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Characterisation of defect centres in SI InP:Fe as a starting material for nuclear radiation detectors

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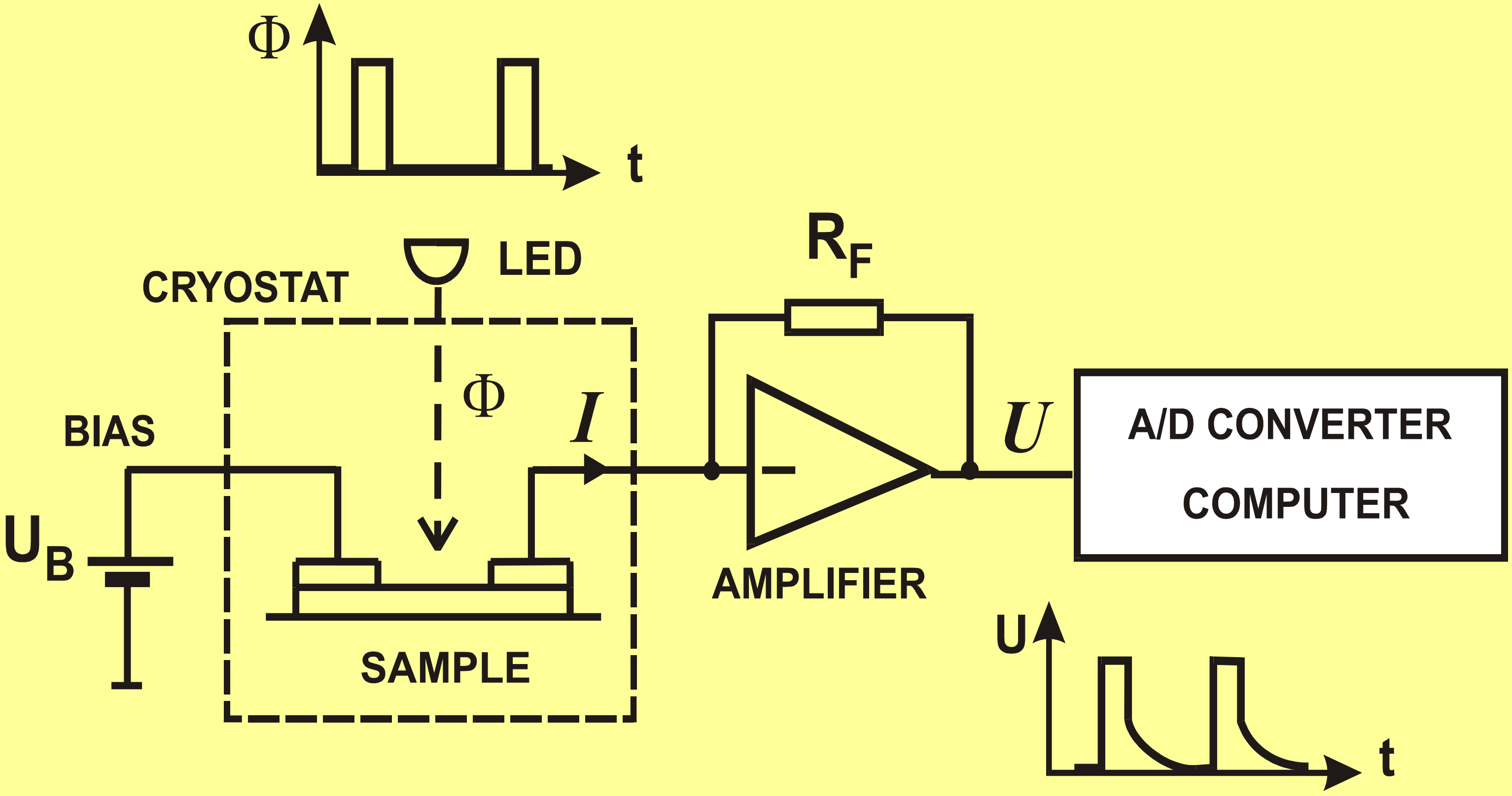
Plan of talk:

- ITME’s activity in the area of InP technology
- Photocurrent kinetics measurements
- Comparison of defect structure of SI InP:Fe with various Hall mobility – application of correlation procedure to analysis of the photocurrent decays
- Potentialities of the Laplace transform algorithm as a effective tool for extraction of defect centres parameters from photocurrent decays

