RESULTS OF THE SIMULTANEOUS INVESTIGATION OF THE MICROWAVE PROBED PHOTOCONDUCTIVITY AND CURRENT TRANSIENTS IN PROTON IRRADIATED FZ Si PAD-DETECTORS

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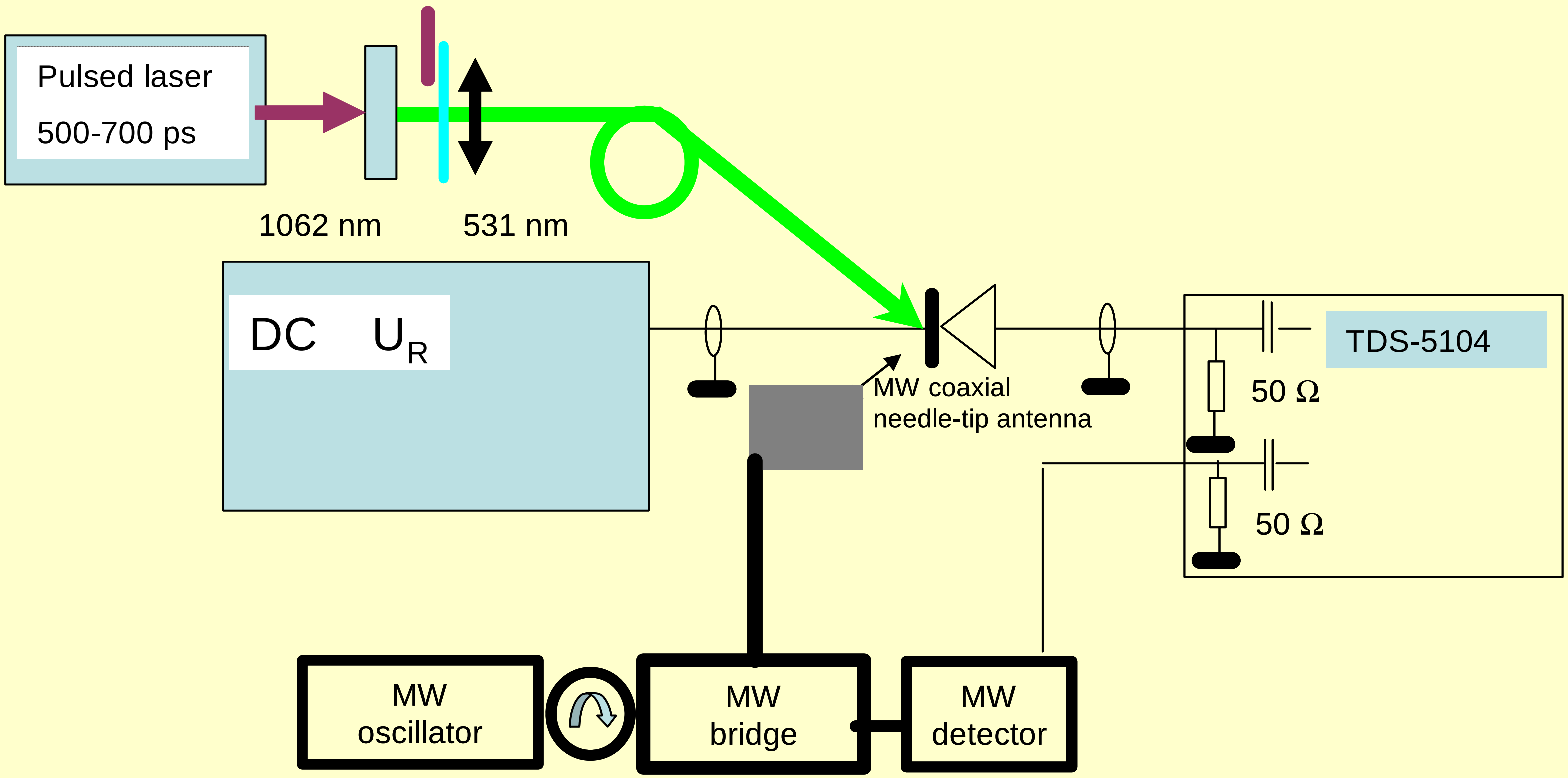
Outline

- Motivation of the correlative investigations of carrier recombination and transport
- Setup of MWR, TCT and CELIV experiments
- Recombination characteristics
- Carrier transit characteristics and parameters
- Summary

Motivation of the correlative investigations of carrier recombination and transport

- ⊕ **To reveal a role of recombination in carrier transit processes**
- ⊕ **To separate carrier recombination and drift parameters**
- ⊕ **To estimate field redistribution**

