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Photoinduced transient spectroscopy of epitaxial silicon irradiated with high proton fluences

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Plan of talk:

- **Background and motivation**
- **Experimental details**
- **Results of HRPITS measurements**
- **Conclusions**

Experimental details

ITME: fabrication of epitaxial layer

1. Starting material: <111>, low resistivity ($\rho<0.02\ \Omega\cdot$cm)
   300 μm thick Czochralski (Cz) silicon substrate
   doped by Sb donors.
2. Thin (75 μm) medium resistivity ($\rho=50\ \Omega\cdot$cm),
   epitaxial silicon layers doped by P donors
   have been grown on the CZ-Si substrates forming
   simple n-n^+ structures.

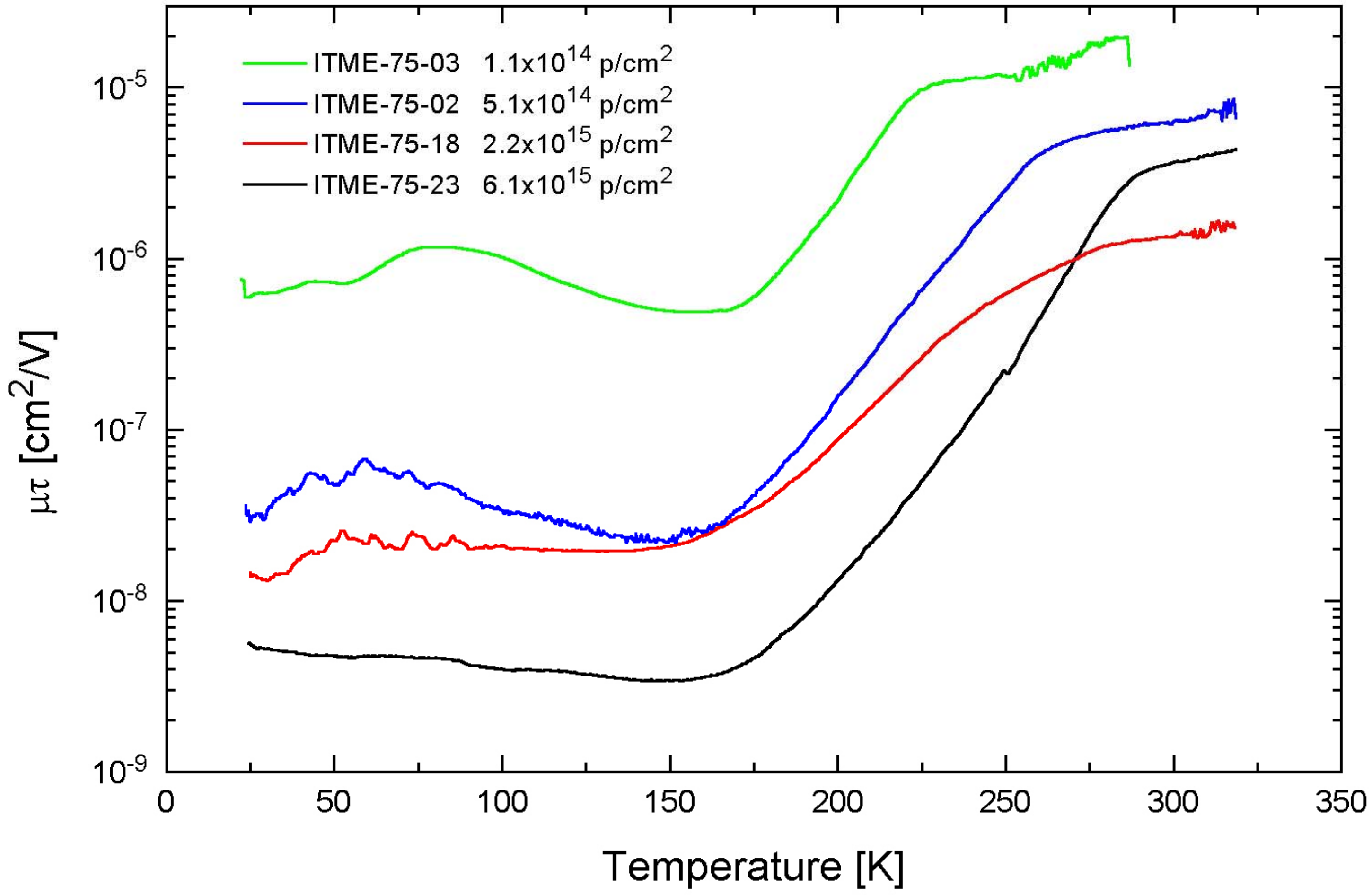
CERN: 24- GeV/c proton irradiation; PS RUN period: P1A-2004

