=	8.00E-03	cm^2
N_S	=	1.31E+16	cm^{-3}
Temp	=	288.74	K
TempX	=	0.01	K
U_R	=	-5.00	V
U_P	=	-0.20	V
I_R	=	-833.47	pA
tau_c	=	100.38	ns
Amp	=	-2.01	pF
N_T	=	5.44E+14	cm^{-3}
$sigma_c$	=	4.20E-17	cm^2
Class	=	55	

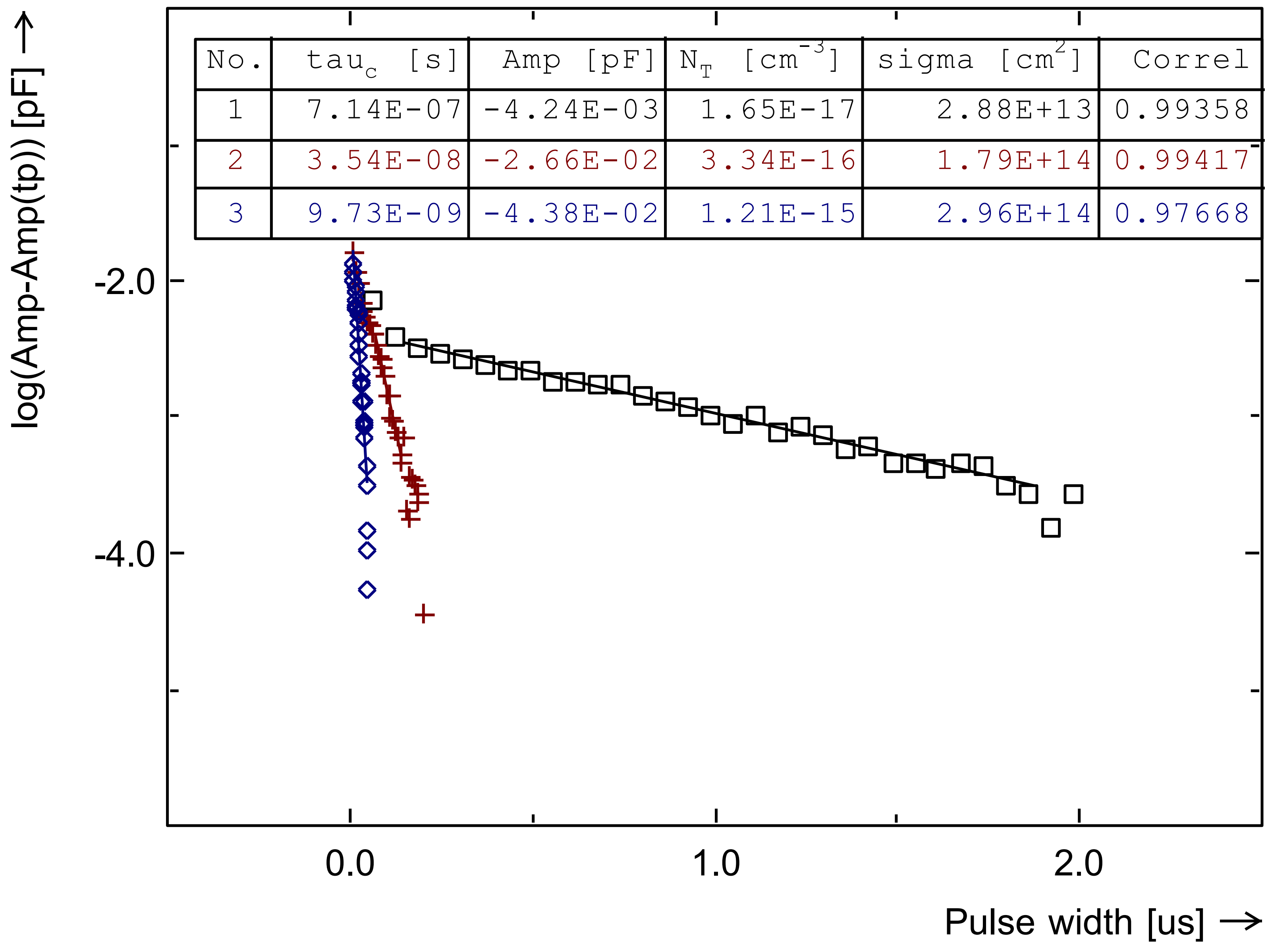

Amplitude [pF] →
1.6
1.2
0.8
0.4
200
400
600
Pulse width [ns] →
No | tau [s] | Amp [pF]
1 | 7.18E-08 | 1.64E+00
2 | 2.51E-07 | 6.69E-01
Name = @A_004.PFA
ID = PT_SiC_ref