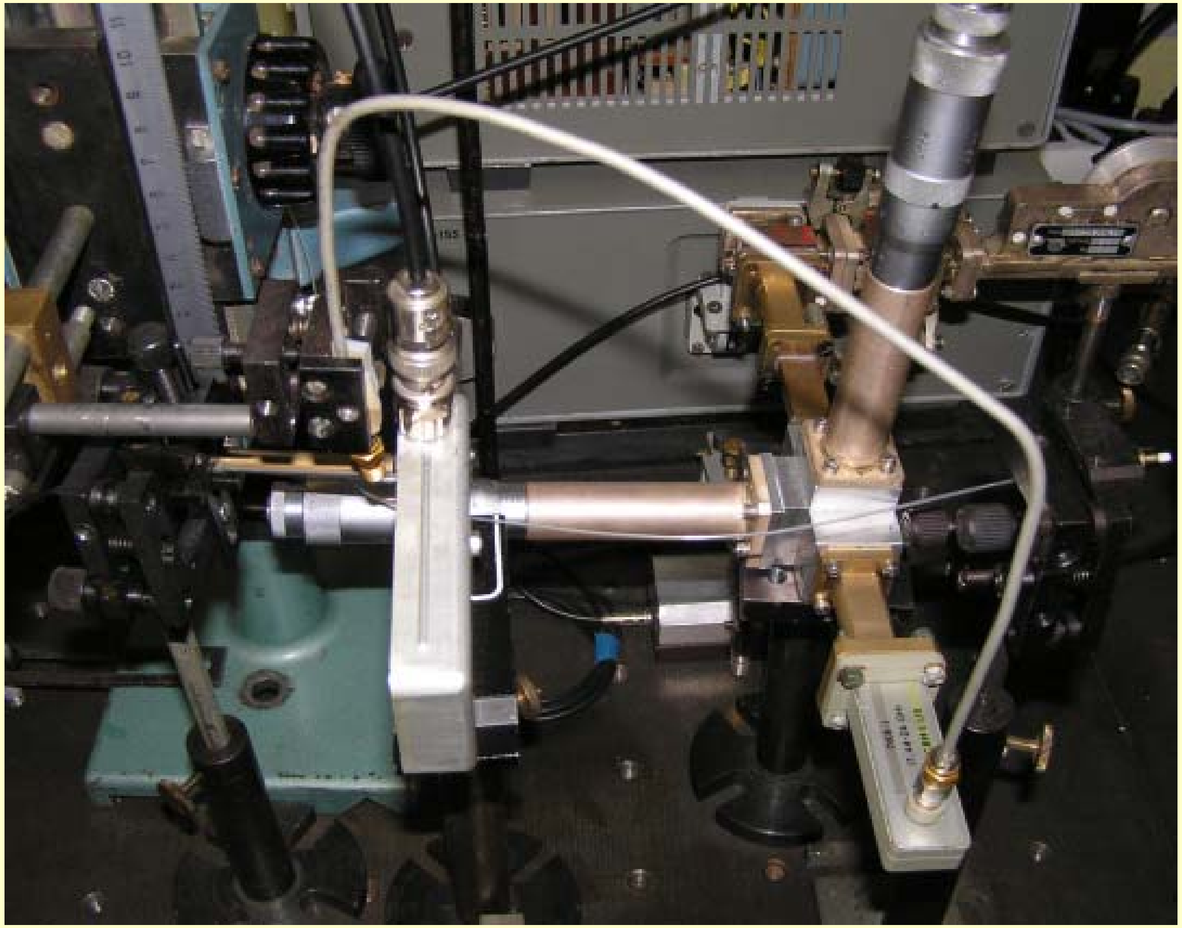
Setup of the simultaneous MWR & TCT measurements

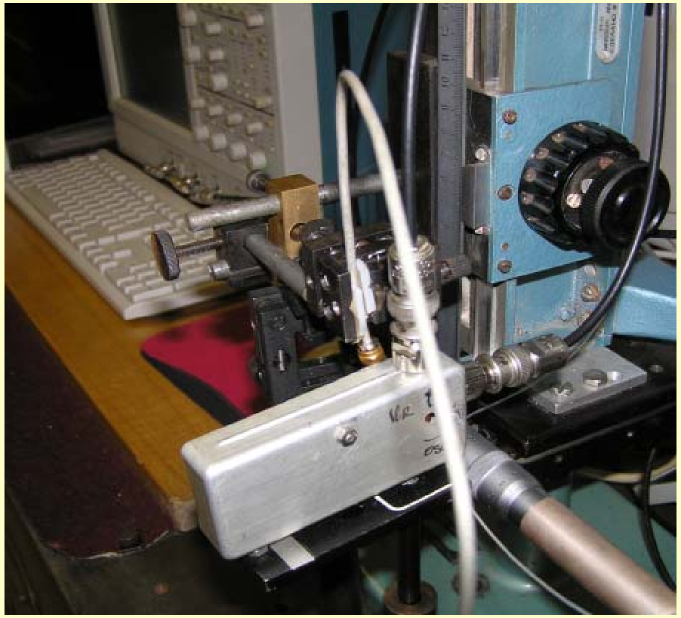


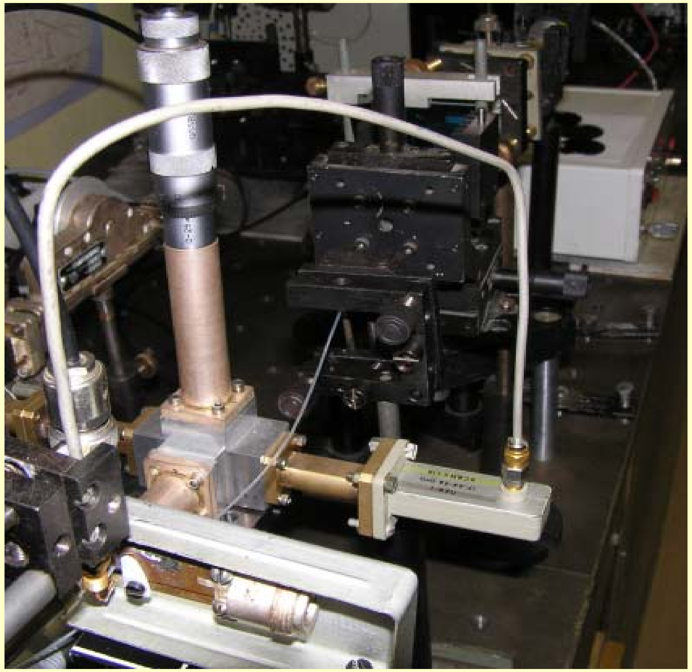
V.Eremin and Z.Li. IEEE Trans. NS, **41** (1994) 1907

