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Transit photo-current measurements of the i-SC CVD and IIa natural diamond.

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Outline

- Introduction
- TOF Set-up
- Samples
- IV-characteristic
- TOF on the IIa natural diamond
- TOF on the i-SC-CVD-1
- Influence of the 2 components beam
- TOF on the SC-CVD-2
- Polarization
- Conclusions

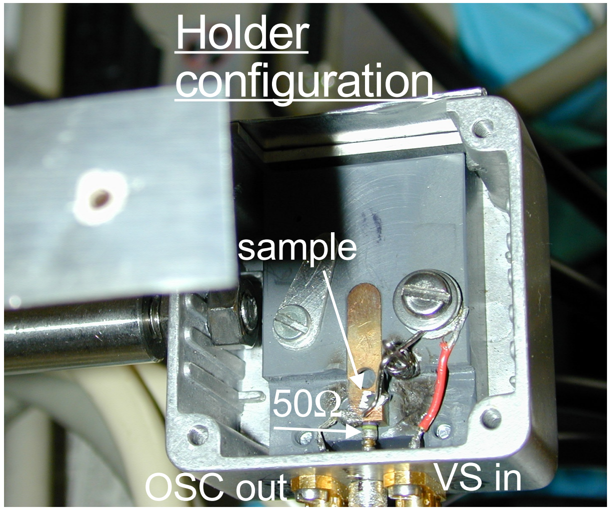
Introduction

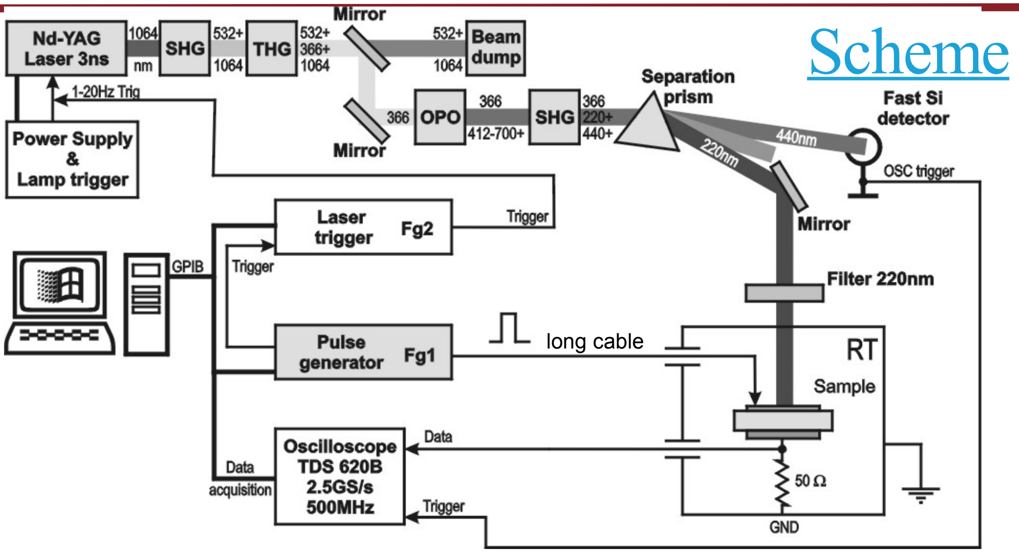
Why Time-Of-Flight technique?

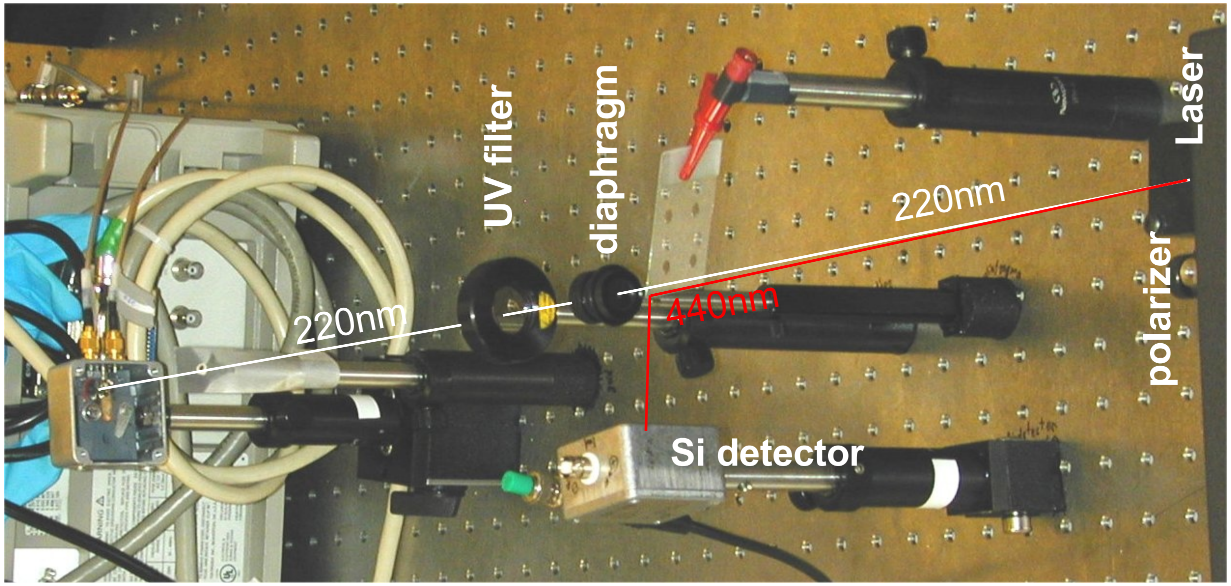
- Electrical properties of the SC-CVD diamond
  $\mu_{dr}(E)$ $Q_s(E)$, $V_s(E)$, μ_0
- Understanding about the charge transport
- Charge trapping kinetics with respect to the defects and impurities

Time-Of-Flight Set-up

Scheme, Holder, Photo

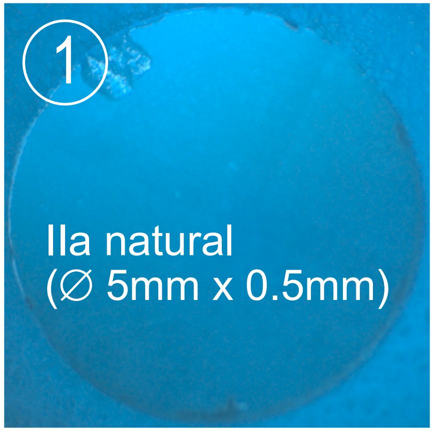


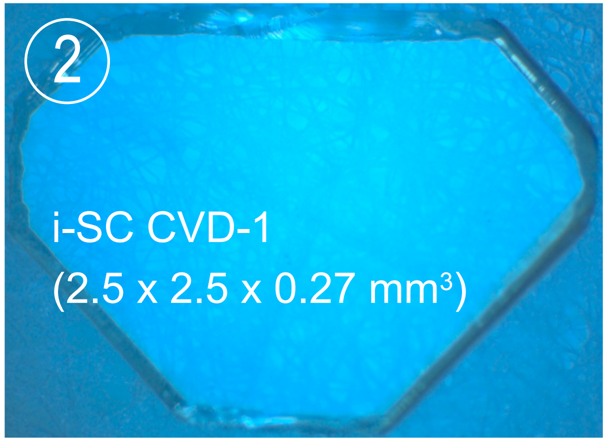


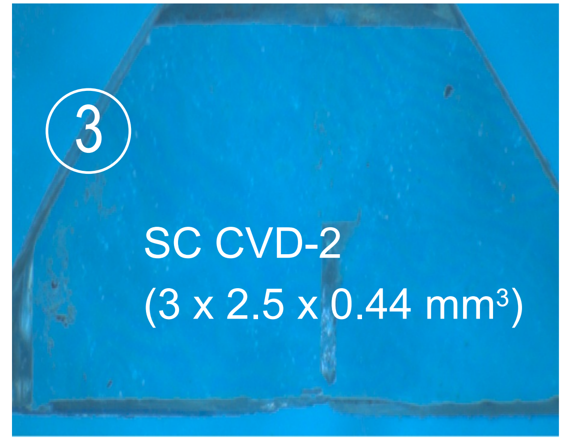


Samples and contacts

Pre-treatment, Cleaning, Contacts configuration and preparation







Cleaning and oxidation

H_2SO_4 + KNO_3 boiling ~ (280°C) 30min, rinse with ultra-pure water×2 and drying by the N_2.