Fluences

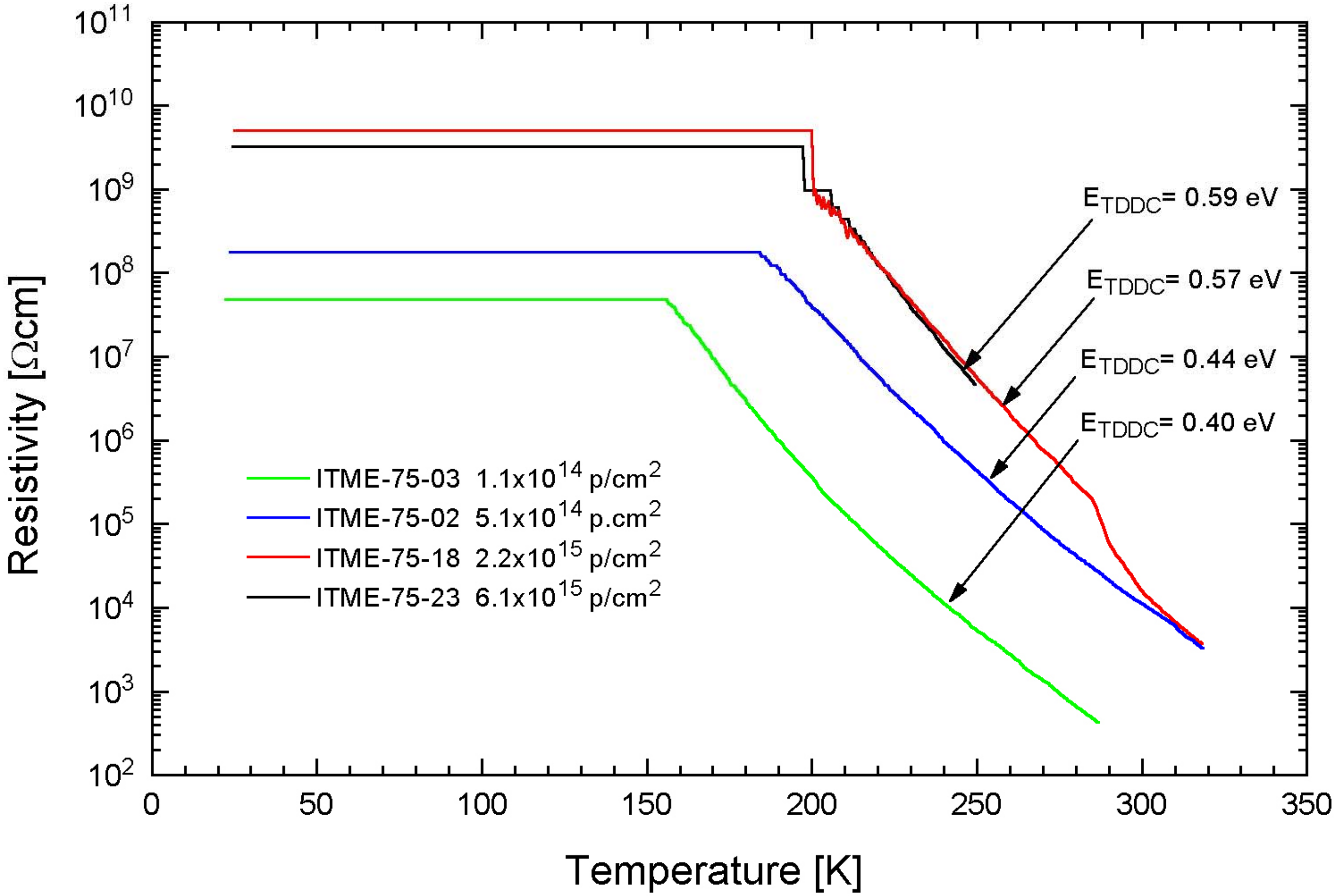
- 1.06×10^{14} p/cm^2 - sample A
- 5.05×10^{14} p/cm^2 - sample B
- 2.17×10^{15} p/cm^2 - sample C
- 6.10×10^{15} p/cm^2 - sample D

After the irradiation all the samples were stored at -20 ^{o}C.