E.Gaubas. Lith. J. Phys., **43** (2003) 145

Arrangement of the MW-PCD and TCT experiments

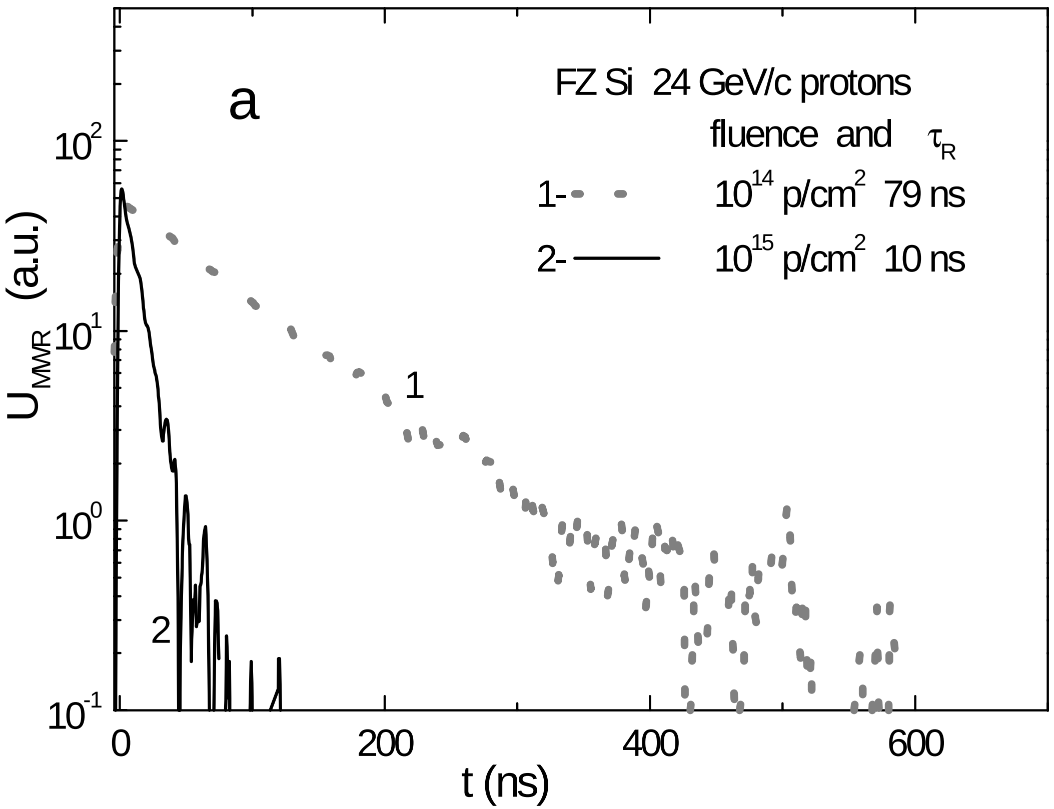


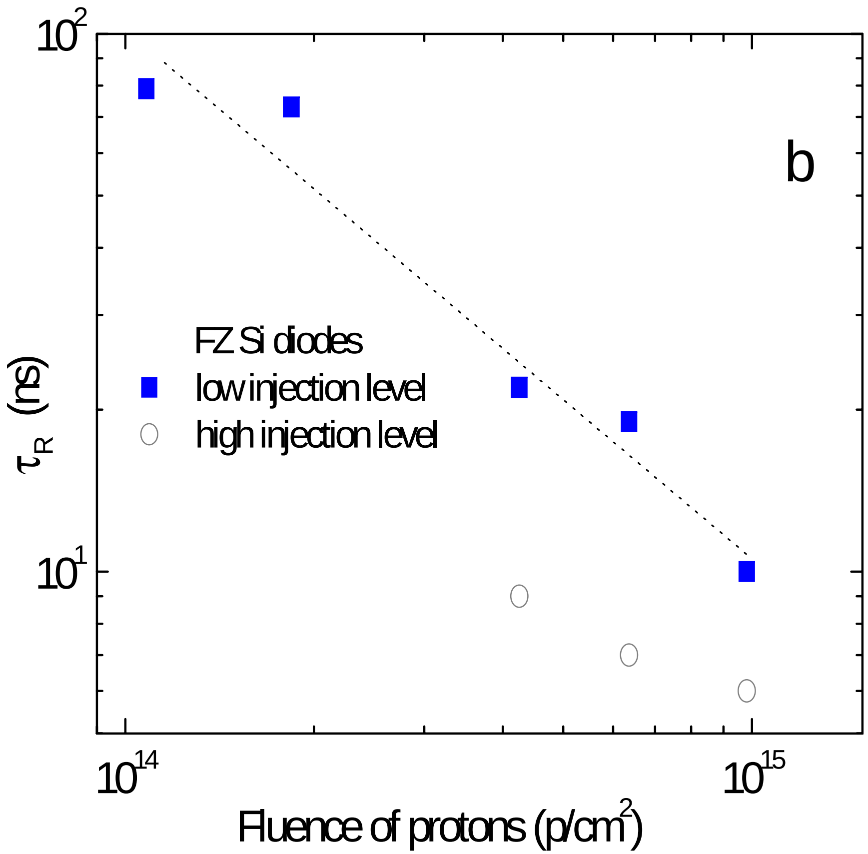




E.Gaubas, J.Vaitkus VIII-rd50 WS, WWW.cern.ch/rd50

RT MWR determined variations of the carrier decay lifetime with irradiation fluence