Polishing

By standart lapidary technique at the WTOCD

Contacts configuration

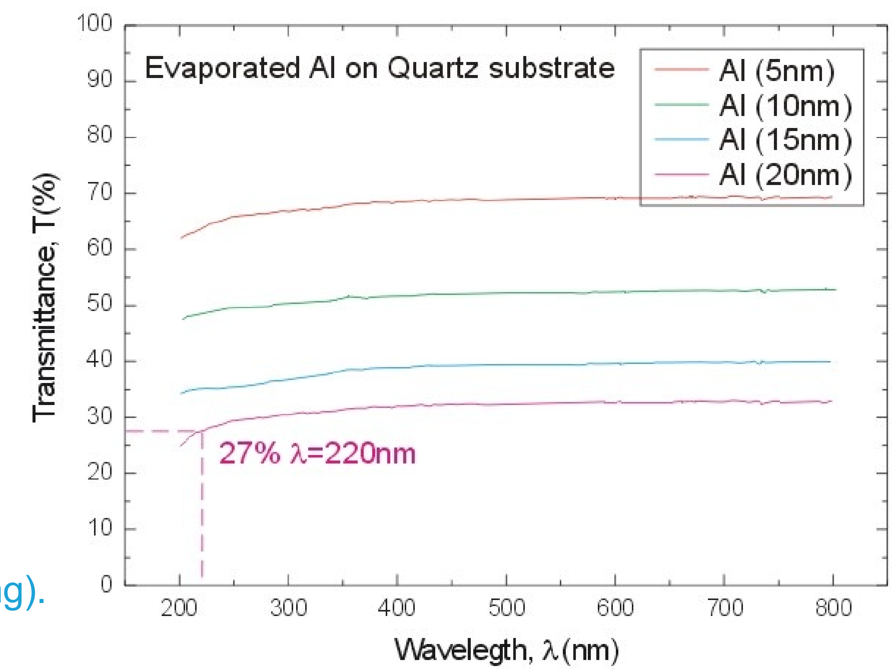
Top contact = 20nm Al (Transmittance=27% and R<1kΩ)

Back contact = 50nm Al (Transmittance=0% and R<1Ω)

Both contacts are circular (∅ 2mm)

Contacts preparation

Evaporation of the Al (in vacuum 10^{-7}atm, without annealing).

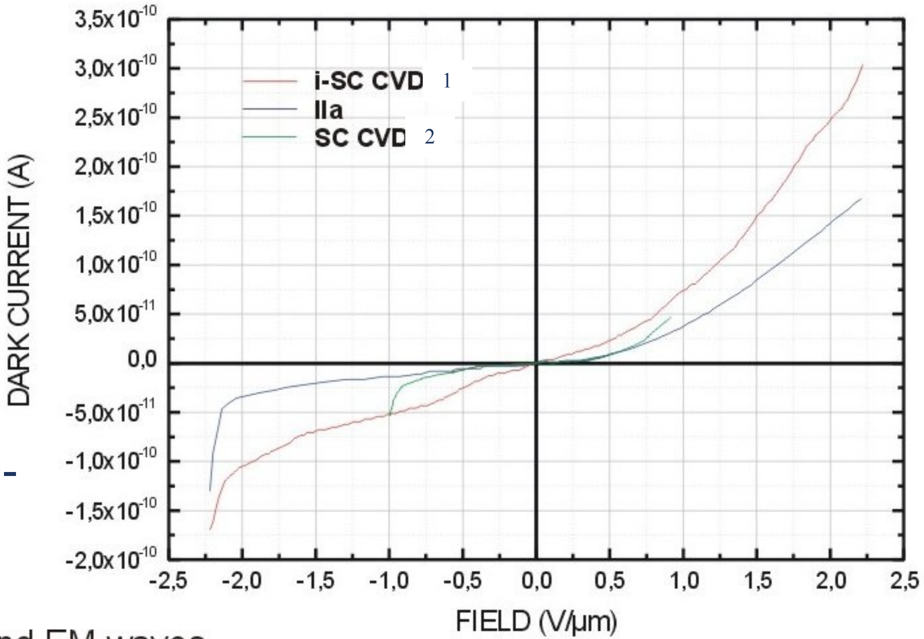


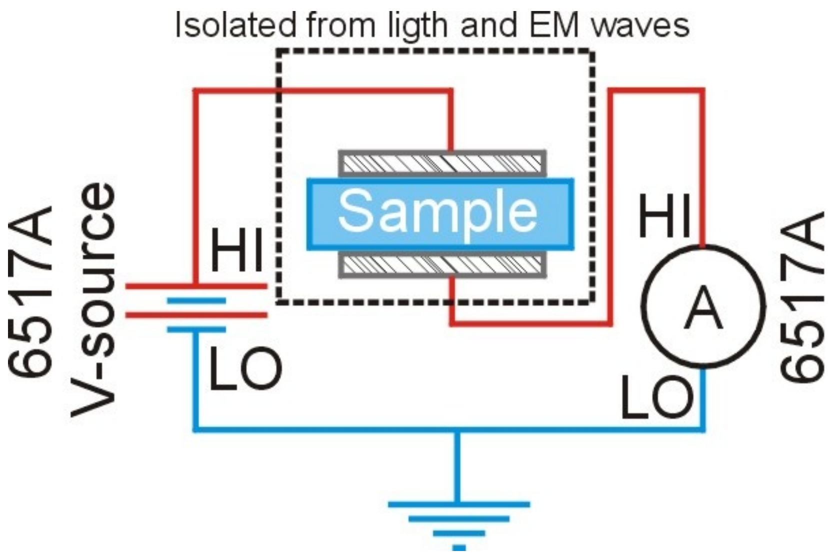
IV-Characterisation

IV characteristics

- By Keithley 6517A High Resistance Meter (+/-1000V)

- All contacts on the samples showed the quasi-blocking behaviour





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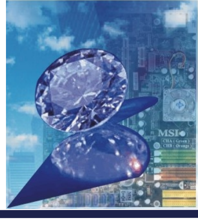
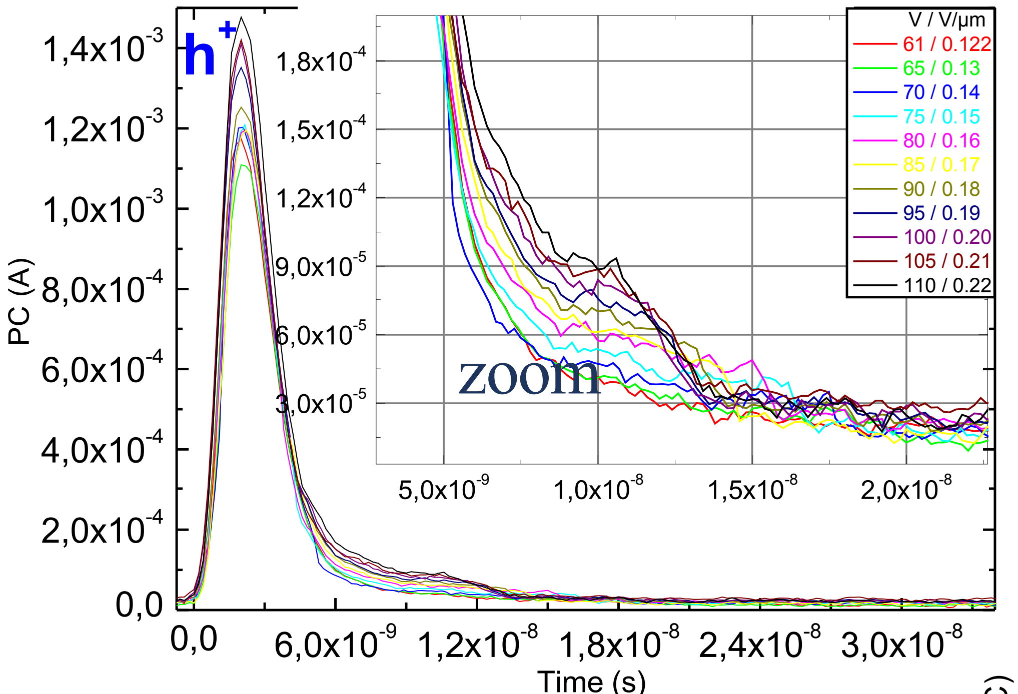
TOF on IIa diamond

Hole transport
AC Field





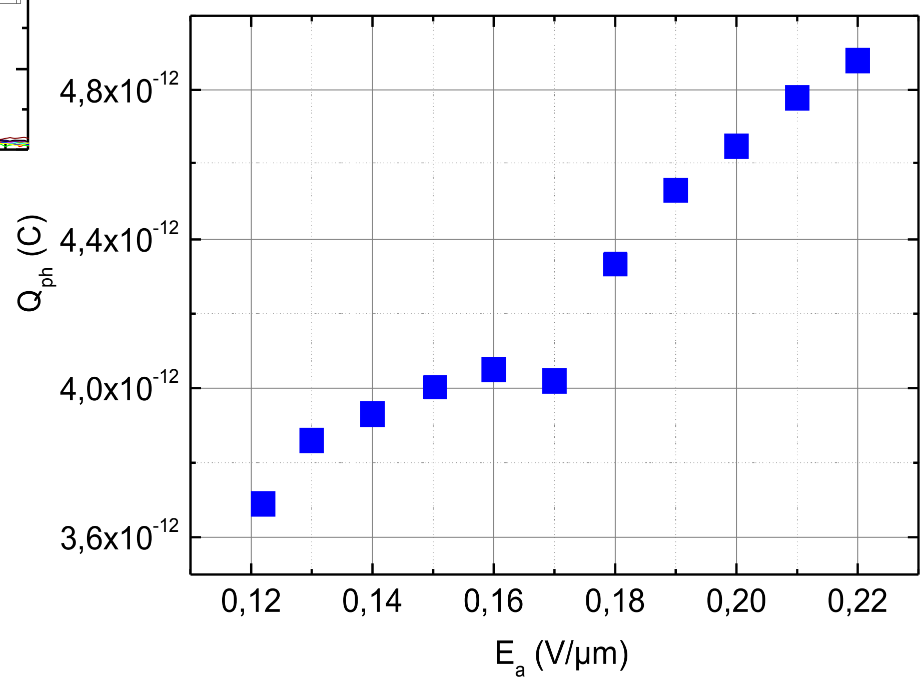
μ_h ~1970-2135 cm^2/Vs

Theoretical value: 2100 cm^2/Vs

L. Reggiani , PRB , 1981

$Q << Q_{SCLC}$

Q_h ~$3.069 \cdot 10^{-12}$ -$4.88 \cdot 10^{-12}$[C]