Effect of proton fluence on $\mu\tau$ of epitaxial Si

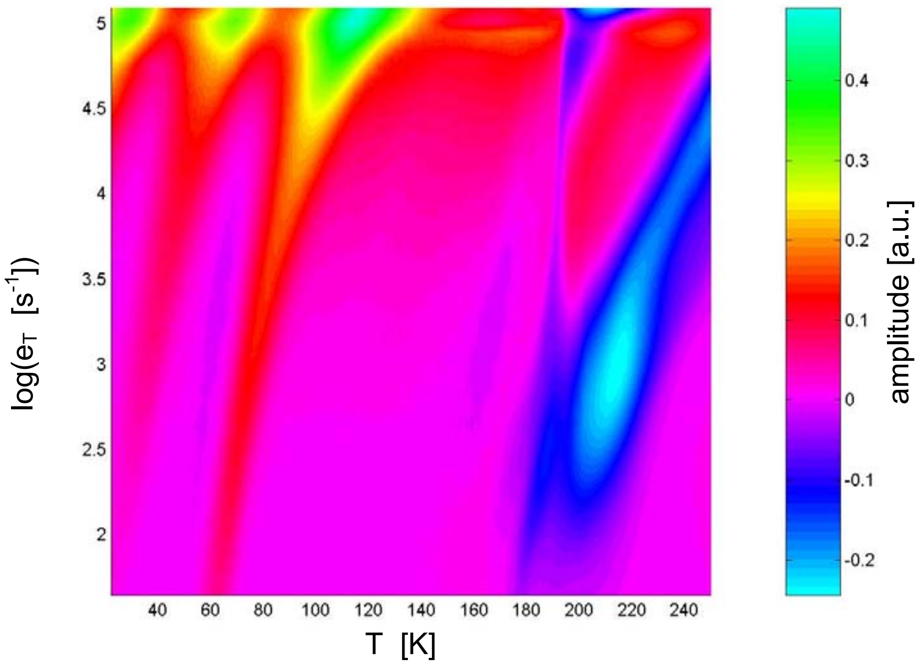


Effect of proton fluence on E_{TDDC} of epitaxial Si

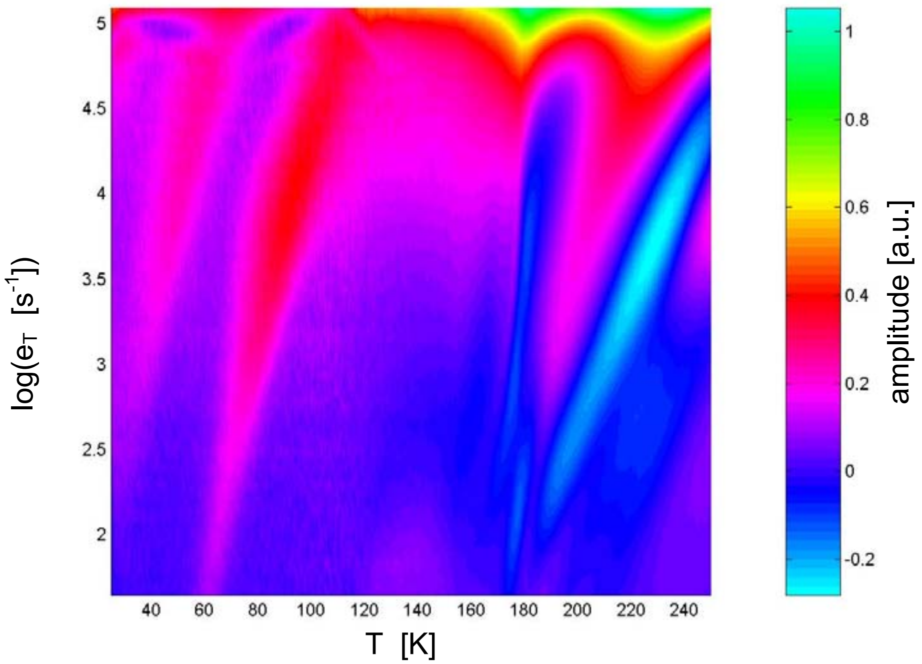


Effect of photon flux on PITS spectral fringes

Epitaxial silicon, proton fluence 1.06×10^{14} p/cm^2 (sample A)