rcID = 1041*
Date = 27.03.2015
Type = n-4H-SiC
Area = 8.00E-03 cm2
NS = 1.31E+16 cm-3
Temp = 288.74 K
TempX = 0.01 K
TW = 1.00 s
UR = -5.00 V
UP = -0.20 V
CR = 96.75 pF
IR =-833.47 pA



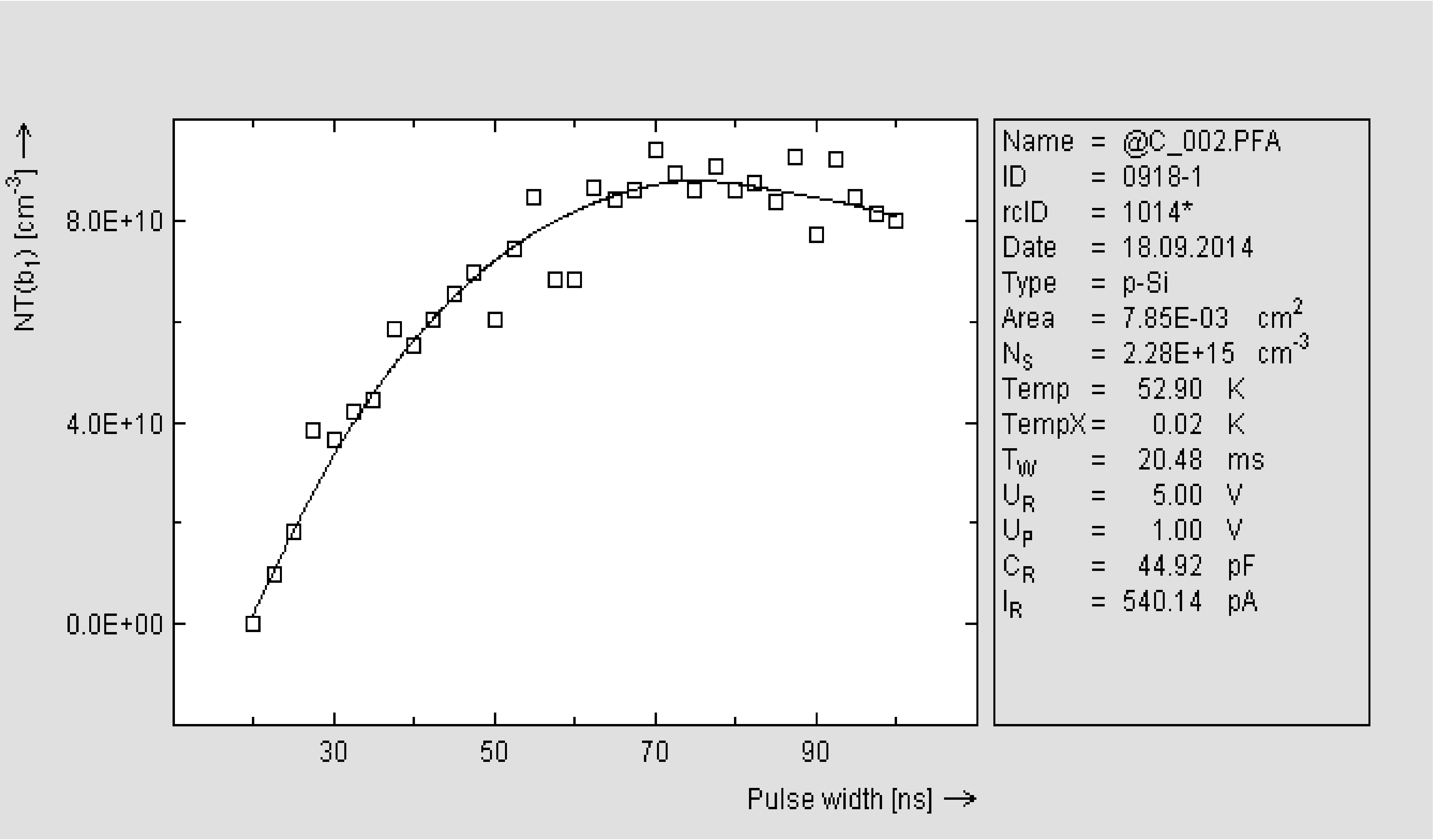
b1 [fF] →
6.5
5.5
0.0
1.0
2.0
Pulse width [us] →
b1 [fF] →
5.5
4.5
3.5
100
200
Pulse width [ns] →
b1 [fF] →
5.0
4.0
3.0
15
25
35
45
Pulse width [ns] →
b1 [aF] →
300
200
100
0
15
25
35
45
Pulse width [ns] →