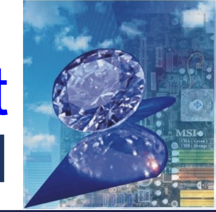
In natural IIa diamond, a part of the charge could be trapped and a small percentage of the charge is drifting,

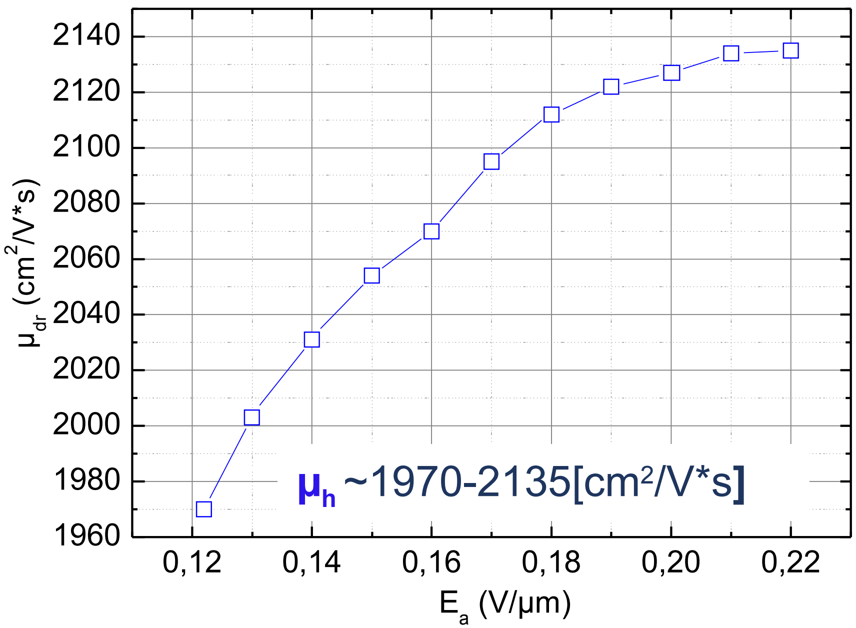
t_{tr} (E) → μ

field dependent t_{tr} can be determined

TOF on IIa diamond

Hole transport
AC Field



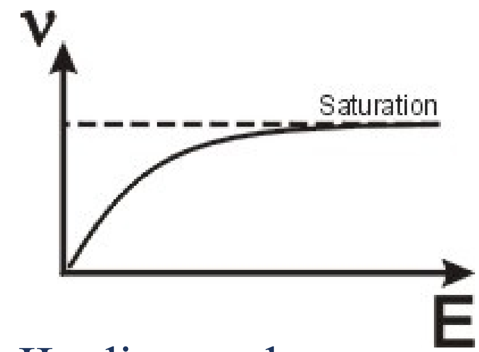


* Low electrical field => opposite behaviour

Trap limited transport decreases the effective mobility.

* High electrical field =>

The effective mobility is increasing due to (V_s) the saturation velocity effect.

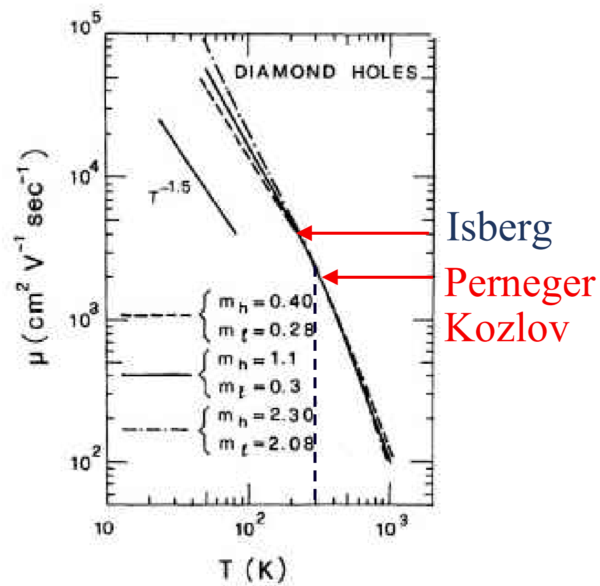


Microscopic mobility in IIa diamond

μ_{0h}~ 2000 cm^2/Vs

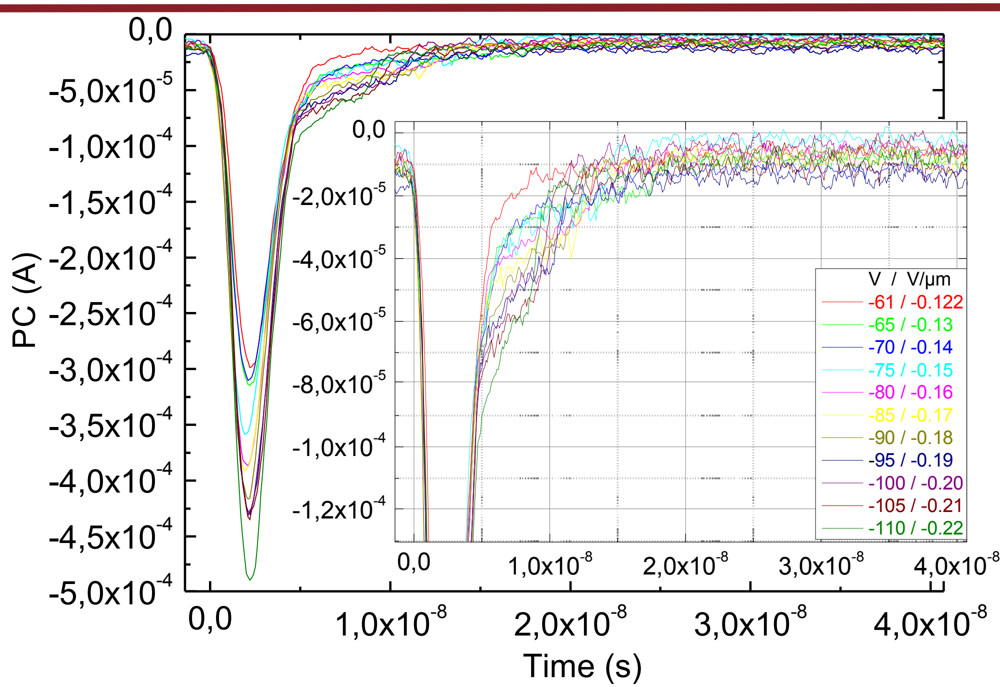
$q << Q_{SCLC}$

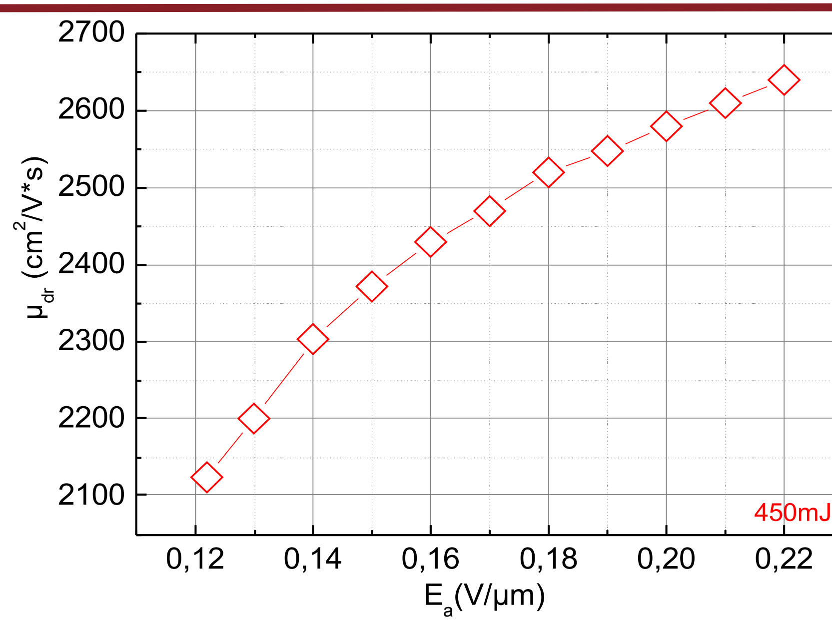
$$\mu_{e,h} = \frac{d^2}{t_{tr} \cdot V_a}$$