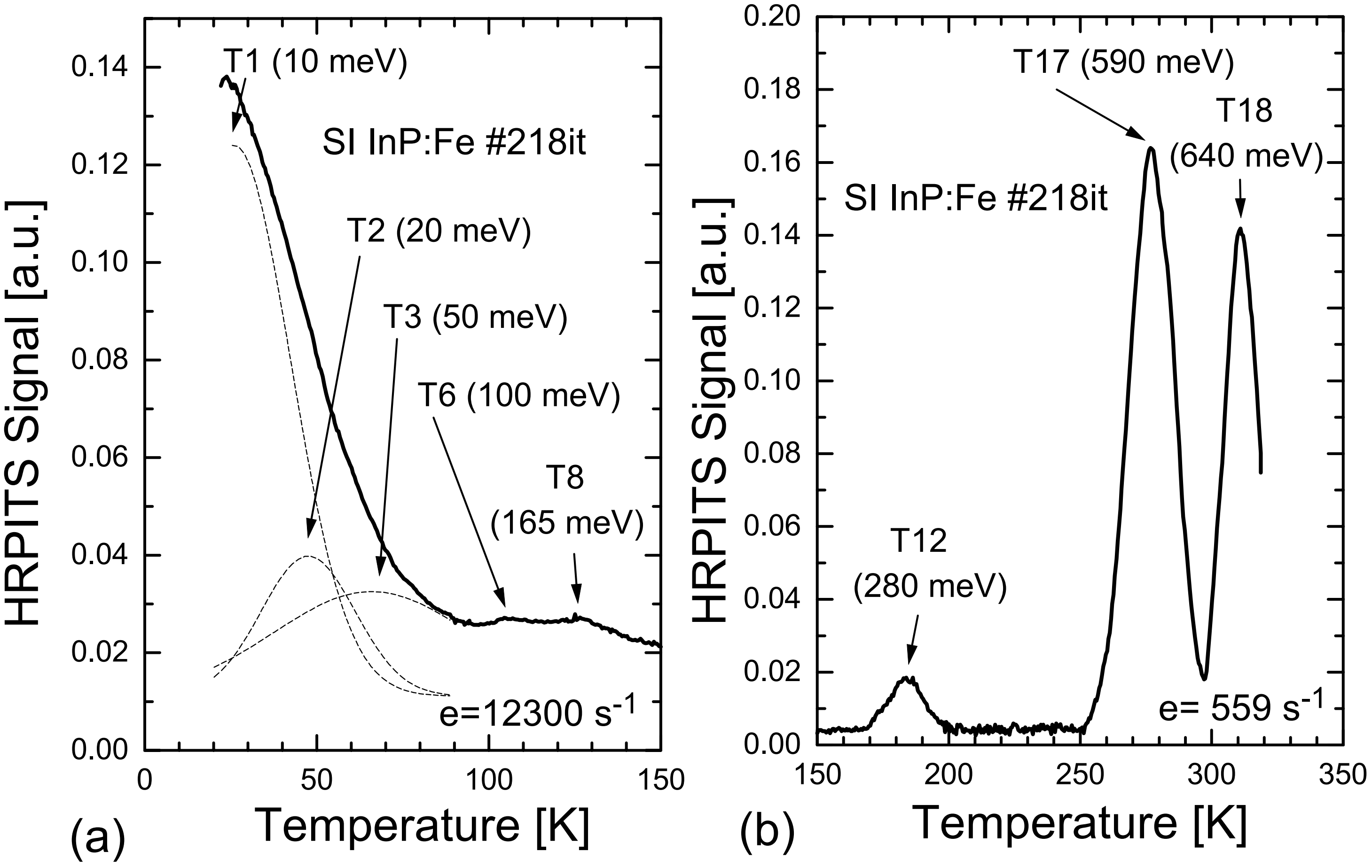
Experimental system



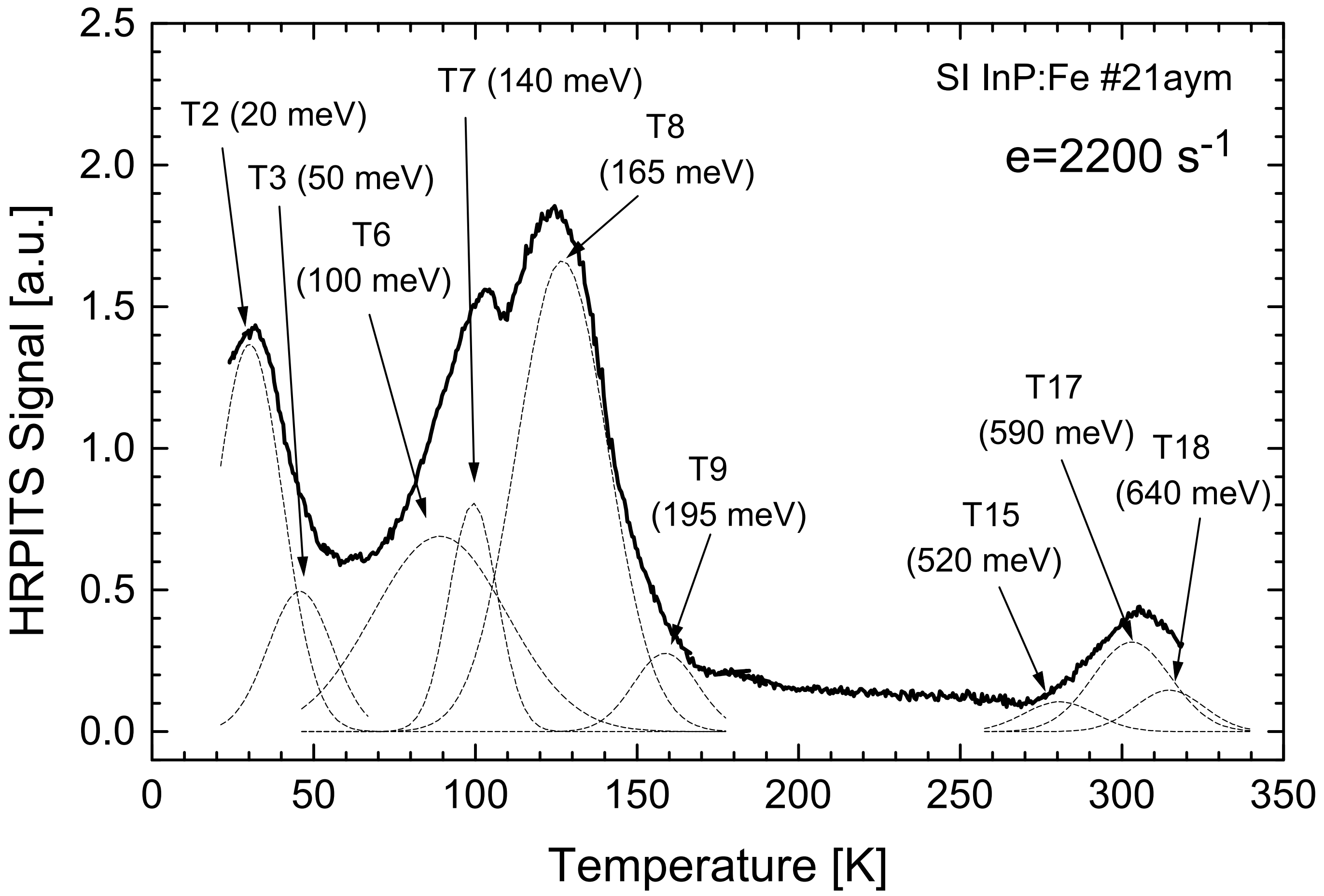
Samples

Parameters of SI InP:Fe samples used for investigation of defect centers

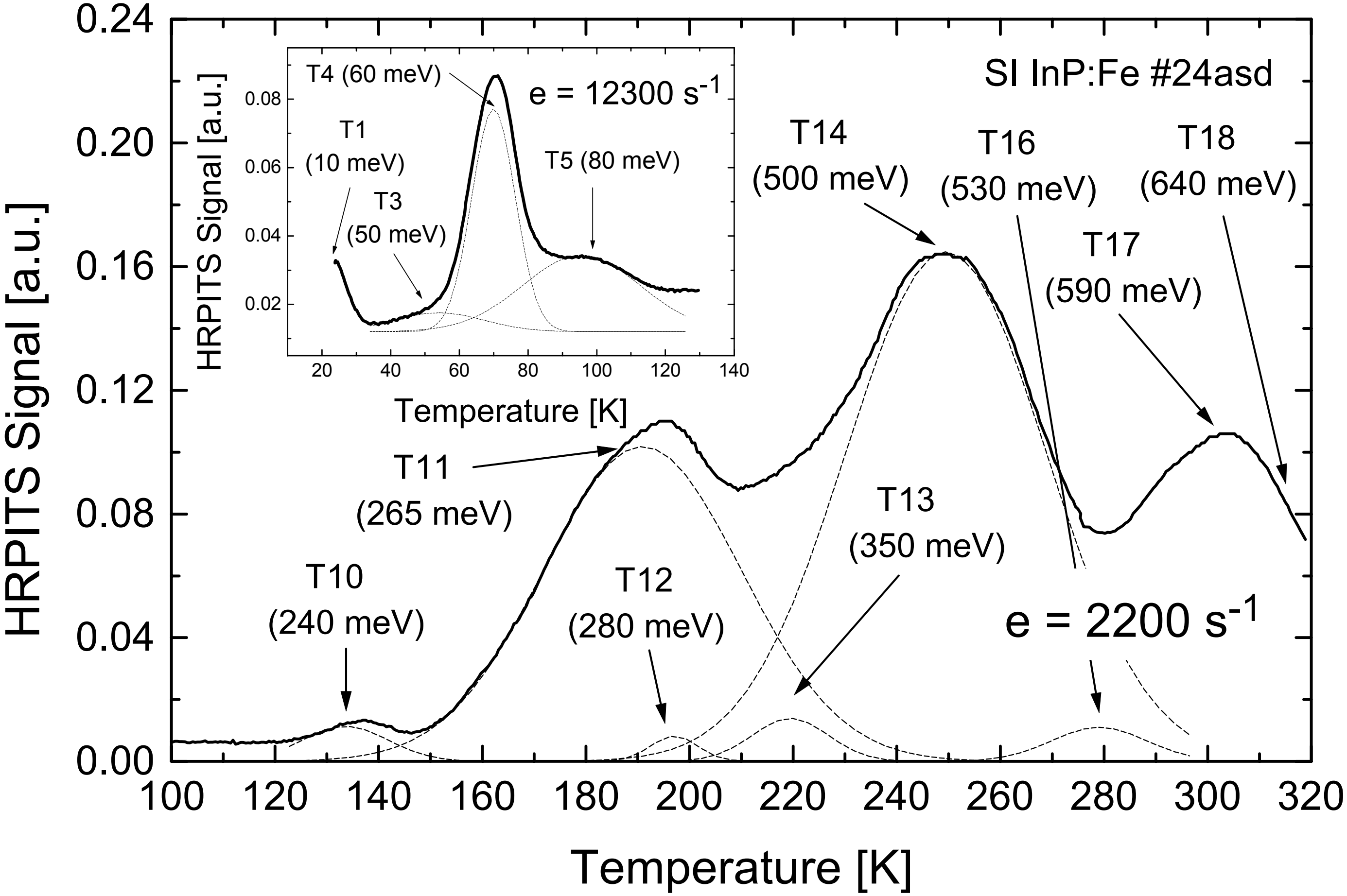
Sample	Resistivity at 300 K (Ωcm)	Hall mobility at 300 K (cm^2/Vs)	[Fe] (cm^{-3})	E_{TDDC} (eV)
#218it	2.0×10^7	1600	1.0×10^{16}	0.51
#21aym	1.47×10^8	2392	4.0×10^{16}	0.59
#24asd	1.43×10^8	2638	9.0×10^{15}	0.63