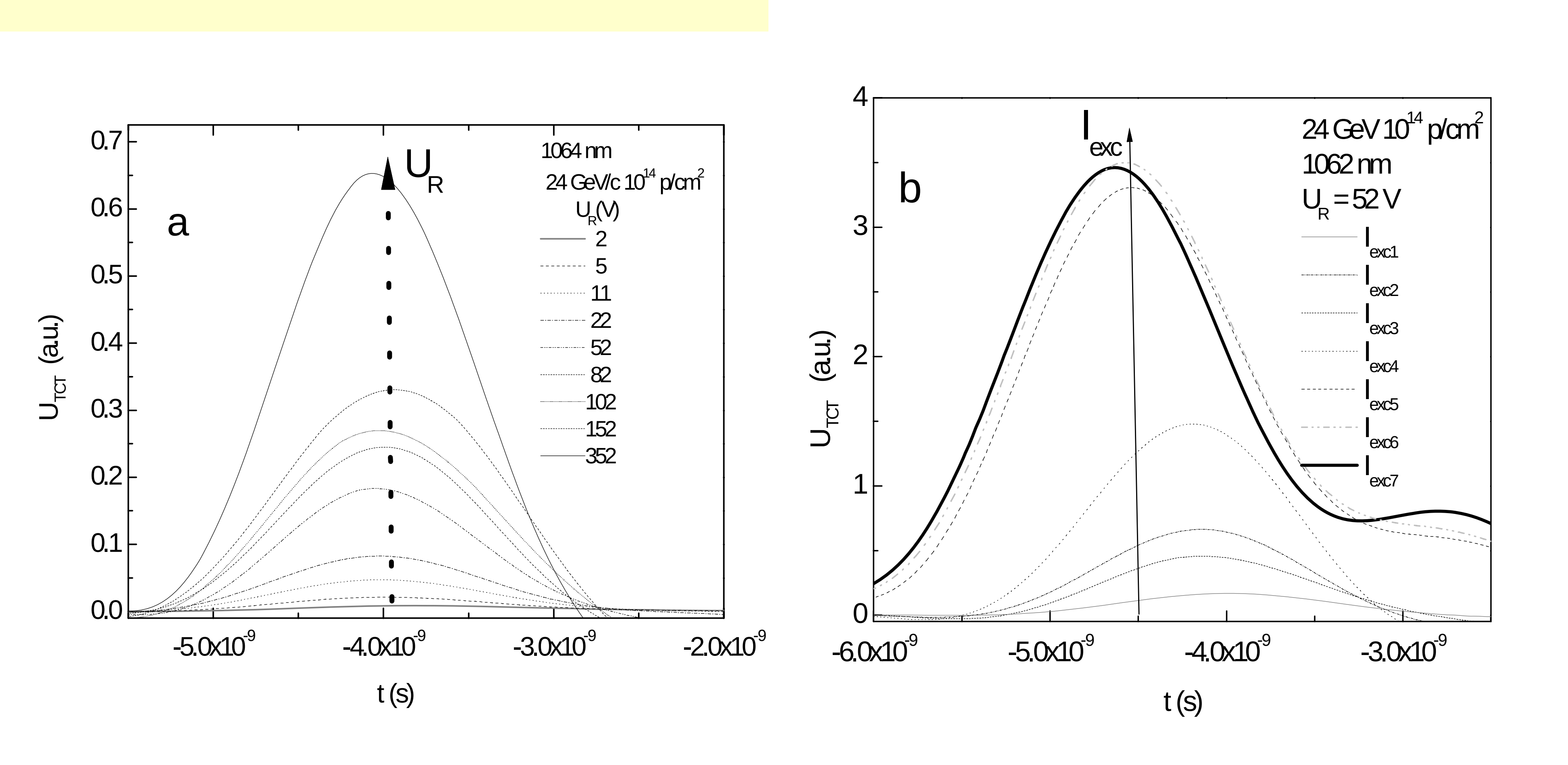




a- Carrier decay transients measured by MWP-PC in FZ Si diodes irradiated with 24 GeV/c protons of fluence 10^{14} (1) and 10^{15} (2) cm^{-2} exhibit recombination prevailing within excess carrier density relaxation

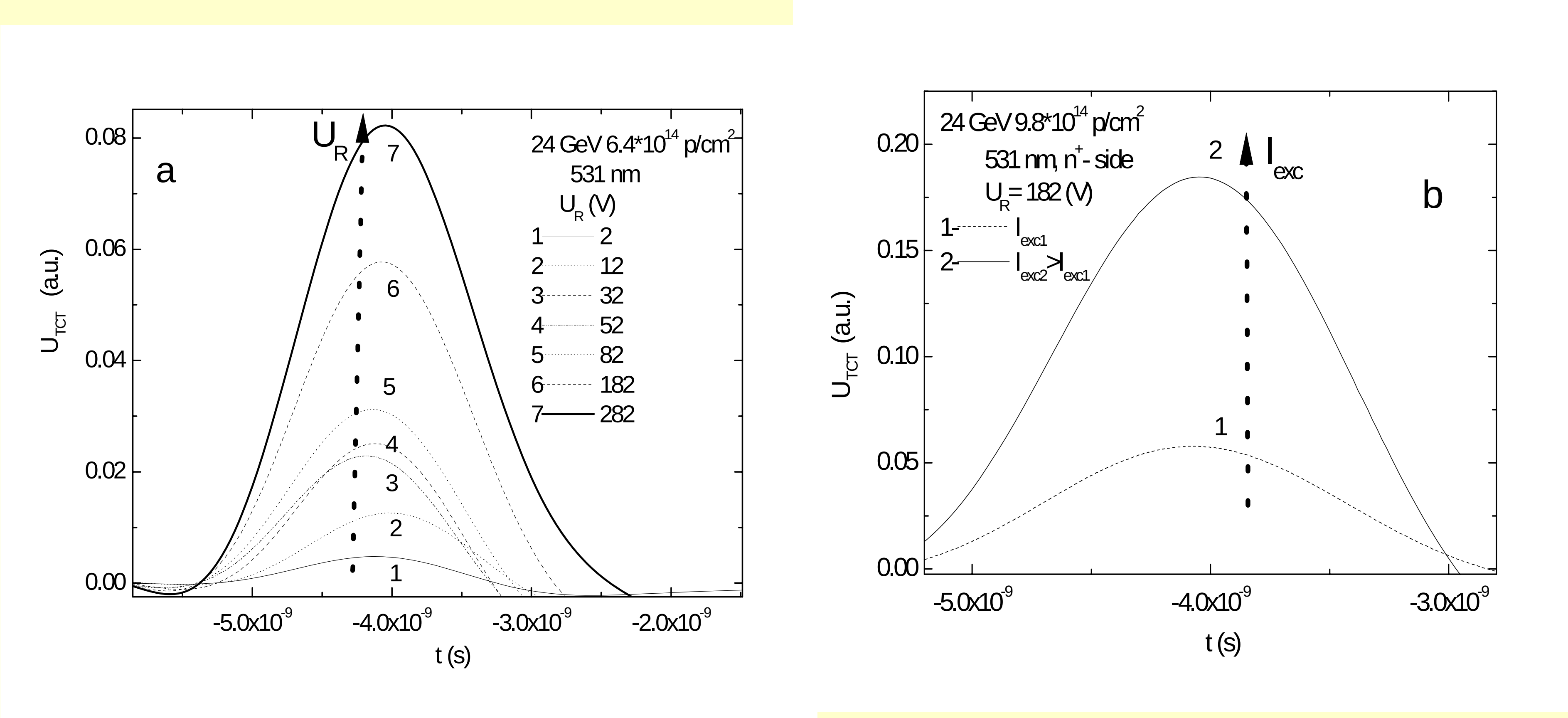
b- Variation of the recombination lifetime with fluence of 24 GeV/c protons, measured at low and high carrier injection levels shows enhancement of concentration of defects

TCT transients at bulk 1062 nm excitation in diodes irradiated with 10^{14} p/cm^2



Current transients measured in FZ Si diode irradiated with protons of fluence 10^{14} cm^{-2} varying bias voltage (a) and 1062 nm 500 ps pulsed excitation density (b).