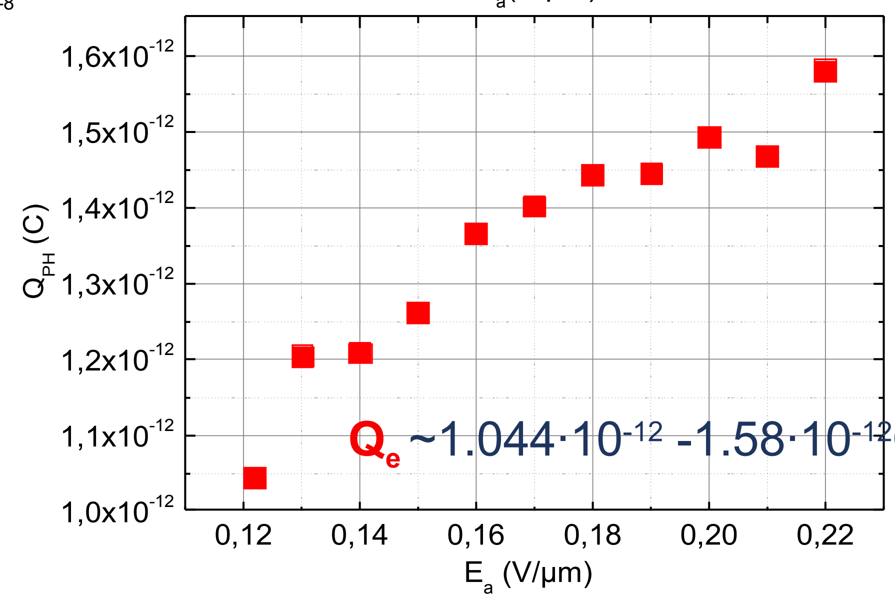
TOF on IIa diamond

Electron transport
AC voltage





μ_e ~2125-2640 cm²/V*s

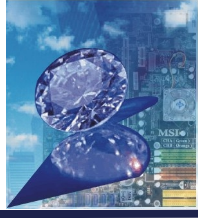


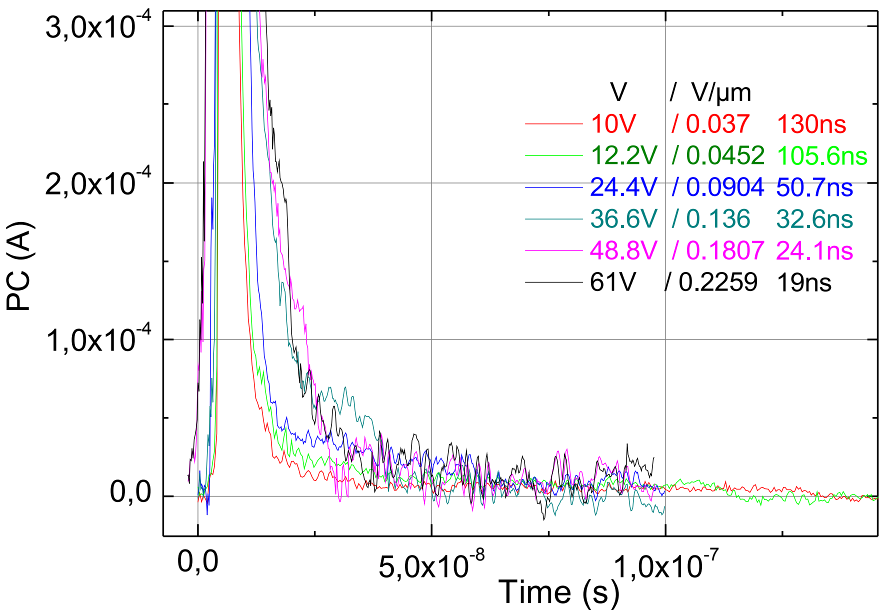
Q_e ~$1.044\cdot10^{-12}$ -$1.58\cdot10^{-12}$C

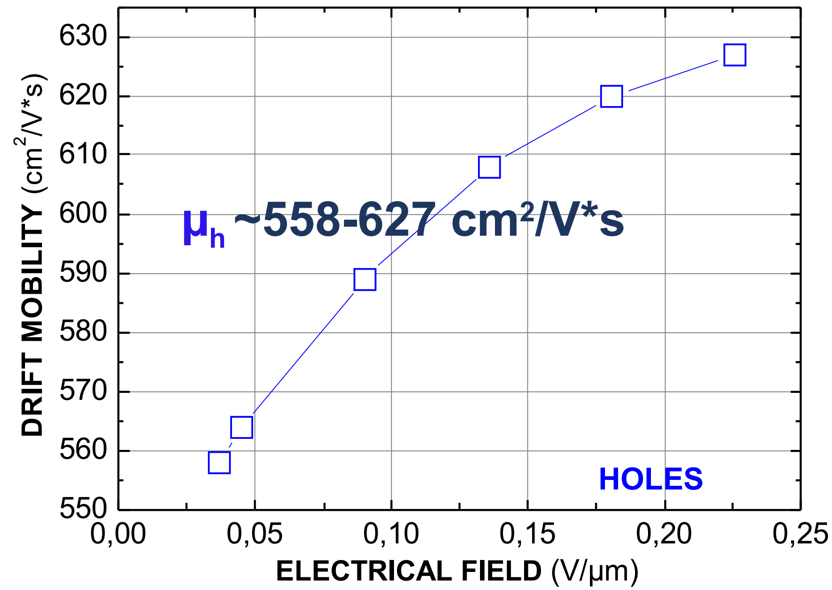
i-SC CVD-1 diamond

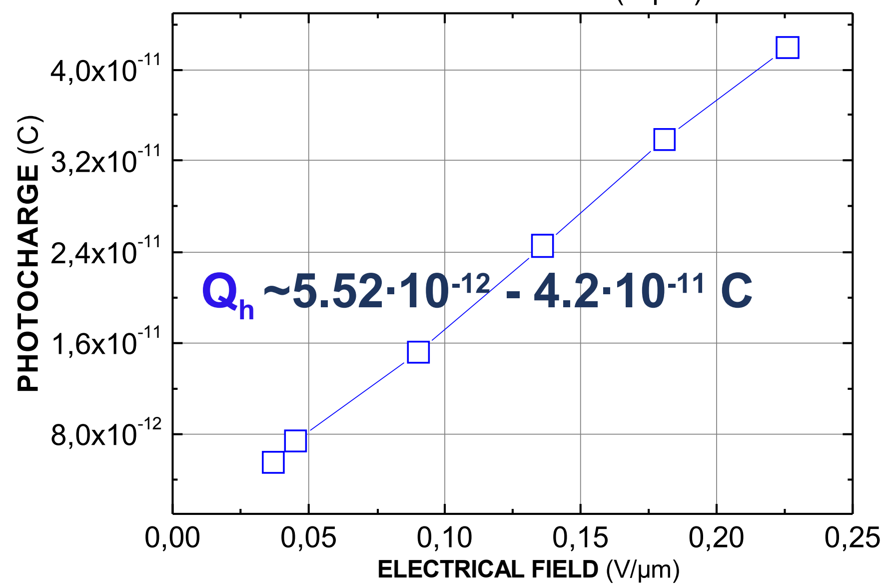
see Anna for growth conditions

Hole transport
AC voltage









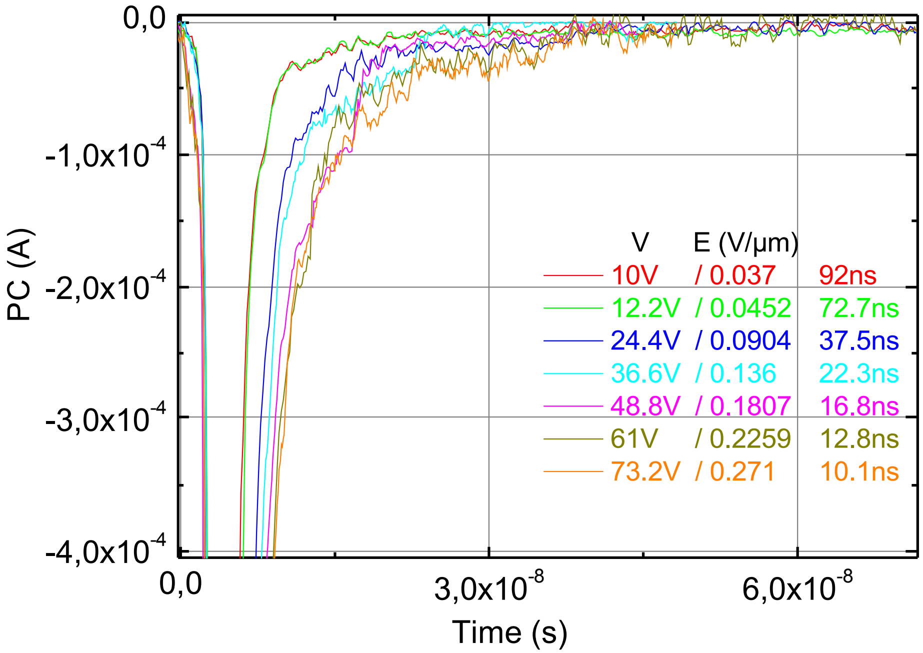
Similar behaviour to IIa diamond (trap limited)

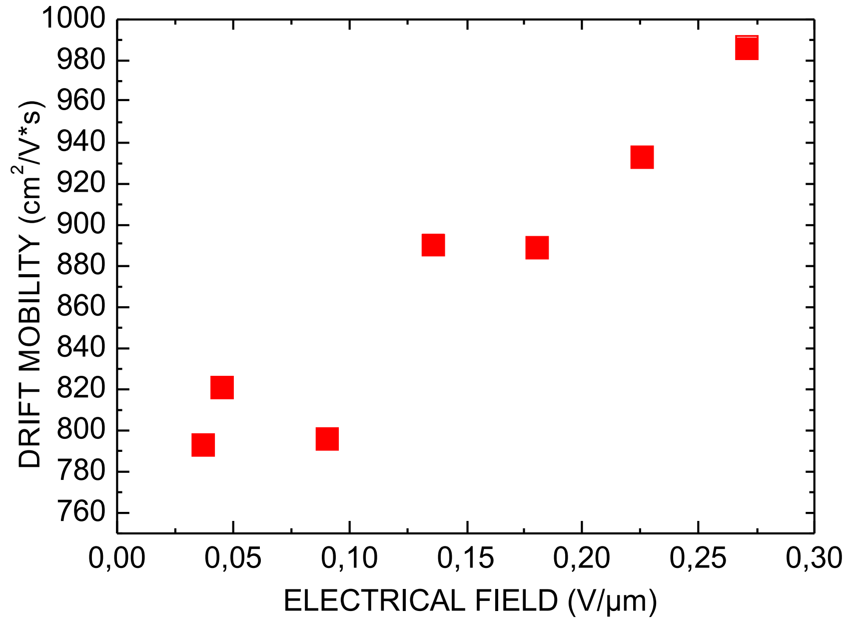
At low electrical fields

Lower mobility values as IIa

i-SC CVD-1diamond

Electron transport
AC voltage





Difficult to determine TOF.