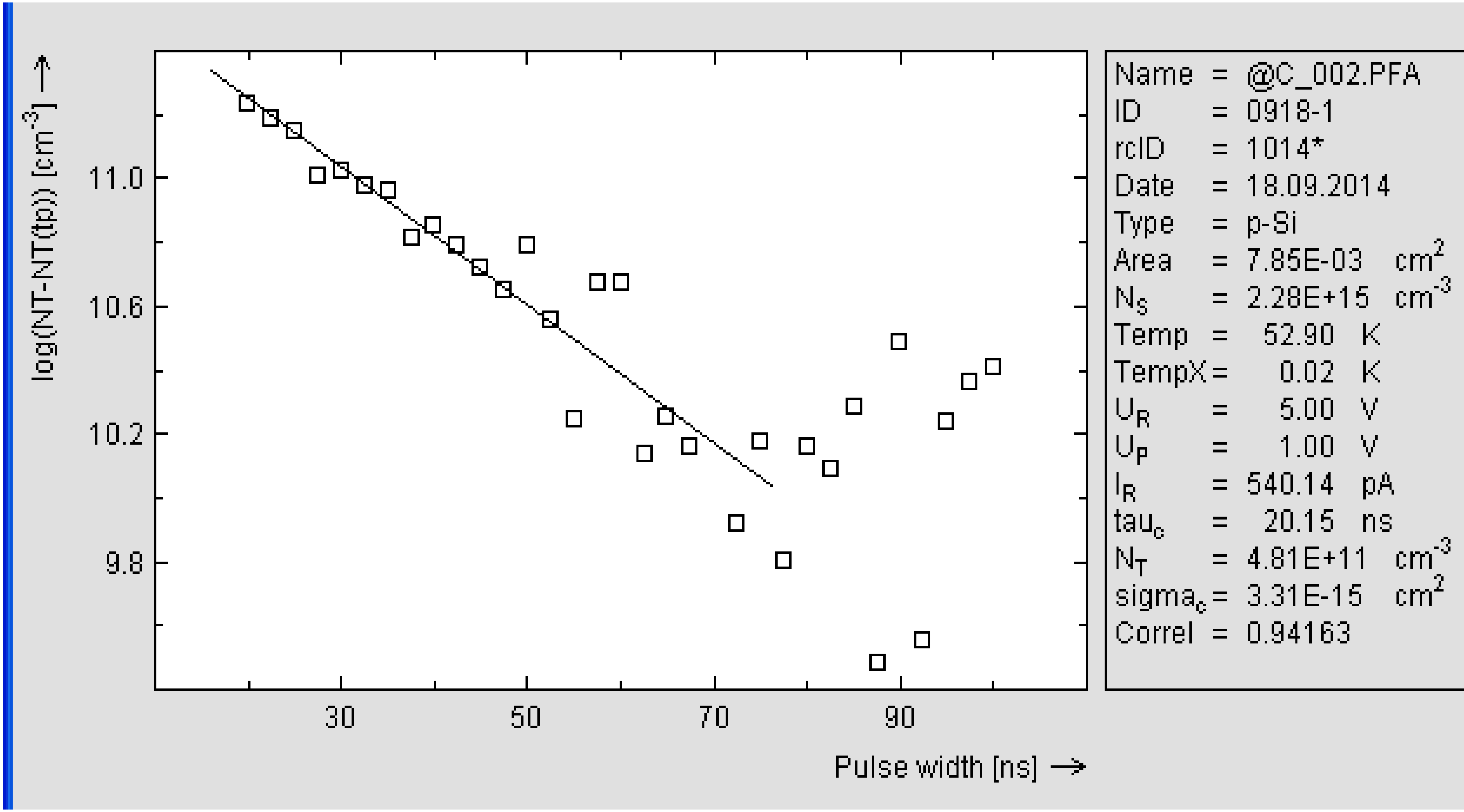


b1 [fF]
6.0
4.0
2.0
0.0
0.0
1.0
2.0
Pulse width [us]



No. | tau_c [s] | Amp [pF] | N_T [cm^-3] | sigma [cm^2] | Correl
1 | 7.14E-07 | -4.24E-03 | 1.65E-17 | 2.88E+13 | 0.99358
2 | 3.54E-08 | -2.66E-02 | 3.34E-16 | 1.79E+14 | 0.99417
3 | 9.73E-09 | -4.38E-02 | 1.21E-15 | 2.96E+14 | 0.97668
log(Amp-Amp(tp)) [pF] →
-2.0
-4.0
0.0
1.0
2.0
Pulse width [us] →


NT(b1) [cm-3]
8.0E+10
4.0E+10
0.0E+00
30
50
70
90
Pulse width [ns]
Name = @C_002.PFA
ID = 0918-1
rcID = 1014*
Date = 18.09.2014
Type = p-Si
Area = 7.85E-03 cm2
NS = 2.28E+15 cm-3
Temp = 52.90 K
TempX = 0.02 K
TW = 20.48 ms
UR = 5.00 V
UP = 1.00 V
CR = 44.92 pF
IR = 540.14 pA



log(NT-NT(tp)) [cm^-3] →
11.0
10.6
10.2
9.8
30
50
70
90
Pulse width [ns] →
Name = @C_002.PFA
ID = 0918-1
rcID = 1014*
Date = 18.09.2014
Type = p-Si
Area = 7.85E-03 cm^2
N_S = 2.28E+15 cm^-3
Temp = 52.90 K
TempX = 0.02 K
U_R = 5.00 V
U_P = 1.00 V
I_R = 540.14 pA
tau_c = 20.15 ns
N_T = 4.81E+11 cm^-3
sigma_c = 3.31E-15 cm^2
Correl = 0.94163

HERA FT1230 DLTS specifications

PhysTech

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Dr. Ludwig Cohausz
Phystech GmbH
Moosburg
Germany

Specifications:

Bias-/Pulsvoltagesource

voltage range : -/+ 20V (optional +/- 100V) ((due to be changed))
voltage setting resolution : 0.3 mV (1.5mV with 100V option)

internal shortest Pulswidth : 10 micro second (1V/micro s)