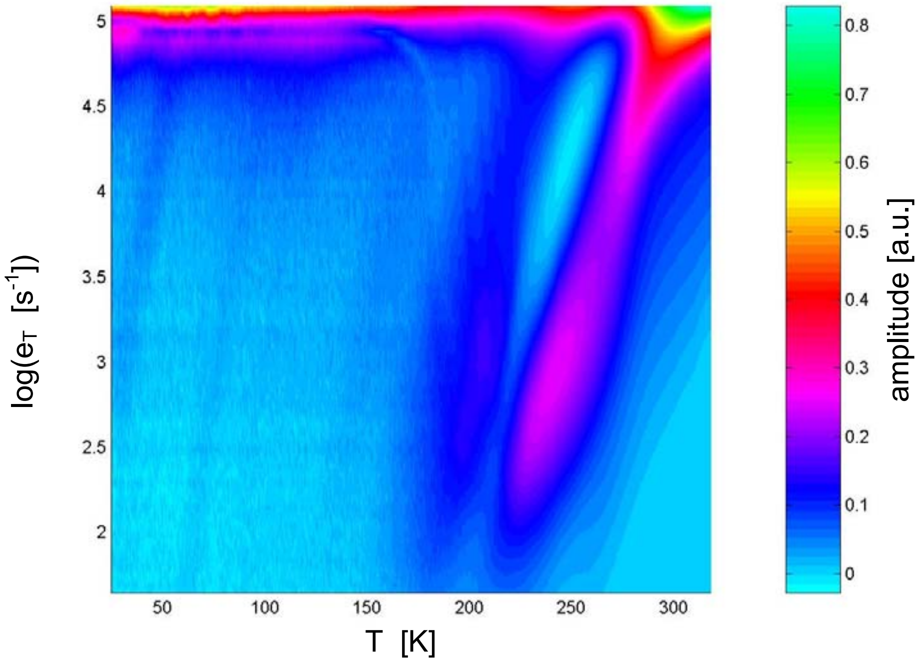
F=1.5×10^{17} cm^{-2}s^{-1}



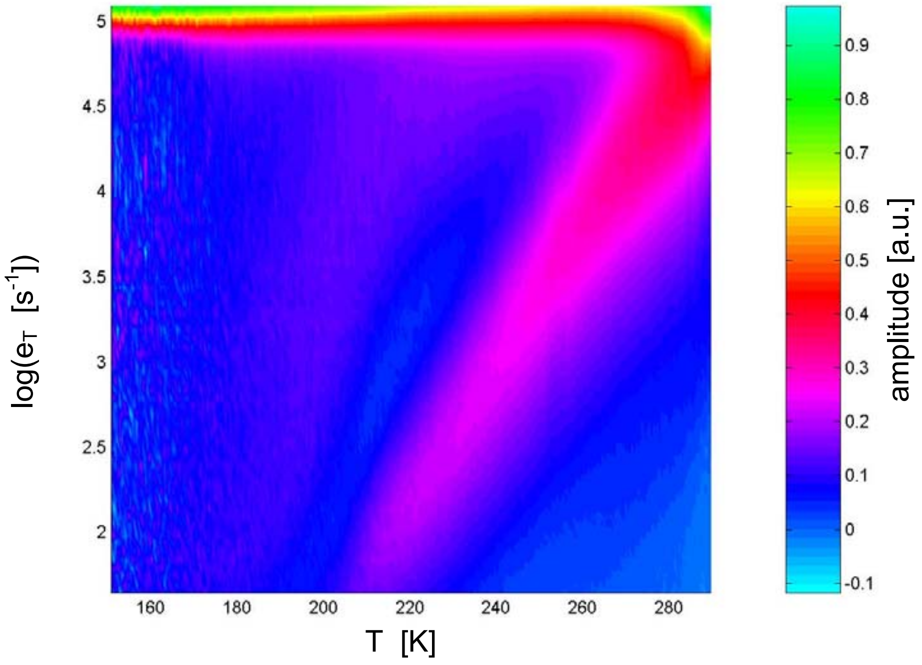
F=3.5×10^{15} cm^{-2}s^{-1}

Effect of photon flux on PITS spectral fringes

Epitaxial silicon, proton fluence 2.17×10^{15} p/cm^2 **(sample C)**