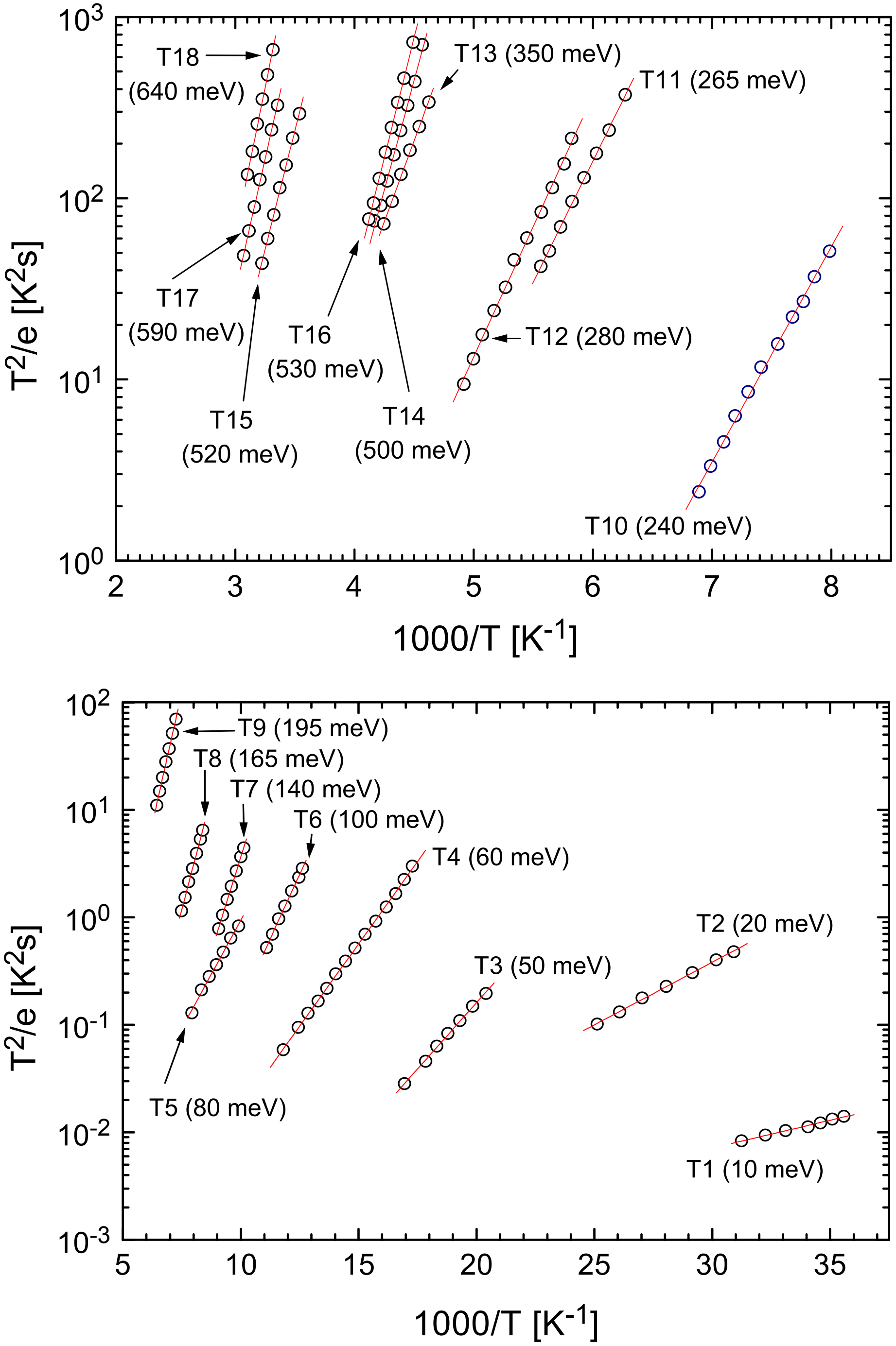
HRPITS spectrum of the SI InP:Fe characterised by the Hall mobility at 300 K equal to 1600 cm^2/Vs;
(a) temperature range of 20-150 K, emission rate window equal to 12300 s^{-1},
(b) temperature range of 150-320 K, emission rate window equal to 559 s^{-1}.



HRPITS spectrum taken at emission rate window of 2200 s^{-1} for the SI InP:Fe characterised by the Hall mobility at 300 K equal to 2392 cm^2/Vs. The peaks obtained from the fitting the spectrum with Gaussian functions are marked with the broken lines.



HRPITS spectrum taken at emission rate window of 2200 s^{-1} for the SI InP:Fe characterised by the Hall mobility at 300 K equal to 2638 cm^2/Vs. The inset shows the part of the spectrum for the emission rate window of 12300 s^{-1} determined at the temperature range from 20 to 130 K. The peaks obtained from the fitting the spectrum with Gaussian functions are marked with the broken lines.



Arrhenius plots for grow-in point defects detected in SI InP:Fe

(a) temperature range of 120-320 K.

(b) temperature range of 20-200 K,

Summary of HRPITS results on parameters of traps detected in SI InP:Fe grown by the LEC method

Trap label	Activation energy E_a (meV)	Pre-exponential factor A ($s^{-1}K^{-2}$)	Tentative identification	Material in which the trap occurs
T1	10	5.0x10^{3}	shallow donors: S, Si [1, 2]	#218it and #24asd
T2	20	5.0x10^{3}	shallow acceptors: Si, Zn [1,2]	#218it and #21aym
T3	50	1.0x10^{5}	shallow donor: native defect or native defect - impurity complex [1, 2]	#218it, #24asd and #21aym
T4	60	7.0x10^{4}	unknown	#24asd
T5	80	1.0x10^{4}	unknown	#24asd
T6	100	1.0x10^{5}	$V_{In}^{0/+}$ [3]	#218it and #21aym
T7	140	3.0x10^{6}	$V_{In}^{-/0}$ [3]	#21aym
T8	165	1.5x10^{6}	native defect observed after electron irradiation (*h*) [4]; D0 (*e*) in [8]	#218it and #21aym
T9	195	2.0x10^{5}	related to V_P (*e*) [6]	#21aym
T10	240	6.5x10^{7}	$P_{In}^{+/++}$ [5]	#24asd
T11	265	6.5x10^{5}	related to Zn [4]	#24asd
T12	280	4.0x10^{5}	E6 in [9]	#218it and #24asd
T13	350	4.0x10^{6}	related to P_{In} (*e*) [6]	#24asd
T14	500	3.0x10^{8}	Fe-donor complex (*e*) [5]	#24asd
T15	520	7.0x10^{6}	P_{In}-Zn complex (*h*) [4]	#21aym
T16	530	1.0x10^{9}	induced by excess of P [4]	#24asd
T17	590	3.0x10^{8}	complex involving Fe^{2+}; B2 (*e*) [5], E1 [9]	#218it and #24asd
T18	640	4.0x10^{8}	$Fe^{2+/3+}$ (*e*) [7]	#218it, #24asd and #21aym

References

1. J. Appl. Phys. **72** (3) 1080-1085, 1992

2. Shmidt *Handbook Series on Semiconductor Parameters*, vol. 1, M. Levinshtein, S. Rumyantsev and M. Shur, ed., World Scientific, London, 1996, pp. 169-190