Trap limited transport similar to the IIa diamond (several defects present PL spectroscopy GR1 , ND1, Si-V, N-V)

μ_e ~793-986 cm²/V*s

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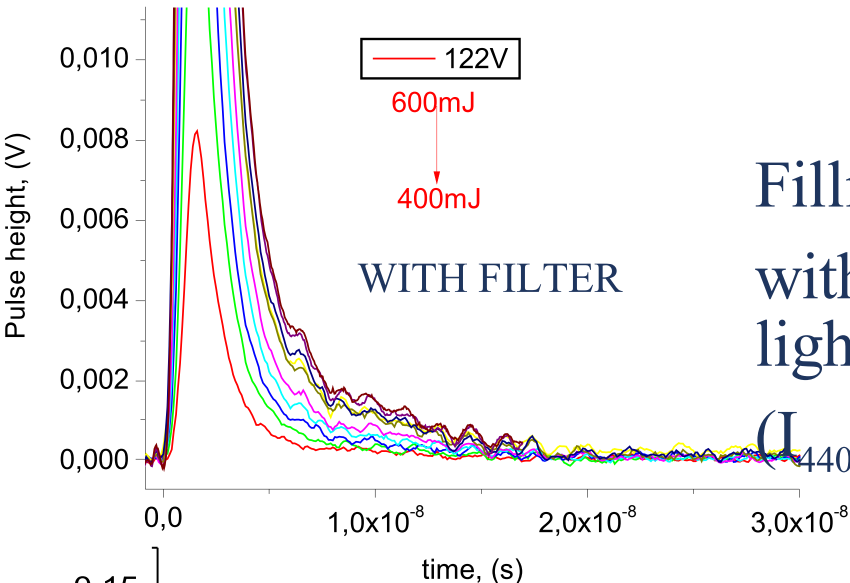
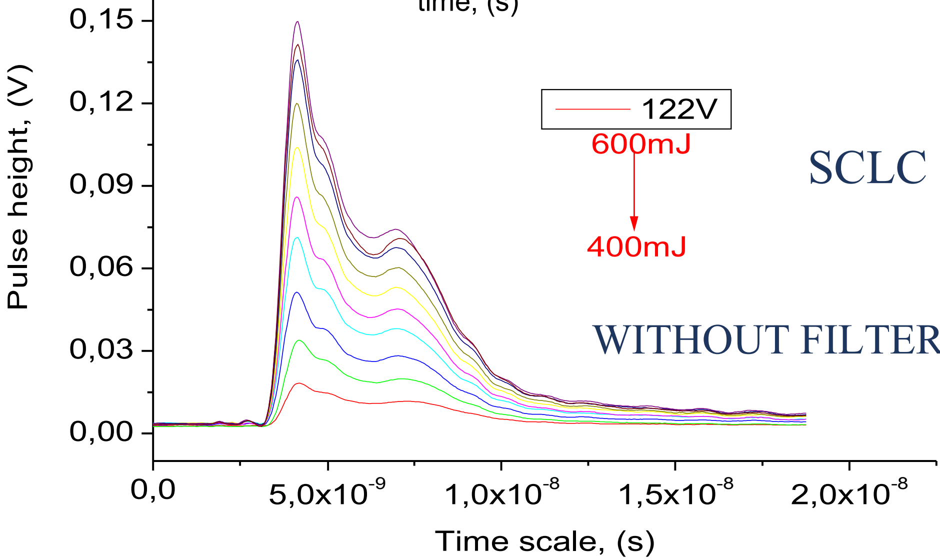
Laser pumping

Hole transport
AC voltage

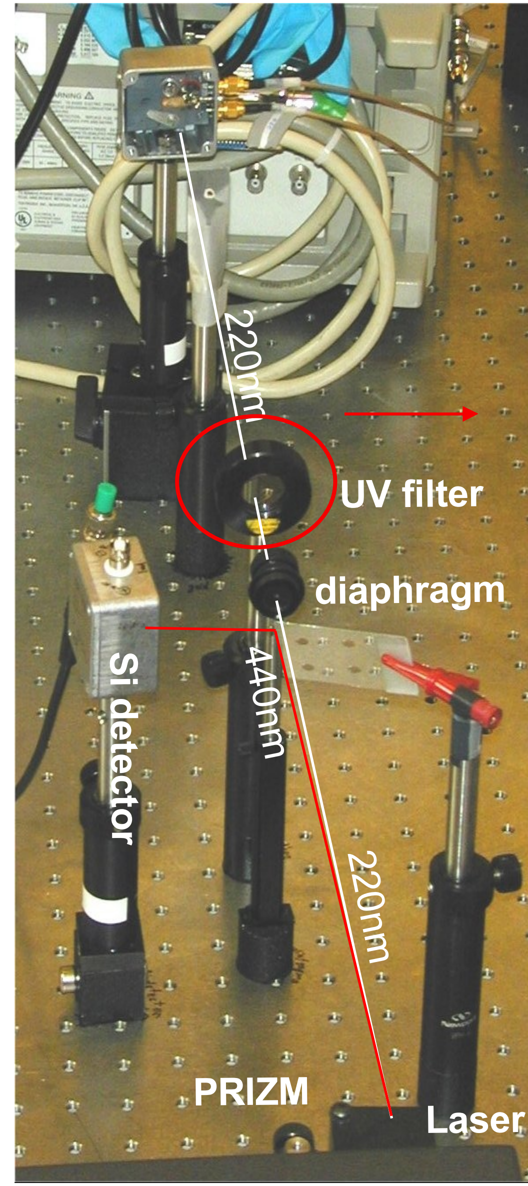


Filling up the traps with the 440 nm light

($I_{440nm} > 10 \times I_{220\ nm}$)



SCLC MODE $q \gg CU_a$



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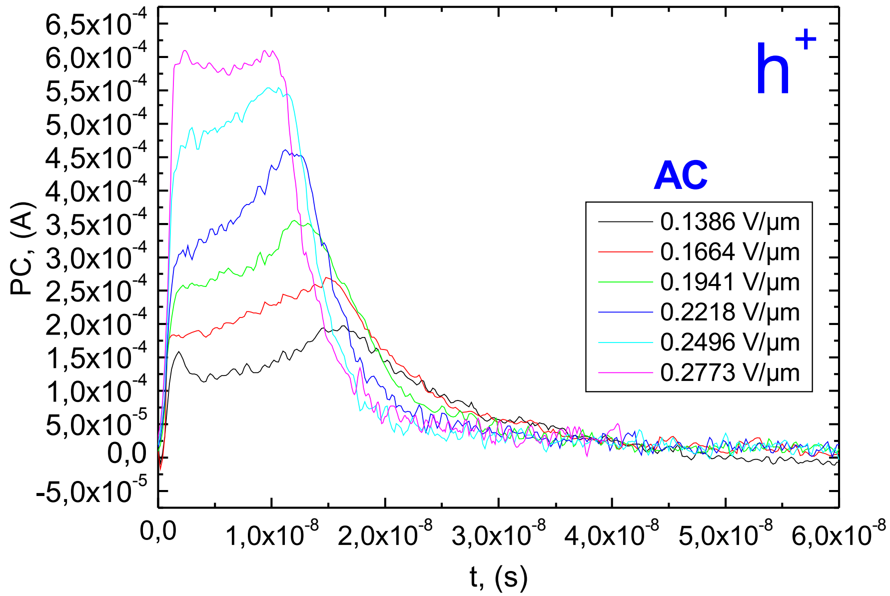
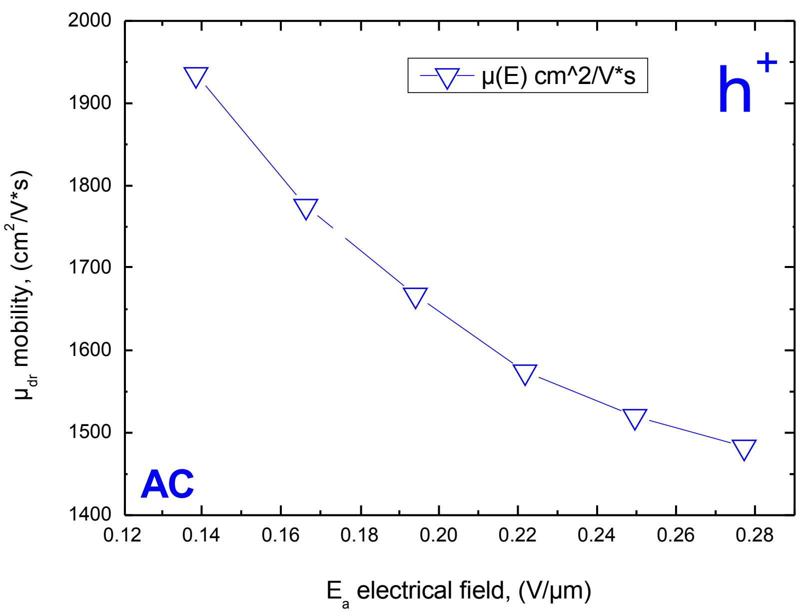
SC-CVD-2