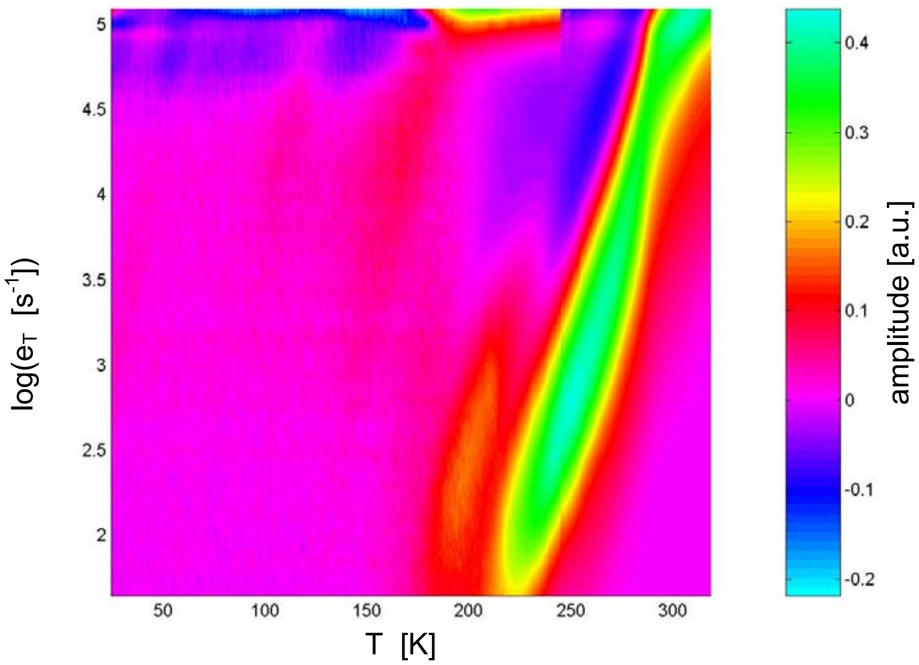
F=1.5×10^{17} cm^{-2}s^{-1}



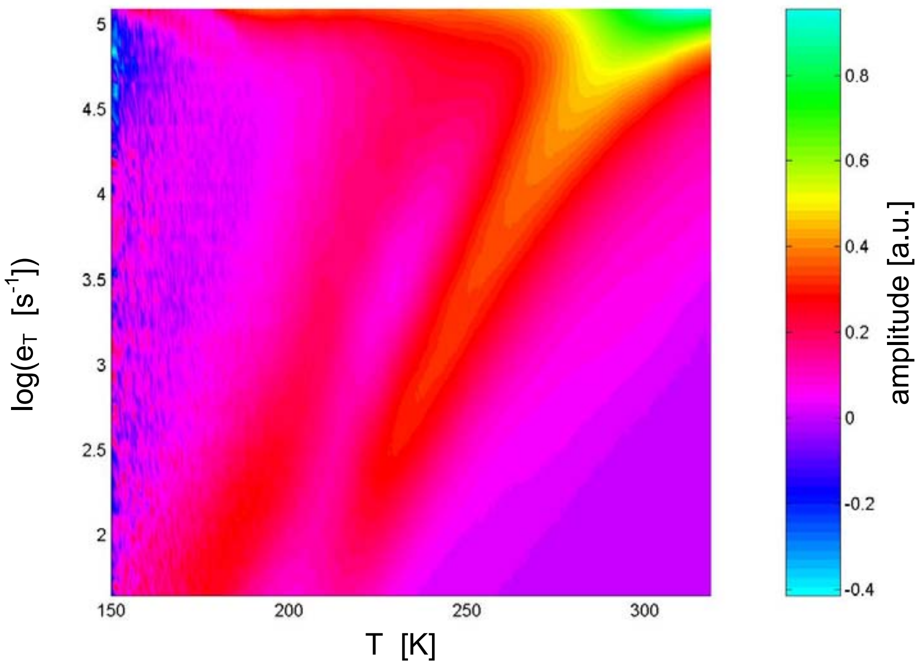
F= 3.5×10^{15} cm^{-2}s^{-1}

Effect of photon flux on PITS spectral fringes

Epitaxial silicon, proton fluence 6.10x10^{15} p/cm^2 (sample D)