3. Phys. Rev. B. **55** (16) 10 480-10 486, 1997

4. *Indium Phosphide and related materials: processing, technology, and devices*, A. Katz, ed., Artech House, Inc., 1992, pp. 75-102

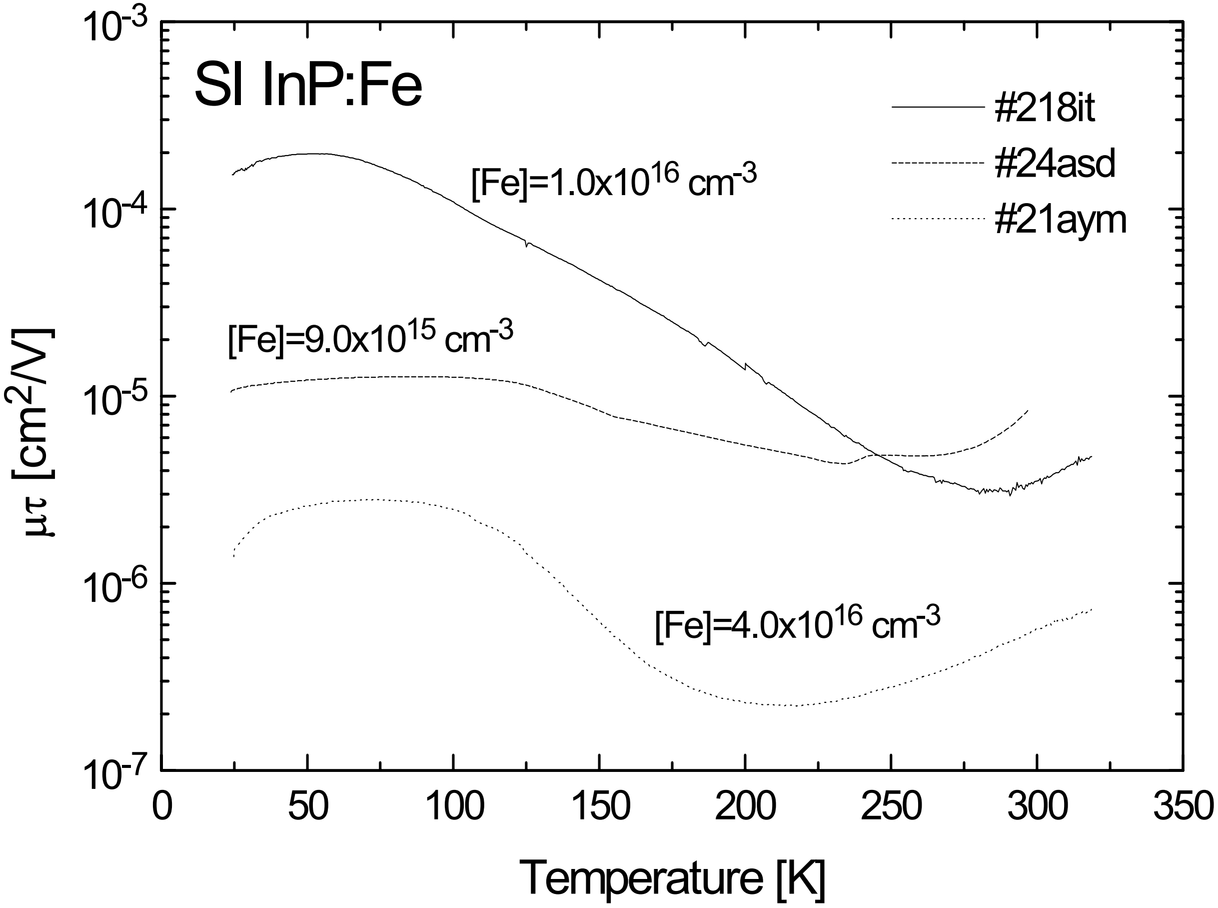
5. Mat. Sc. Eng. B **28** 95-100, 1994

6. J. Electronic Mat. **27** (10) L68-L71, 1998

7. Acta Phys. Pol. **A77** (1) 87-90, 1990

8. J. Appl. Phys. **79** (9) 6947-6950, 1996

9. J.Cryst.Growth **68** 326-333, 1984



τ [s] at 300 K

#218it - 2.2×10^{-9}

#24asd - 3.2×10^{-9}

#21aym - 2.4×10^{-10}

Mobility-lifetime product for electrons as a function of temperature for samples of SI InP:Fe with various iron concentration.

Conclusions (I)

- Defect structure of SI InP:Fe is very complex. The defect centres detected by the HRPITS technique can be divided into the following categories: shallow donor and acceptor impurities, native defects, shallow impurity - native defect complexes and iron related defects.
- The Hall mobility is mainly affected by the shallow donor concentration.
- The carrier lifetime is determined by the iron concentration and the concentration of shallow impurities.
- The ratio of $[Fe^{2+}]/[Fe^{3+}]$ is determined by the concentration of shallow donors.

LAPLACE TRANSFORM ALGORITHM

By applying a LAPLACE TRANSFORM METHOD, the set of the photocurrent transients measured in varies temperatures are transformed into two–dimensional spectrum $g(e_T, T)$ according with the following equation:

$$i(t,T) = \int_{e_T(\min)}^{e_T(\max)} g(e_T, T)\exp(-e_T t)\,de_T$$

where: $i(t,T)$ are discrete values of the photocurrent transient for given temperature T and e_T is the thermal emission rate of charge carriers.

LAPLACE TRANSFORM ALGORITHM (2)

The two-dimensional spectrum $g(e_T, T)$ is calculated numerically using the program CONTIN proposed by S. Provencher. This program employs the Tikhonov regularisation procedure to match the spectrum to the digitised experimental data $i(t,T)$.

All calculations are performed in MS Windows® environment.