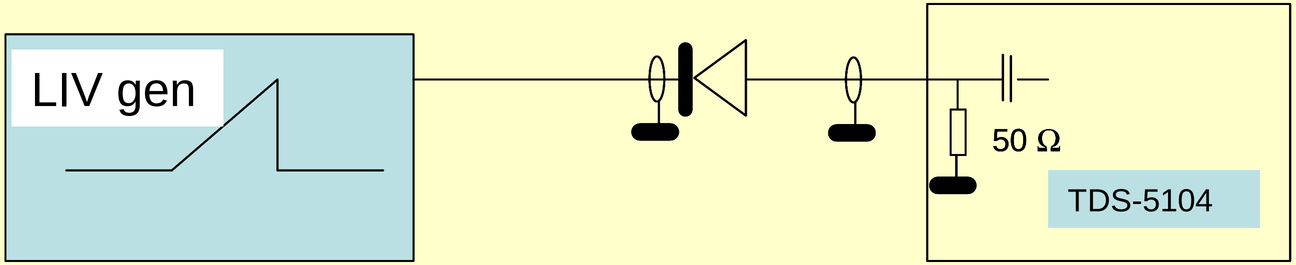
TCT transients at surface 531 nm excitation in diodes irradiated with 6×10^{14} and 10^{15} p/cm^2

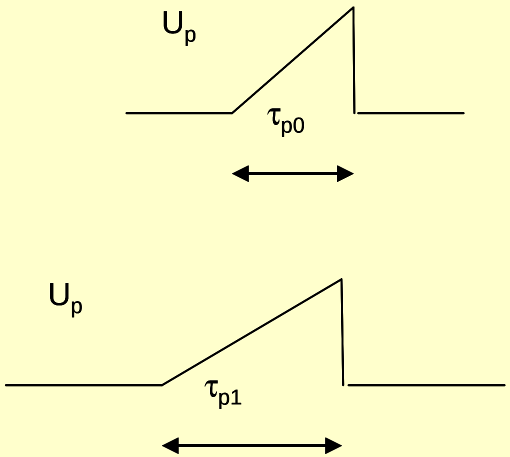


Current transients measured in FZ Si diode irradiated with protons of fluence 6.4×10^{14} cm^{-2} varying bias voltage (a) and n$^+$ surface excitation density (b) at bias voltage 182 V.

Principles of the ***C***harge ***E***xtraction by ***L***ineary ***I***ncreasing ***V***oltage (***CELIV***) technique

U_R





$C_g=j_0/A$

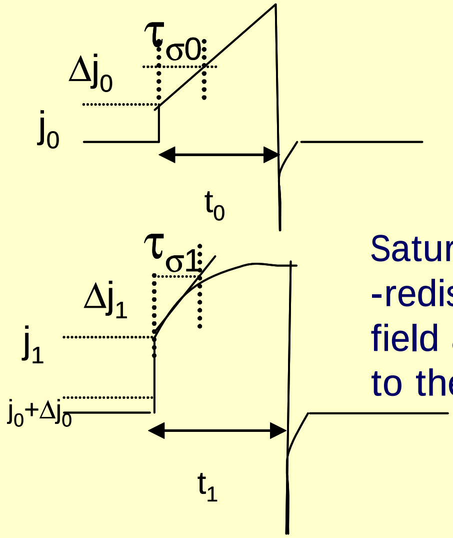
$\tau_{\sigma 0}^{-1}=[dj(t)/dt]|_{t=0}/j_0$

$\tau_{p0} << \tau_{p1}$

$C_s=j_1/A$

$\tau_{\sigma 1}^{-1}=[dj(t)/dt]|_{t1=0}/j_1$

$\sigma_{nc}=\varepsilon\varepsilon_0 \tau_{\sigma 1}^{-1}$



Initial/fast

Saturated $t>\tau_{\sigma 1}$, $C_s>C_g$
-redistribution of electric field and E concentration to the contact regions

Response by the equilibrium carrier extraction

$d_{tr}=[C_g/C_s]*d_g$

$\tau_{tr}=d_{tr}^2/\mu U_p$

G.Juška, K.Arlauskas, M.Viliunas, and J.Kocka. Phys. Rev. Lett. 84 (2000) 4946.

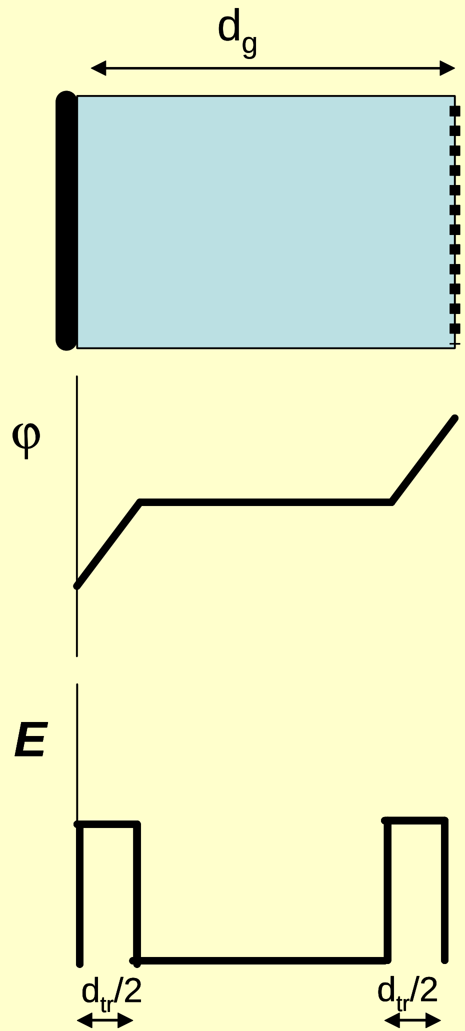
Parameters measured by charge extraction under linearly increasing voltage (CELIV) technique

Parameters extracted by CELIV technique in diode irradiated with 10^{14} p/cm^2 fluence.