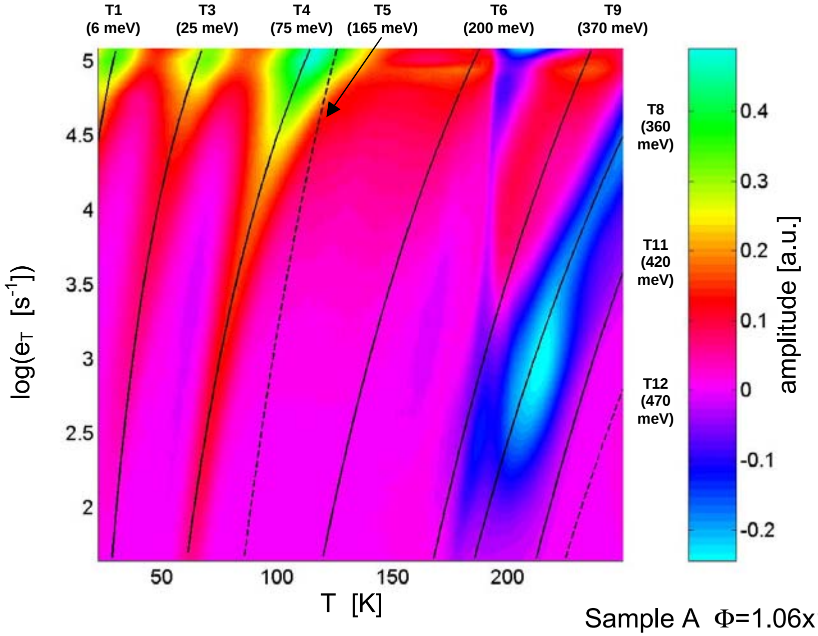
F=1.5x10^{17} $cm^{-2}s^{-1}$



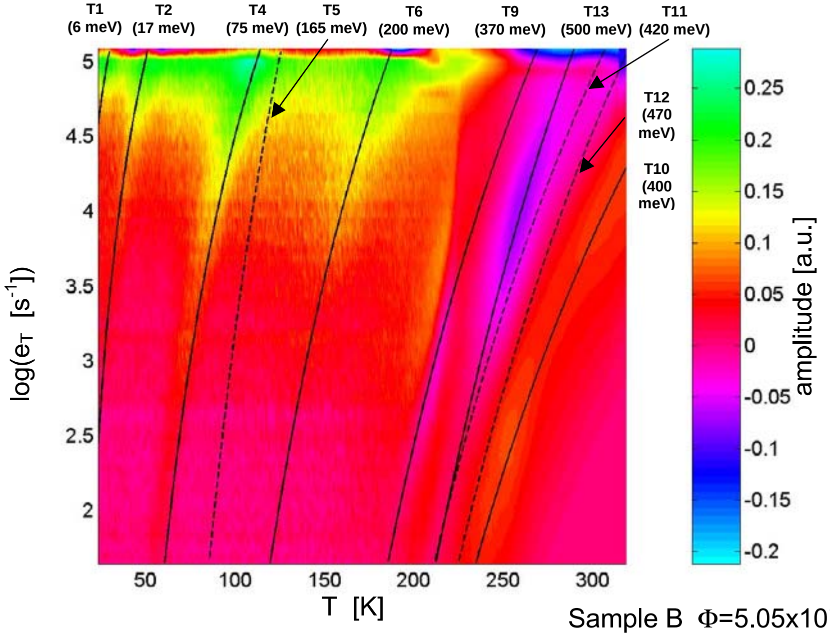
F=3.5x10^{15} $cm^{-2}s^{-1}$

Effect of proton fluence on defect structure of epitaxial silicon

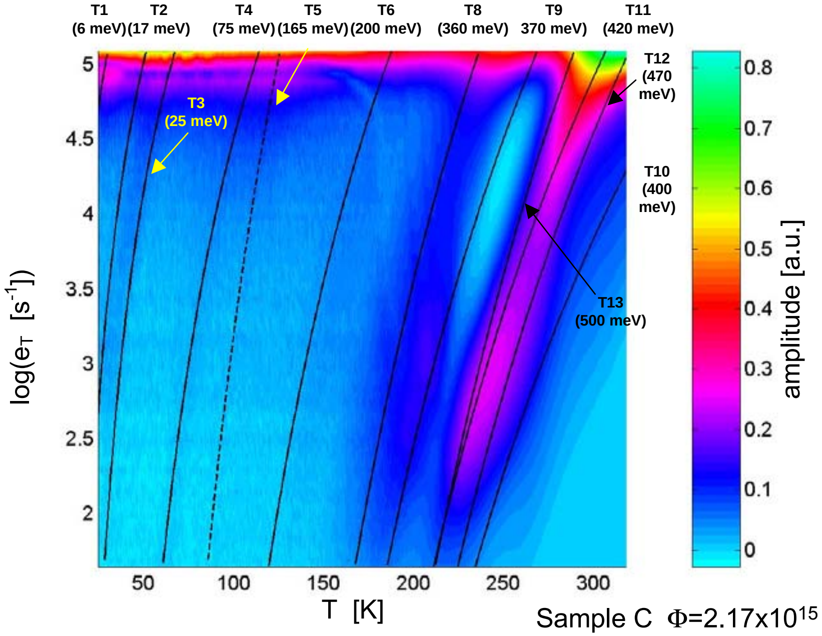
Comparison of PITS spectral fringes for $F=1.5\times10^{17}$ cm^{-2}s^{-1}