SAMPLE

Semi-insulating (SI) InP:Fe grown by LEC method
#24asd

- wafer orientation (100),
- resistivity at 300 K: 1.43x10^8 Ωcm,
- activation energy of temperature dependent dark current 0.63 eV.

Grown-in defects in SI InP:Fe

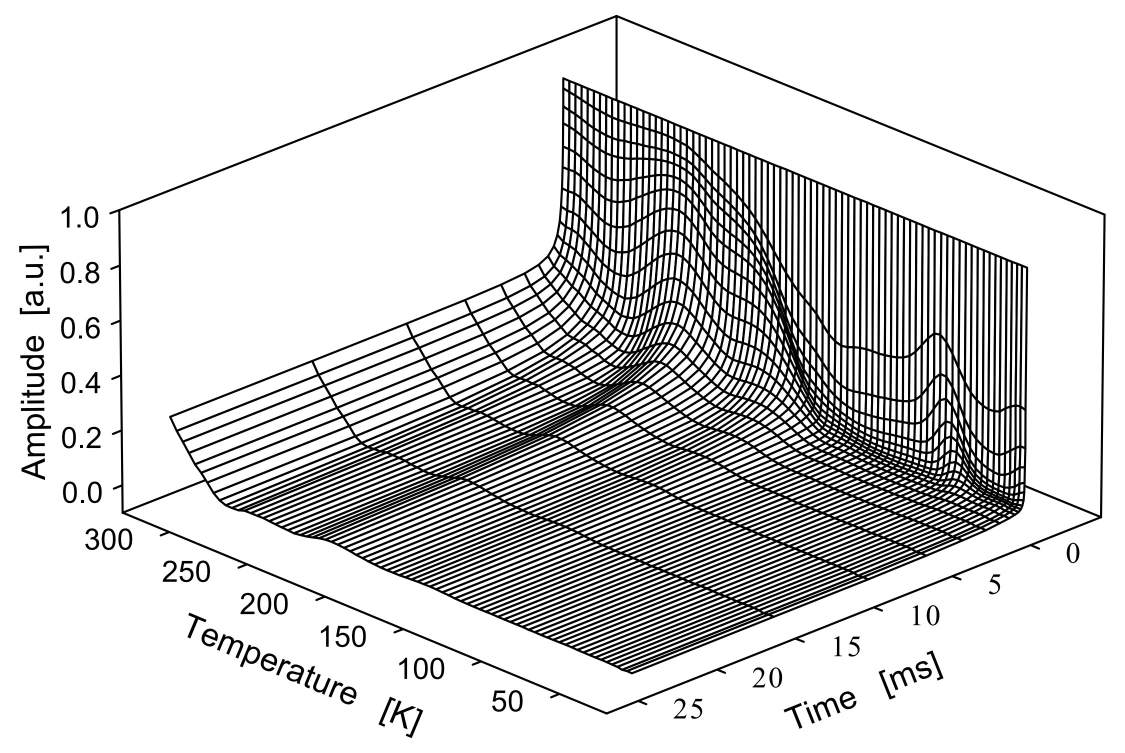


Fig.1. Three-dimensional (3D) visualization of photocurrent decays recorded at the temperature range of 30 – 330 K for SI InP:Fe. The amplitude of decays is normalized to the value at t=0.