U_p (V)	C_g (pF)	C_s (pF)	$\tau_{\sigma 0}$ (μs)	σ_{nc} ($\Omega^{-1}cm^{-1}$)	d_{tr}/d_g	τ_{tr} (ns)
2.4	13	240	0.50	10^{-8}	0.054	≤1
11.1	13	170	0.50	4×10^{-9}	0.076	<1
35.8	13	110	0.50		0.109	<1
212.0	13	60			0.22	<1

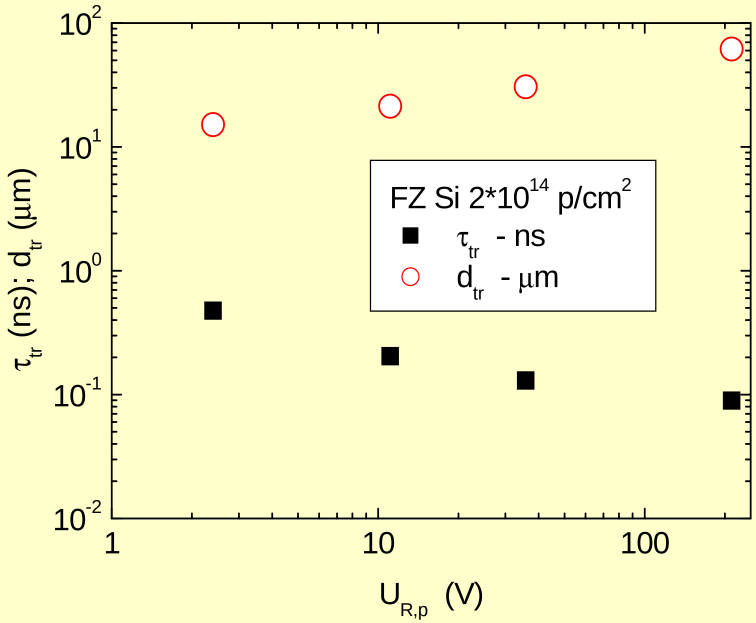
The typical parameters of geometrical (C_g) and structural (C_s) capacitance, of dielectric relaxation time ($\tau_{\sigma 0}$) ascribed to the bulk conductivity, conductivity (σ_{nc}) ascribed to near-contact range, a ratio (d_{tr}/d) of the carrier transit length (d_{tr}) to geometrical thickness (d_g), and estimation of carrier transit time (τ_{tr}) determined by CELIV technique at different peak voltage (U_p) values of saw-shape pulse, are listed in Table . These values have been measured by varying saw-shape pulse duration and voltage.

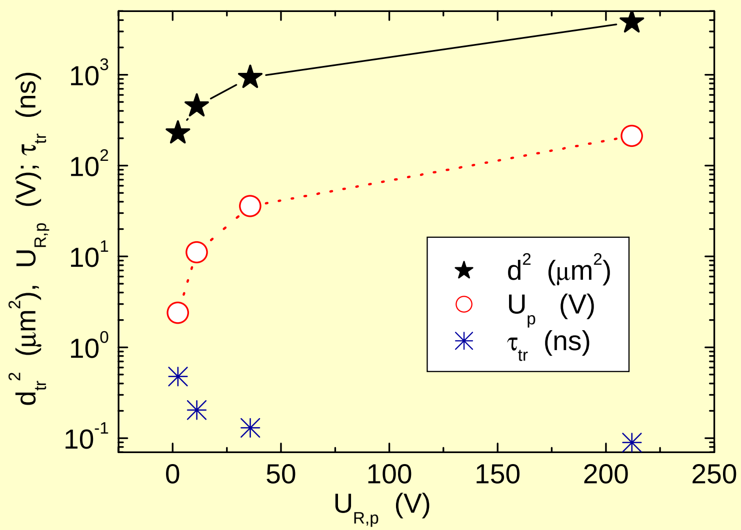
Electric field redistribution estimated by the CELIV technique



$$d_{tr}/d_g=C_g/C_s$$

$$\tau_{tr}=d_{tr}^2/2\mu U$$





SUMMARY

- The recombination decay timescale of 8 - 80 ns is much longer than TCT signal timescale (2-3 ns) observed varying biasing and excitation density for the 10^{14} and 10^{15} p/cm^2 irradiated diodes. However, the carrier transit time is in the sub-nanosecond scale when duration of the TCT signal rise and drop-off slopes are of about of 1 ns, close to time resolution of the experimental circuit ($\tau_L \leq 700$ ps, $\tau_{RC} = 1$ ns) .

- The recombination processes prevail at room temperature, as revealed from the analysis of MW-PCD transients. A decrease of recombination lifetime with proton irradiation fluence is determined. Large capture cross-section of the order of 10^{-12} cm^2 can be deduced from the absolute values of recombination lifetime, at defects concentration less than 10^{13} cm^{-3}.

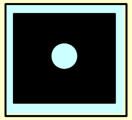
- The increase of capacitance of the reverse biased diode structure with time, during the saw-shape pulse, and subsequent its saturation has been revealed in the timescale longer than dielectric relaxation time by CELIV technique.

- The effective carrier transit length increases with increase of pulsed bias voltage. Value of carrier transit length is nearly 20 times less than geometrical thickness of the diode at low bias peak voltages, and this d_{tr} remains 4 times less than d_g even in the range of high *Up* voltages. Such a layered structure contains the increased bulk resistivity with intricate field distribution nearby contact.

- TCT signal is determined by relatively thin transit length with inherent carrier transit times in the sub-nanosecond time-scale, as observed in our experiments. The dielectric relaxation and recombination lifetimes are much longer than the carrier transit time τ_{tr}.