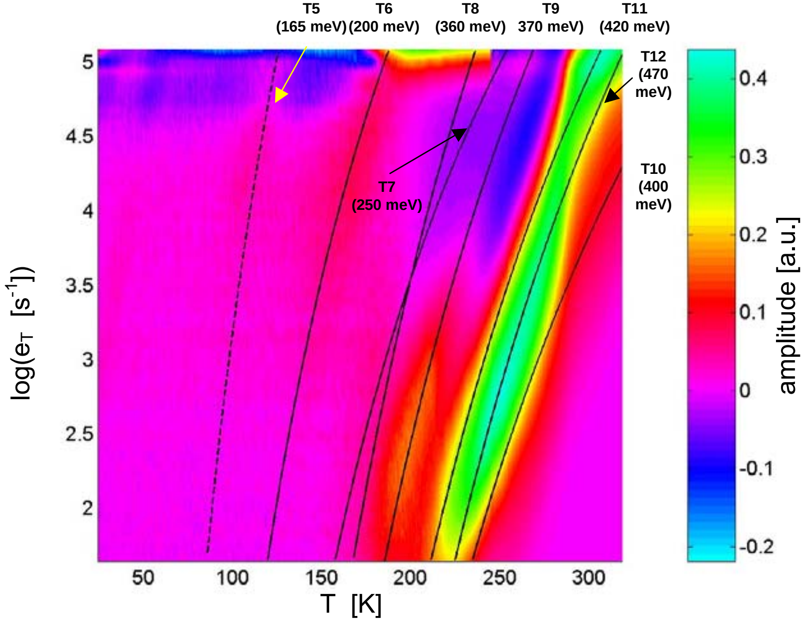
Sample A $\Phi=1.06\times10^{14}$ p/cm^2



Sample B $\Phi=5.05\times10^{14}$ p/cm^2



Sample C $\Phi=2.17\times10^{15}$ p/cm^2



Sample D $\Phi=6.10\times10^{15}$ p/cm^2

Parameters of defect centres detected by the PITS method in the samples A, B, C and D of epitaxial silicon subjected to 24 GeV/c proton irradiation

Defect centre	Activation energy E_a (meV)	Pre-exponential factor A ($s^{-1}K^{-2}$)	Identification
T1	6	1.5×10^3	shallow donor
T2	17	2.2×10^3	shallow donor
T3	25	2.4×10^3	shallow donor
T4	75	1.8×10^4	interstitial related (I_4)
T5	165	3.0×10^7	$VO^{-/0}$
T6	200	8.0×10^5	$V_2^{0/+}$
T7	250	1.7×10^5	$VOH^{+/0}$
T8	360	1.0×10^8	$VOH^{-/0}$
T9	370	1.5×10^7	C_iP_s
T10	400	8.7×10^5	C_iO_i
T11	420	1.0×10^7	$V_2^{0/-}$
T12	470	3.0×10^7	VP
T13	500	7.6×10^8	hydrogen related (V_2H ?)

Model of trap concentration calculation

$$S(T) = \frac{I(t_1) - I(t_2)}{I_0 - I_\alpha}$$

$$I(t_1) = Ke_n \exp(-e_n t_1) \qquad K = qn_T V$$

$$I(t_2) = Ke_n \exp(-e_n t_2) \qquad V = \frac{wl}{\alpha}$$

$$n_T = \frac{S(T_m) I_0 \alpha}{qwle_n G_A [\exp(-t_1 e_n) - \exp(-t_2 e_n)]}$$

$$n_T(0) = \frac{(nc_n + e_p^o + e_p) N_T}{nc_n + pc_p + e_n^o + e_n + e_p^o + e_p}$$

$$n_T(\infty) = \frac{N_T}{1 + \frac{e_n}{e_p}}$$

$I_0 = I(0)$ - the photocurrent at the moment of switching off the illumination pulse

$I_\alpha = \lim_{t \to \alpha} [I(t)]$ - the photocurrent at the moment of switching on the next illumination pulse

n_T - the concentration of the traps filled with electrons

V - the volume of the active region

K - the electric charge released by the thermal emission

α - the absorption coefficient

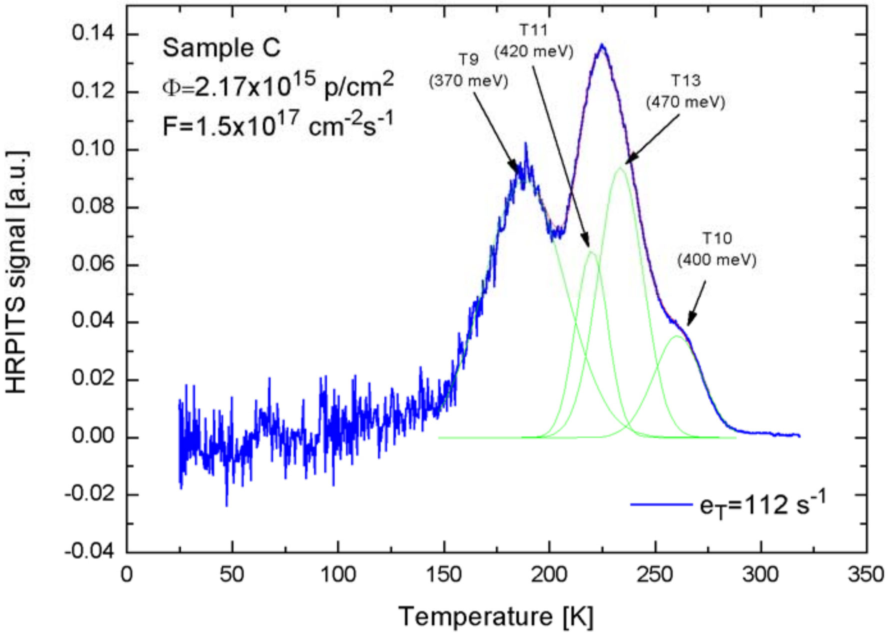
w - the distance between the ohmic contacts