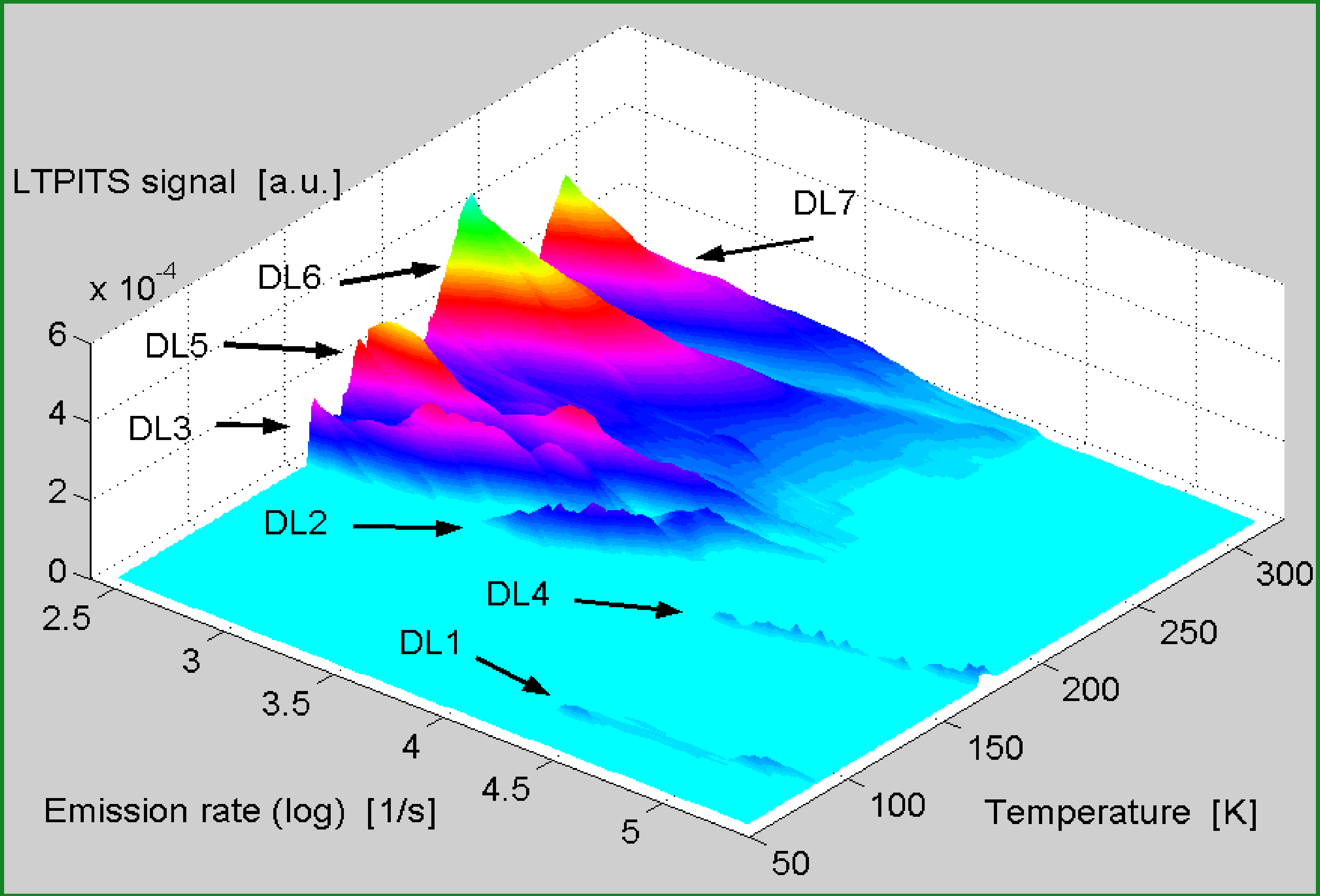


Fig.2. Laplace spectral surface corresponding to the photocurrent decays shown in Fig.1. The thermal emission from the seven defect centers, labeled as DL1-DL7, manifests itself through the narrow folds on the surface.

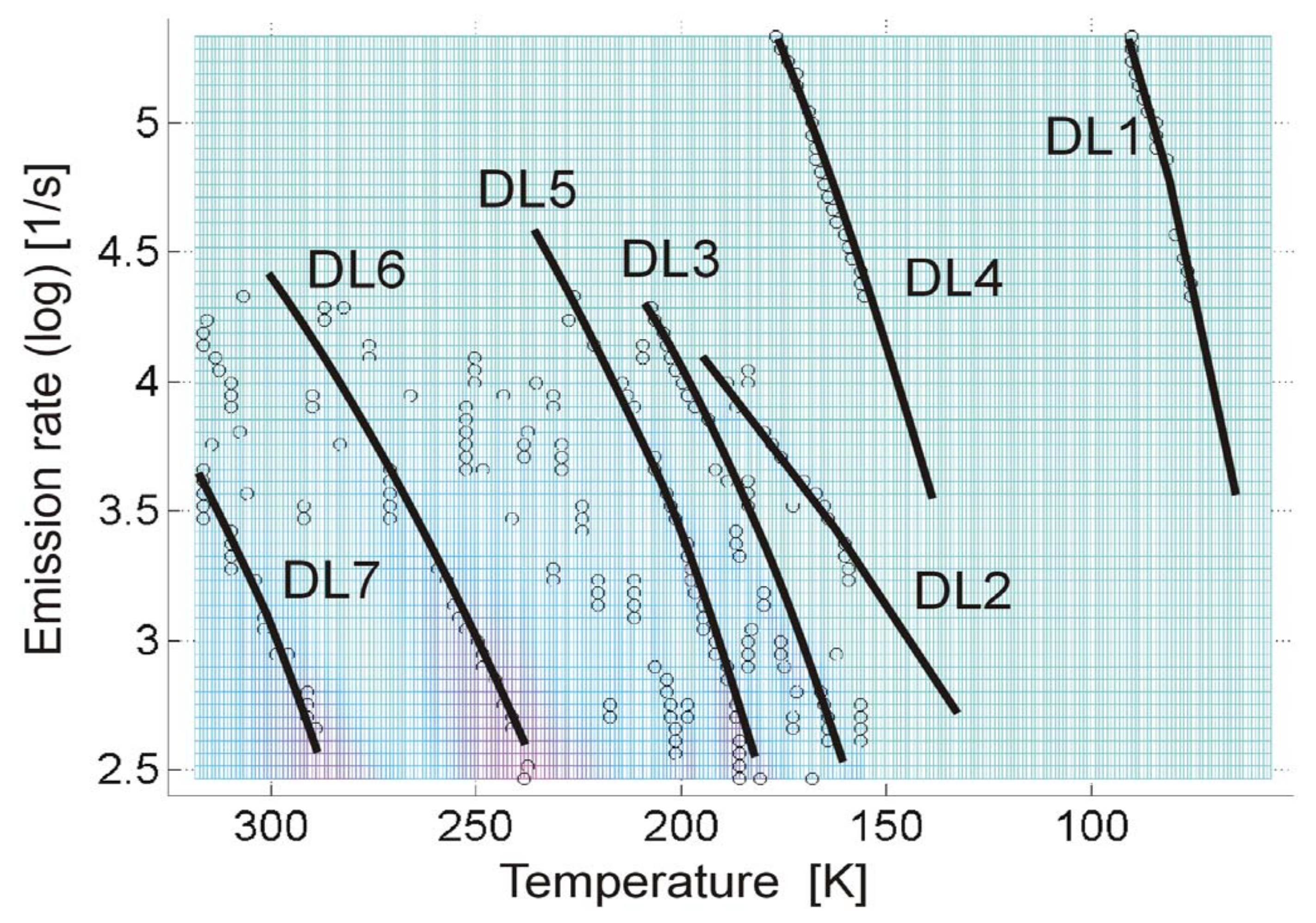


Fig.3. Temperature dependences of emission rate for defect centers DL1-DL7 detected in SI InP:Fe. The non-linearity of the solid lines is due to lack of T^2 correction of the ordinate axis.

Traps parameters extracted from the photocurrent transients for SI InP:Fe using the Laplace transform algorithm.