Thank You for attention

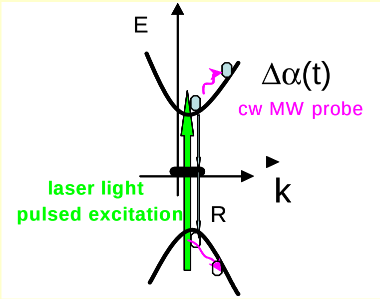
Samples



The pad-detectors fabricated on n-type FZ Si have been investigated. The optical window of about 2 mm diameter in the centre of the diode and the boundary (of 1 mm width) of the detector area were left non-metallized. The non-metalized detector areas have been exploited for the measurements.

Measurement techniques and instruments

Microwave probed photoconductivity (MW-PCD)

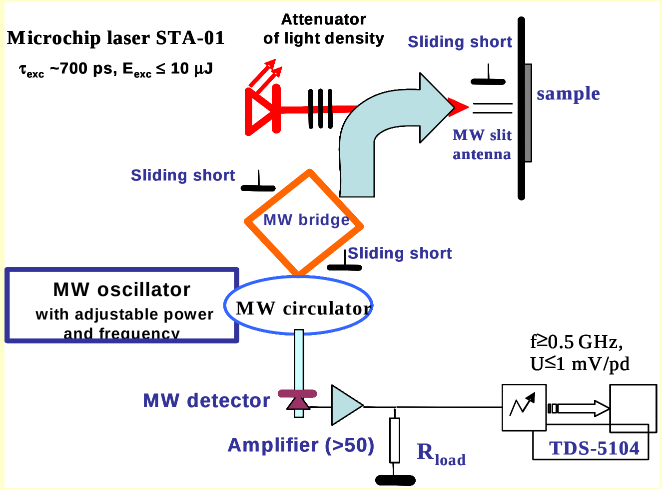


MWA $\lambda > 100\mu m \Rightarrow \alpha_0 = (4\pi/c\ \sqrt{\varepsilon})\sigma_{dc}$,

transient:

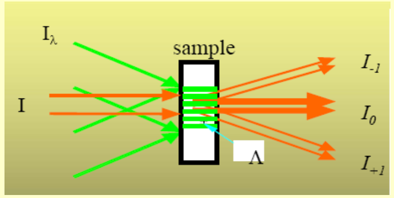
$\Delta\alpha(t) \propto \Delta\ \sigma(t) \propto \mu_{FC}\ n_{exFC}\ (t)$

E.Gaubas. Lith. J. Phys., 43 (2003) 145.

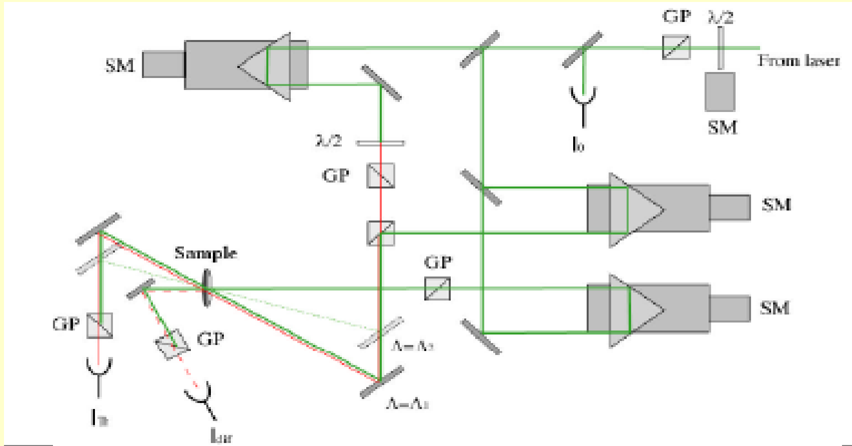


The microwave probed photoconductivity (MW-PCD) technique is based on the direct measurements of the carrier decay transients by employing MW absorption by excess free carriers. Carriers are photoexcited by 1062 nm light generated by pulsed (500 ps) laser and probed by 22 GHz cw microwave probe.

Transient gratings (TG)