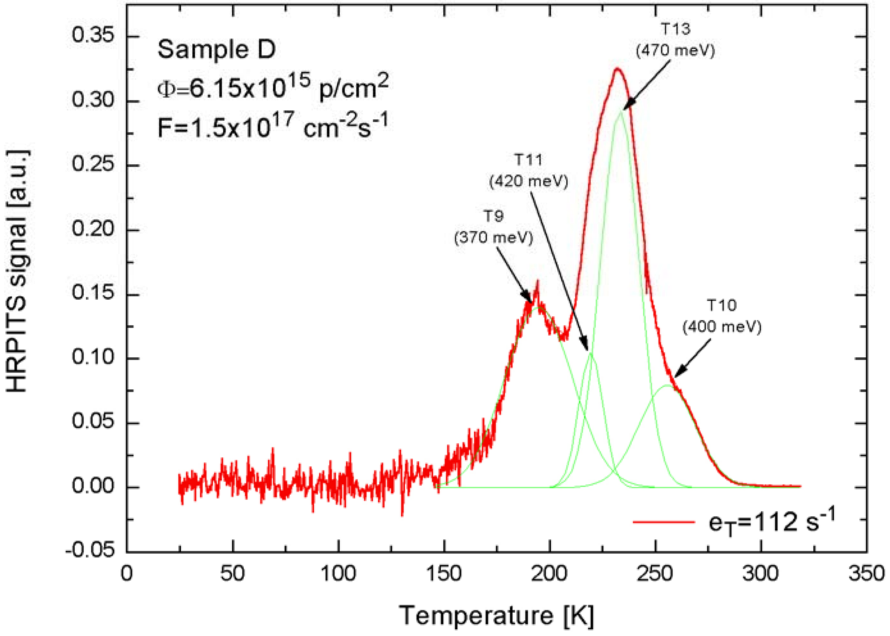
l - the ohmic contact width

G_A - the current amplifier gain

N_T - the trap concentration

The effect of proton fluence on trap concentrations





Defect centre	Activation energy E_a (meV)	Pre- exponential factor A ($s^{-1}K^{-2}$)	Trap concentration ($x10^{15}$ cm^{-3})	
			Sample C	Sample D
T9	370 (C_iP_s)	$1.5x10^7$	0.14	0.12
T10	400 (C_iO_i)	$8.7x10^5$	3.7	3.3
T11	420 ($V_2^{0/-}$)	$1.0x10^7$	9.9	21.2
T13	470 (VP)	$3.0x10^7$	7.9	21.7

Concentration of shallow donors in sample A (Φ=$1.06x10^{14}$ p/cm^2) :

- T1 (6 meV) - $5.0x10^{12}$ cm^{-3},
- T2 (25 meV) - $2.3x10^{13}$ cm^{-3} and

concentration of interstitial related defect

T4 (75 meV) - $2.1x10^{14}$ cm^{-3}

Conclusions

- Photoinduced Transient Spectroscopy with implementation of two-dimensional analysis of photocurrent decays has been used to investigation irradiation centres produced by high-energy proton irradiation in epitaxial silicon.
- It has been shown that the irradiation with proton fluences of 1.06x10^{14}, 5.05x10^{14}, 2.17x10^{15} and 6.10x10^{15} p/cm^2 results in shifting the Fermi-level position to 0.40, 0.44, 0.57 and 0.59 eV, respectively.
- Apart from typical radiation-induced point defects in Si such as: shallow donors, $VO^{-/0}$, $V_2^{0/+}$, C_iP_s, C_iO_i, $V_2^{0/-}$ and VP, some hydrogen related defects as well as an interstitial related defect have been found.
- With increasing the fluence from 2.17x10^{15} to 6.17x10^{15} p/cm^2 the concentrations of $V_2^{0/-}$ and VP rise from 1.0x10^{16} to 2.12x10^{16} cm^{-3} and from 8.0x10^{15} to 2.17x10^{16} cm^{-3}, respectively.
- The concentrations of C_iP_s and C_iO_i are of the order 1.0x10^{14} and 3.0x10^{15}, respectively, and not affected by the increase of proton fluence from 2.17x10^{15} to 6.17x10^{15} p/cm^2.

Acknowledgement

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