Trap	E_a [meV]	A [$K^{-2}s^{-1}$]	σ [cm^2]	ΔT [K]	Identification
DL1	59	4.89×10^4	3.88×10^{-16}	65-90	T4
DL2	86	0.539×10^2	-	150-175	T5
DL3	172	3.22×10^3	2.56×10^{-17}	160-190	not det. by corr. proc.
DL4	227	2.07×10^7	1.64×10^{-13}	120-180	T10
DL5	369	1.11×10^8	-	180-205	T11
DL6	370	4.21×10^5	-	240-275	T14
DL7	640	7.74×10^8	6.14×10^{-12}	280-320	$Fe^{2+/3+}$; T18

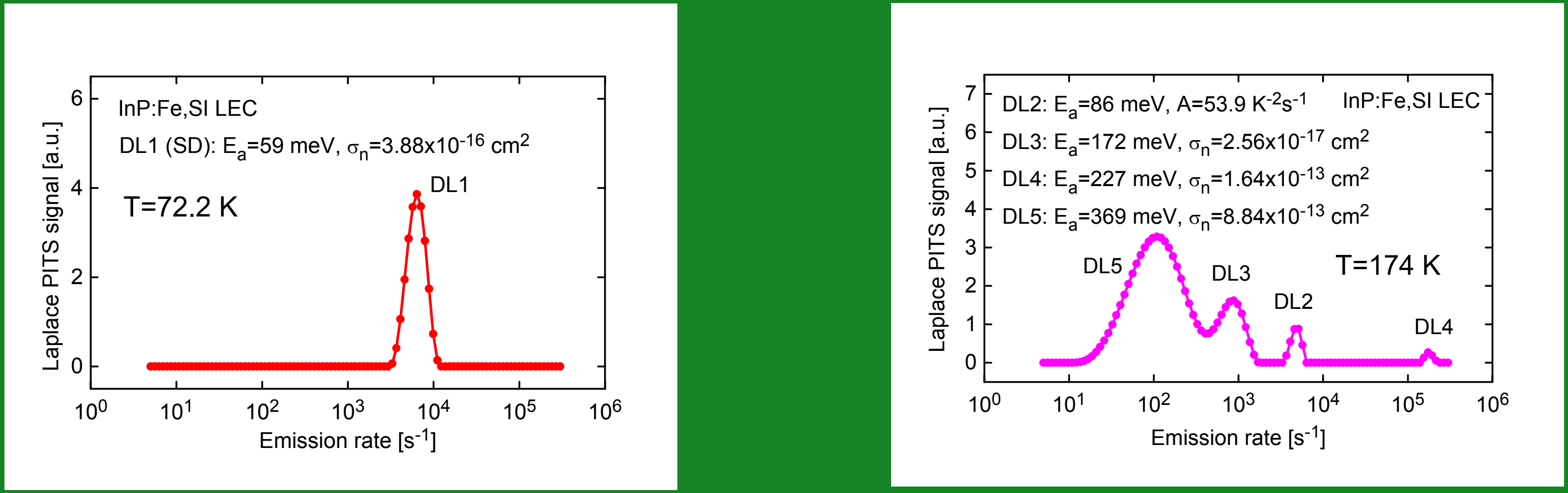


Fig.4. One-dimensional Laplace-PITS spectra for traps DL1-DL4 detected in SI InP:Fe.

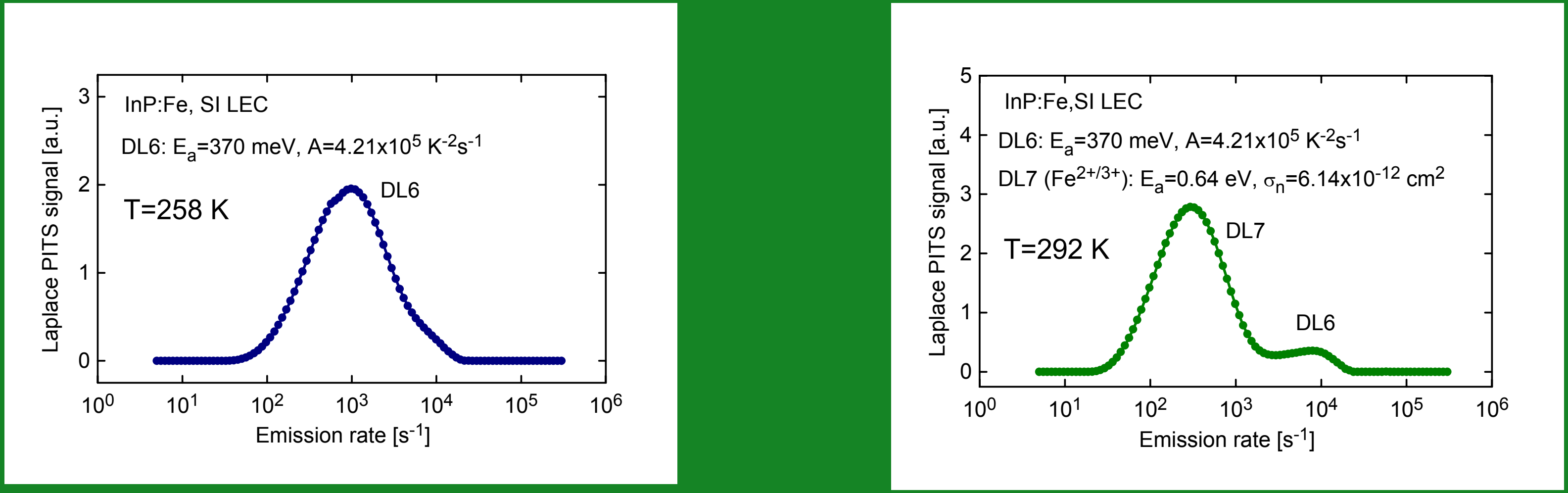


Fig.5. One-dimensional Laplace-PITS spectra for traps DL5 and DL6 detected in SI InP:Fe.

Conclusions (II)

- The Laplace transform algorithm was applied to determine parameters of traps from the photocurrent decays recorded for SI InP:Fe.

- The parameters of traps are in a good agreement with those determined by means of the correlation procedure.

- The new algorithm allows better separation of defects with similar properties compared to the correlation procedure.

- Owing to the elements of computational intelligence, the algorithm significantly diminishes ambiguity of defect centers characterization and fastens the calculation procedure.