Hole transport
AC voltage



TOF measurement on optimised sample



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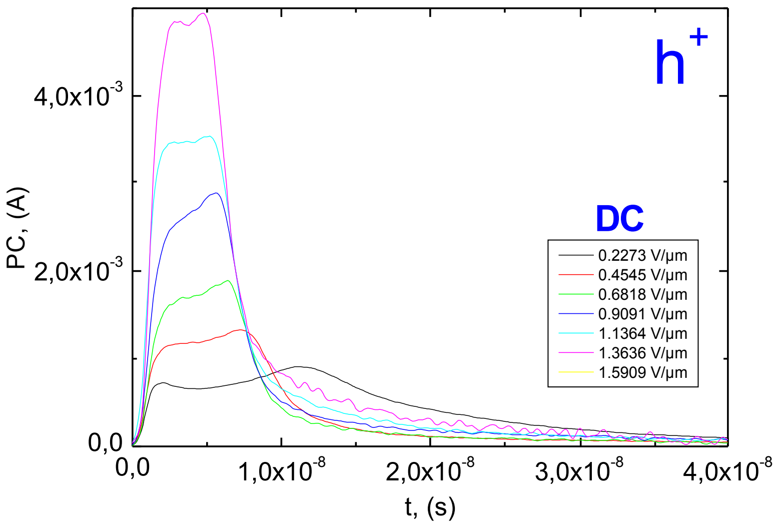
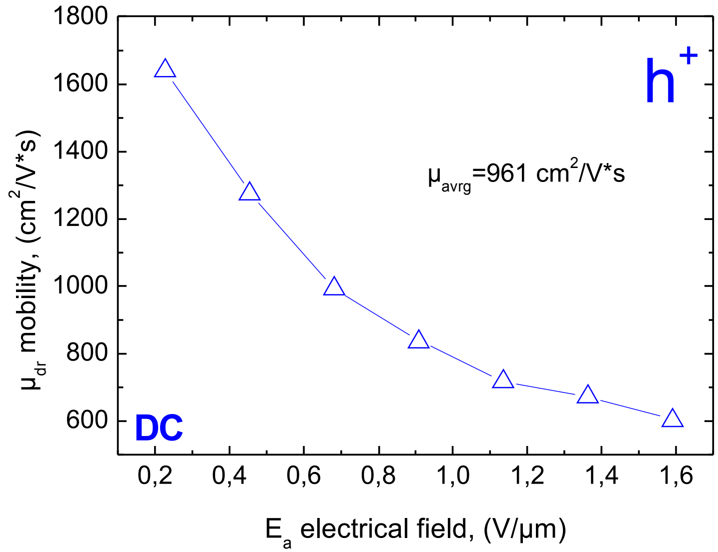
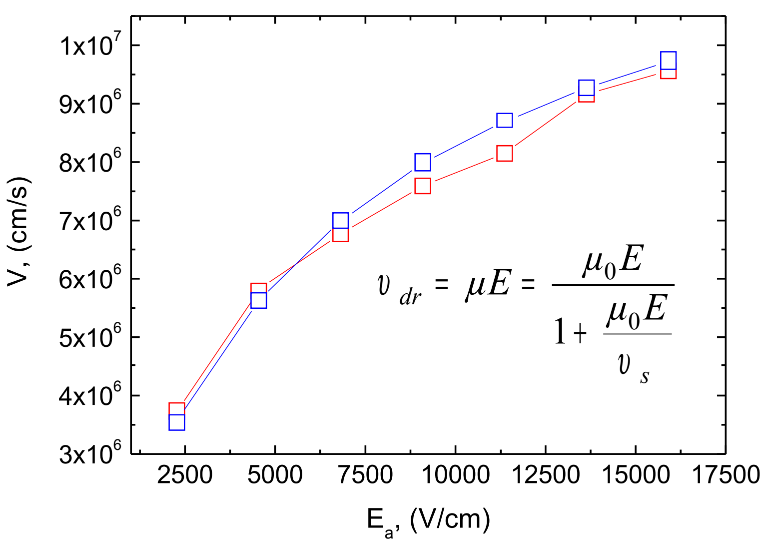
SC-CVD-2

Hole transport DC voltage







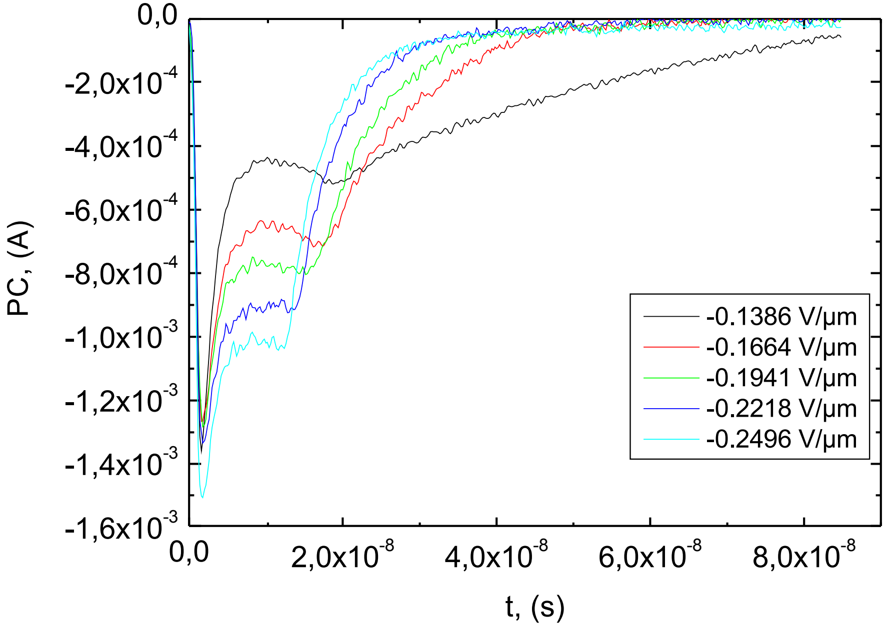
Data fitting for low Electrical fields

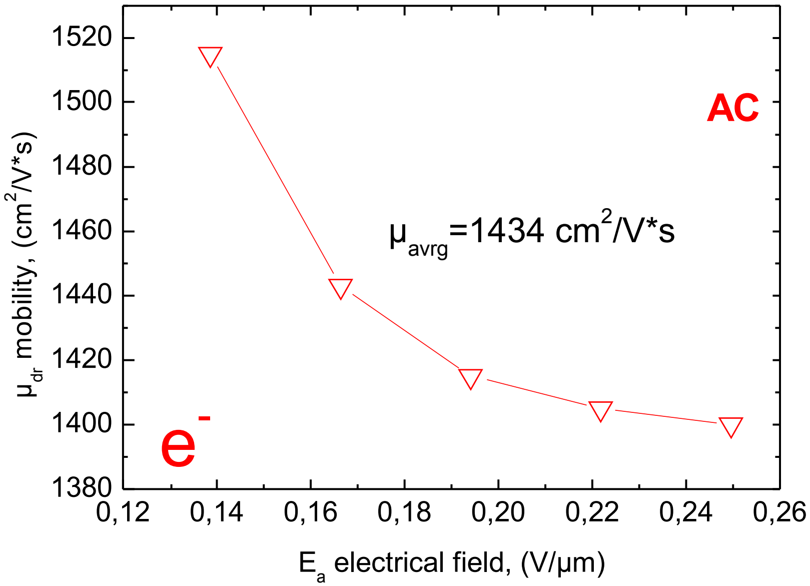
V_s=1.37E-7cm/s

μ_0=2392cm²/Vs

SC-CVD-2

Electron transport
AC voltage





AC field 0.1 – 0.3 V/µm

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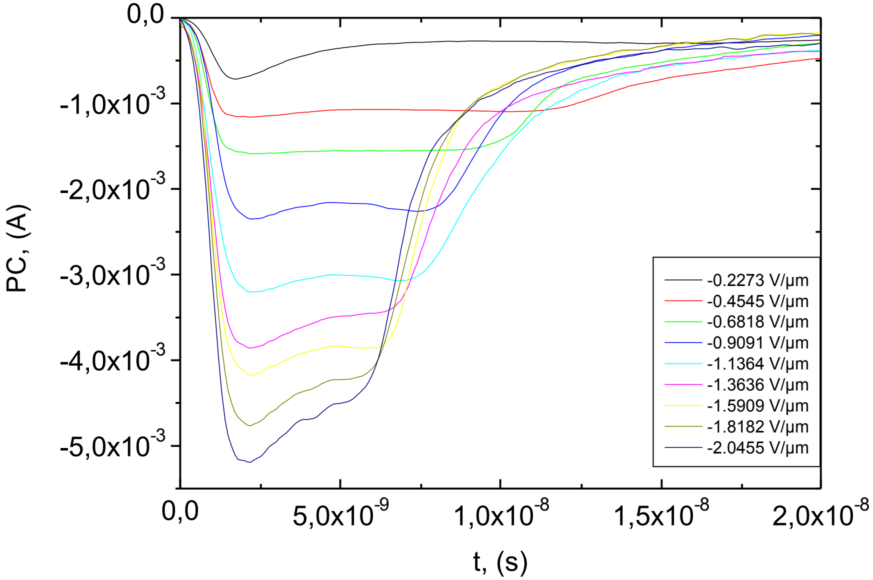
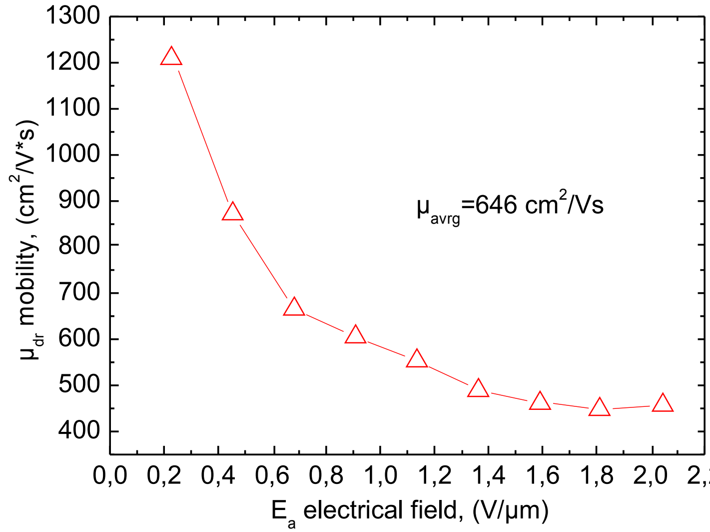
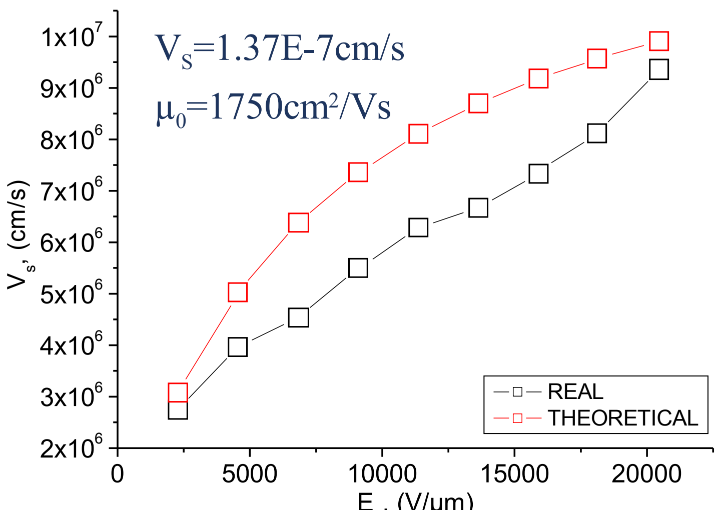
SC-CVD-2