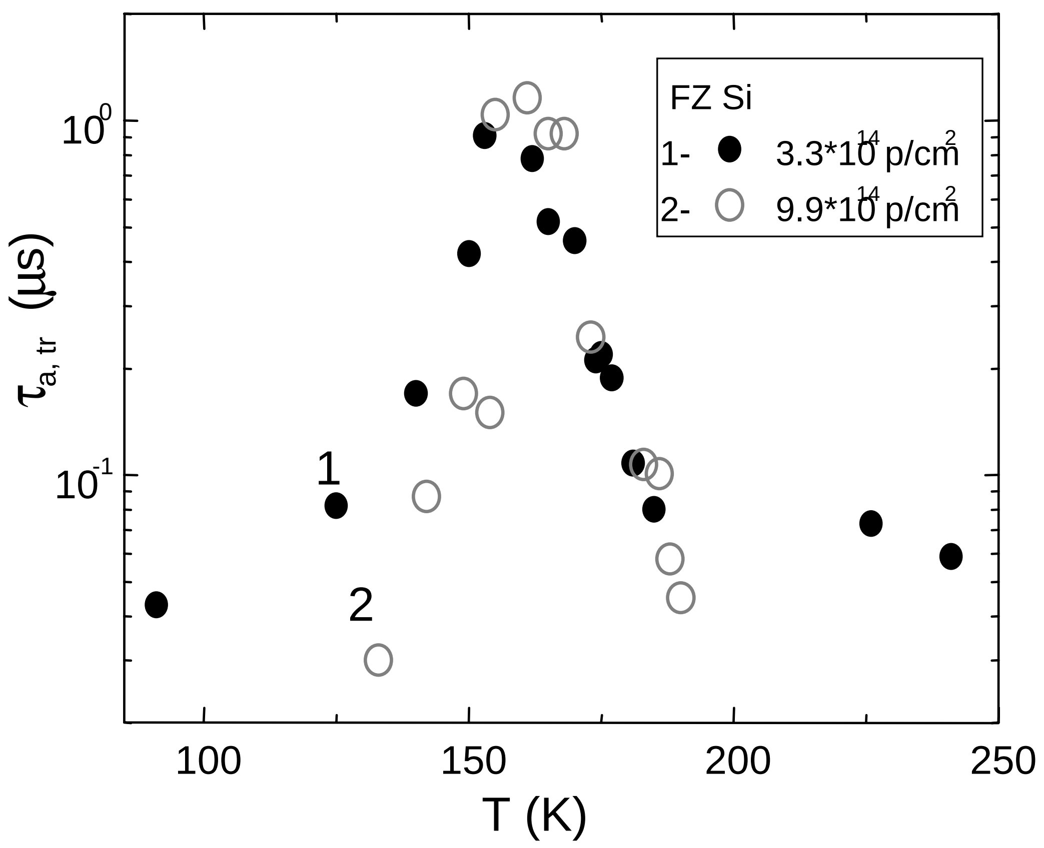


K.Jarasiunas, J.Vaitkus, E.Gaubas, et al. IEEE Journ. QE, QE-22, (1986) 1298.



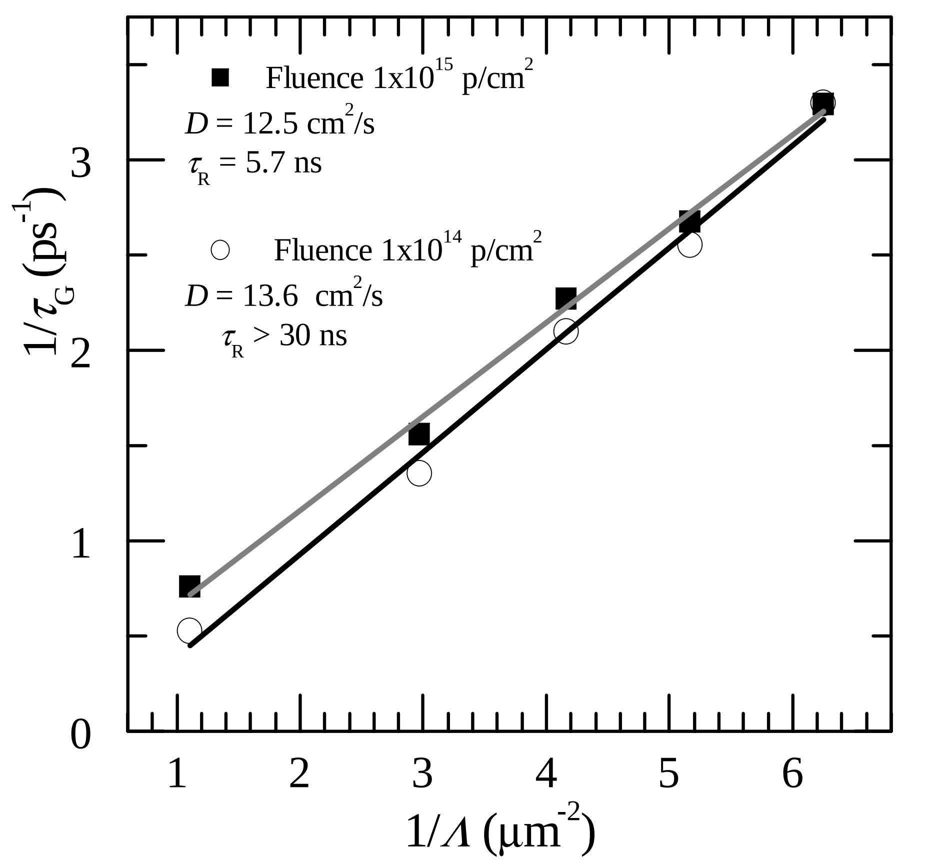
Diffraction efficiency ($\eta = I_{-1}/I_0$) ***on light induced transient grating is a measure*** $\eta \propto (\Delta N)^2$ ***of excess carrier density, while its variations in time*** $\eta(t) \propto \exp(-2t/\tau_G)$ ***by changing a grating spacing*** (Λ) ***enable one to evaluate directly the parameters of grating erase*** $1/\tau_G = 1/\tau_R + 1/\tau_D$ ***through carrier recombination*** (τ_R) ***and diffusion*** $\tau_D = \Lambda^2/(4\pi^2 D)$ ***with D as a carrier diffusion coefficient.***

Variations of the carrier trapping lifetime with temperature



Asymptotic (trapping) lifetime variation with temperature in FZ Si diodes irradiated with protons of fluence 3×10^{14} (1) and 10^{15} (2) cm^{-2}.

TG technique shows the carrier mobility inherent for a rather perfect crystalline structure



Erase time of transient grating as a function of grating spacing

Basics of CELIV technique (G.Juška, K.Arlauskas, M.Viliunas, and J.Kocka. Phys. Rev. Lett. 84 (2000) 4946.)

Carriers are at time t extracted up to the extraction depth L(t): $0<L(t)<d_g$ for $U_R(t)=At$

$dL(t)/dt + [\sigma/2\varepsilon\varepsilon_0 d_g]L^2(t) = \mu At/d_g$

for $0<x<L(t)$

$E(x,t)=E(0,t)-enx/\varepsilon\varepsilon_0$; E(0,t) field at blocking electrode, E(d,t) field at back electrode

extracted charge: $Q(t)=enL(t)=[E(0,t)-E(d,t)]*\varepsilon\varepsilon_0$;

$dQ/dt=j_d=\sigma E(d,t)$

$U_R(t)=\int_0^d E(x,t)dx=E(d,t)*d_g+\{[E(0,t)-E(d,t)]/2\}L(t)$

$j(t)=\varepsilon\varepsilon_0\, dE(x,t)/dt + (\sigma/d_g)*\int_{L(t)}^d E(x,t)dx = \varepsilon\varepsilon_0 A/d_g + (\sigma/d_g)\, E(d,t)\, [d_g-L(t)]$

$j(t)=\varepsilon\varepsilon_0 A/d_g + [\sigma/\mu]*[1-L(t)/d_g]*[\{\mu At/d_g\}-\{\sigma/2\varepsilon\varepsilon_0 d_g\}L^2(t)]$