external fast pulse generator : 20 ns (+/- 10V)
longest Pulswidth : > 100h

optical pulse trigger available at the option port for TTL modulation inputs of Laser power supplies

Specifications:

Digital transient recorder **with variable oversampling technic**

max. samplings per transient : **2E6 (buffered), 2E9 (streaming)**

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Specifications:

Digital transient recorder **with variable oversampling technic**

max. samplings per transient	: **2E6 (buffered), 2E9 (streaming)**
fastest sampling intervall	: **850 nano seconds**
shortest period width	: **27 micro seconds**
longest periodwidth	: **110 h**

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Specifications:

Phystech Capacitancemeter

with automatic reverse bias capacitance compensation and automatic range setting

Compensation range : **1 pF - 3300 pF**
HF - frequency : 1 MHz
HF signal : **15mV, 100mV**
ranges : 5 **pF - 5000 pF (4) (100mV)**

Current measurement amplifier with automatic range setting
max. measurement current : 15 mA
current resolution : **<1 pA**
This amplifier can be used for I/V measurements as well

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FT 1230 HERA DLTS features

- C/V , I/V
- C-DLTS / Capacitance - DLTS
- I-DLTS / Current - DLTS
- CC-DLTS / Constant Cap. DLTS
- Laplace DLTS
- ITS (ICTS)
- MIS Analysis / Zerbst DLTS

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