Electron transport
DC voltage







⟸ Should use higer voltages

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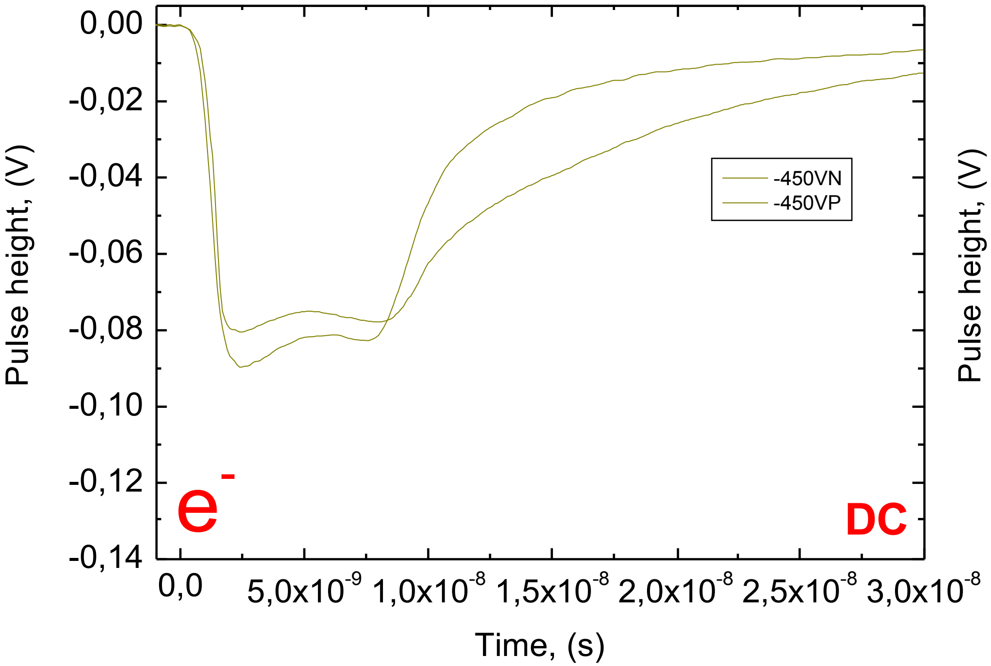
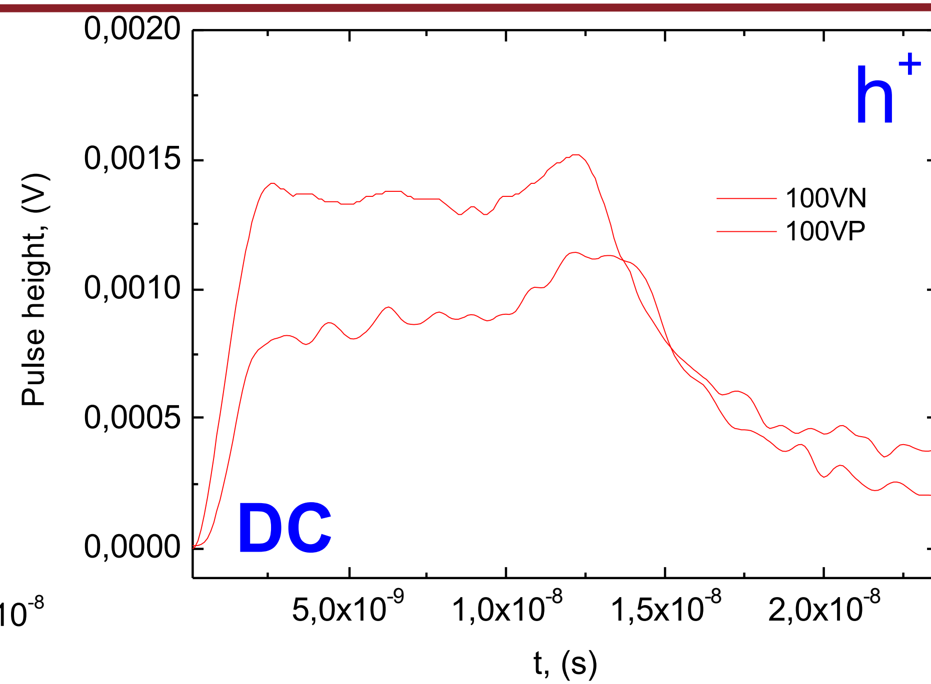
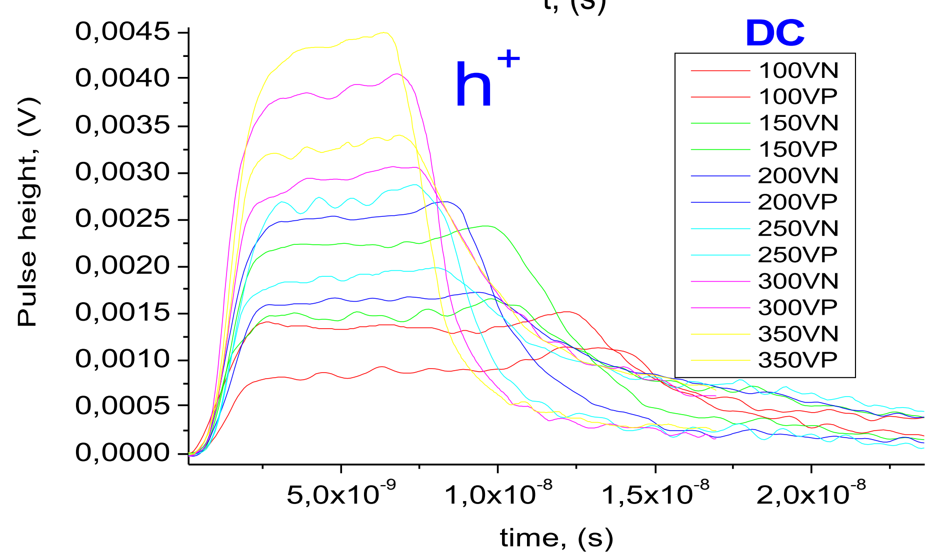
POLARIZATION
on SC-CVD-2







Charge accumulation at the contacts can be reduced by AC field universiteit hasselt INSTITUUT VOOR MATERIAALONDERZOEK

CONCLUSIONS

* Laser TOF (Triplled YAG with doubled OPO (210-250 nm or 250-420nm) has been built with AC and DC field to study the charge transport in SC-CVD diamond.

* TOF data on IIa diamond (unselected) shows a trap limited transport with a significant portion of the charge beeing trapped , however the voltage depended TOF signal can be determined leading to the mobility of 2400 cm^2/Vs IIa diamond.

* Similarly to IIa diamond samples showing in specroscopy defects (PL) lead to trap limited transport and mobilities +/- 1000 cm^2/Vs.

* Sample optimisation leads to higher mobility values, after substracting the polarization effect.

* The μ_o = 2100 for holes. Holes is in the excellent agreement with the theoretical data. μ_0=1750 cm^2/Vs for electrons.

(Kozlov PRB….)

$$\mu_{ac} = \alpha T^{-3/2},$$

$$\alpha = \frac{2^{5/2}\pi^{1/2} e \hbar^4 \rho s^2}{3K_B^{3/2}} \frac{1 + (m_h/m_l)^{1/2}}{E_1^2 m_l^{5/2}[1 + (m_h/m_l)^{3/2}]^2},$$

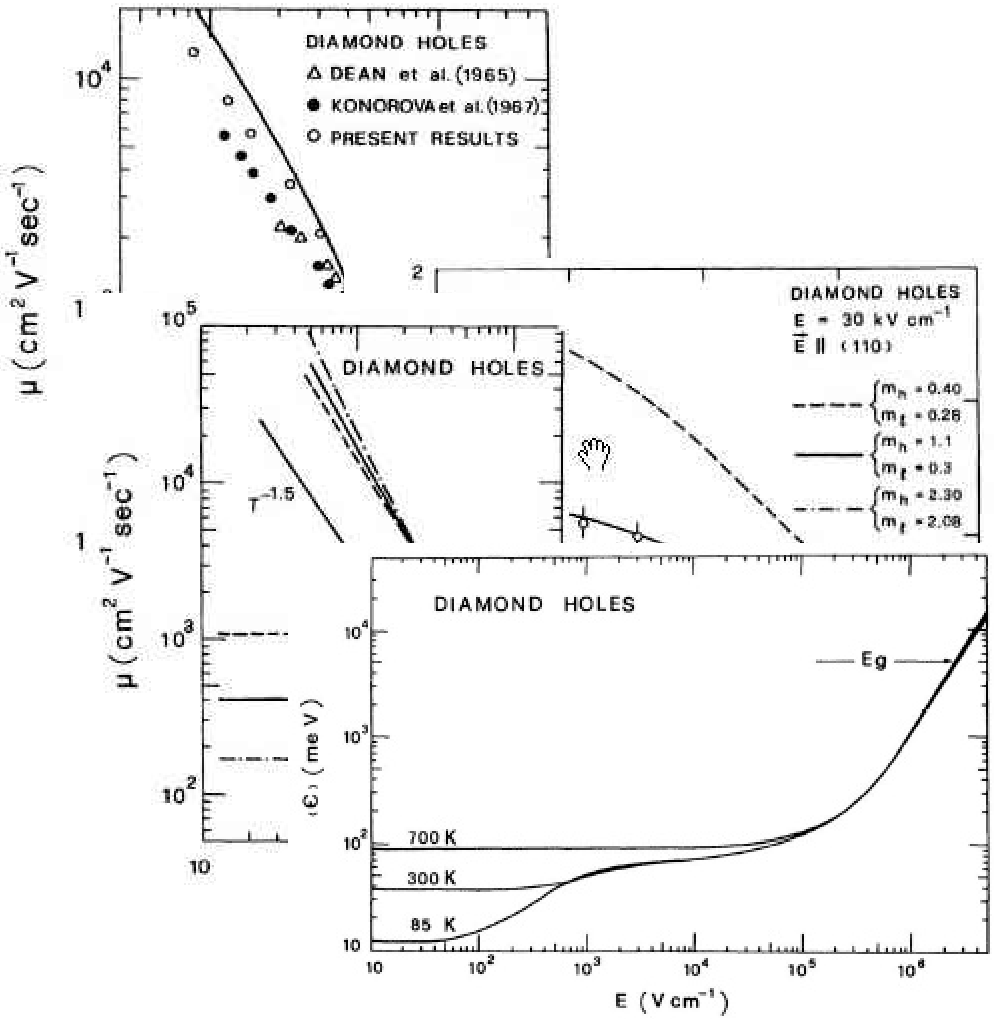
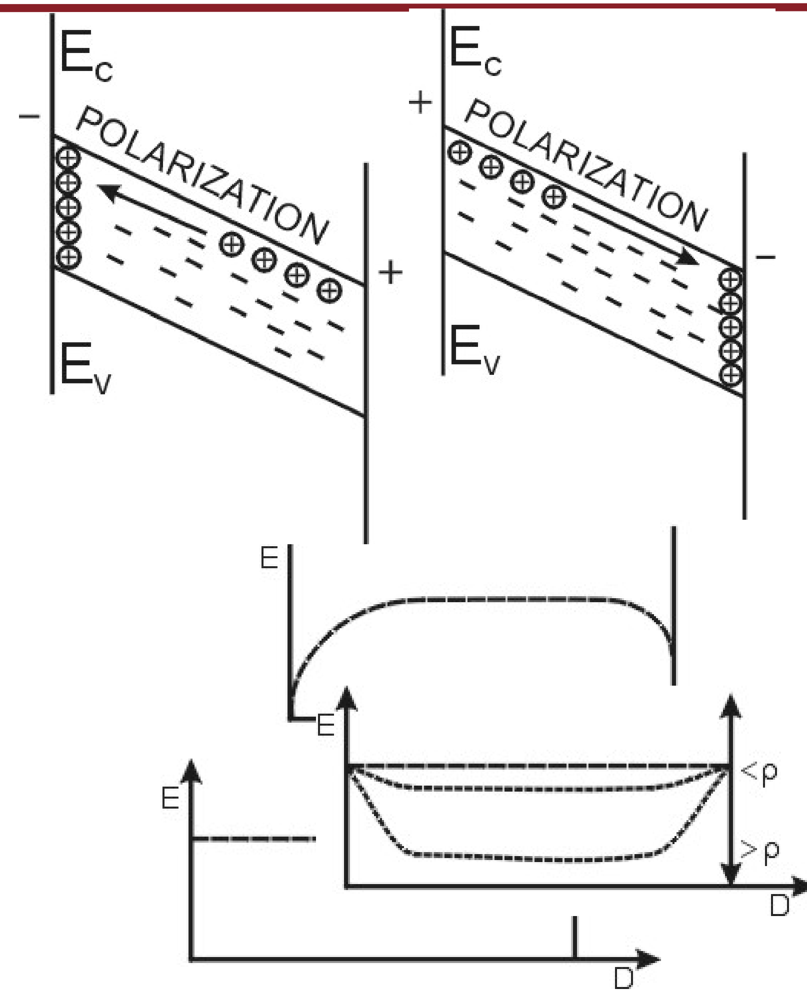


FIG. 8. Mean-hole energy as a function of electric field at the different temperatures indicated. E_g is the energy gap of diamond.



$$t_{relax} = R_s C_s = \rho\, \varepsilon$$

TABLE II. Constants of diamond.

Lattice constant	$a_0 = 3.57\times10^{-8}$ cm	Ref. 33
Crystal density	$\rho = 3.51$ g cm^{-3}	Ref. 34
Longitudinal sound velocity	$s_l = 18.21\times10^5$ cm sec^{-1}	Ref. 35
Transverse sound velocity	$s_t = 12.30\times10^5$ cm sec^{-1}	Ref. 35
Optical phonon equivalent temp.	$\theta_{op} = 1938$ K	Ref. 8
Static dielectric constant	$\epsilon_0 = 5.7$	Ref. 12
Energy gap	$E_g = 5.49$ eV	Ref. 8
Spin orbit energy	$\Delta = 0.006$ eV	Ref. 8
Heavy-hole effective mass	$m_h = 1.1$	Ref. 7
Light-hole effective mass	$m_l = 0.3$	Ref. 7
Acoustic deformation potential	$E_1^0 = 5.5$ eV	Ref. 7
Optical deforma		Ref. 7

[a] The two formalis

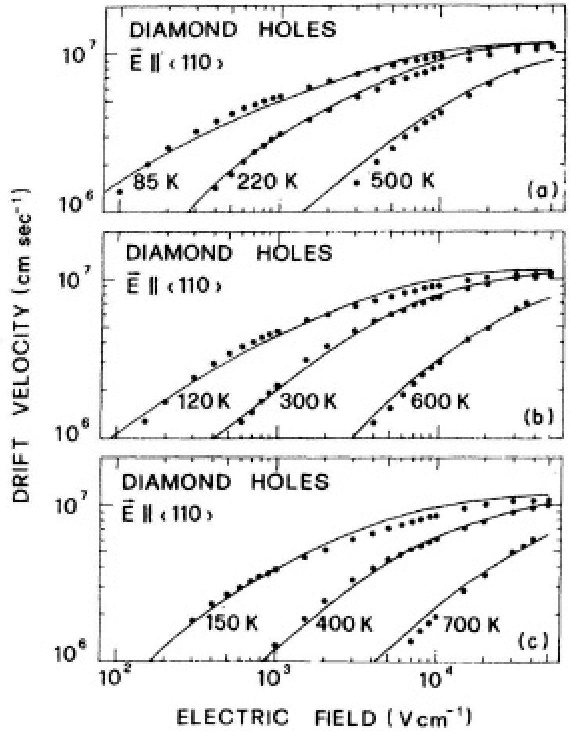


FIG. 3. Hole-drift velocity v_d as a function of electric field E applied parallel to ⟨110⟩ direction at the different temperatures indicated. Filled circles refer to experimental data, continuous lines indicate the theoretical results.

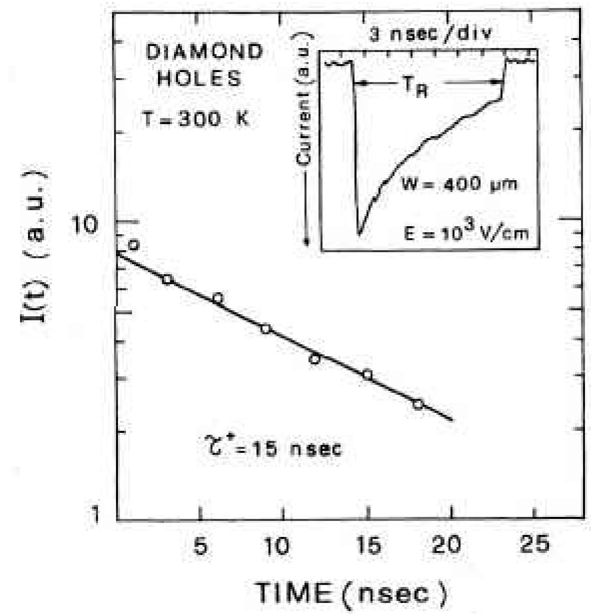
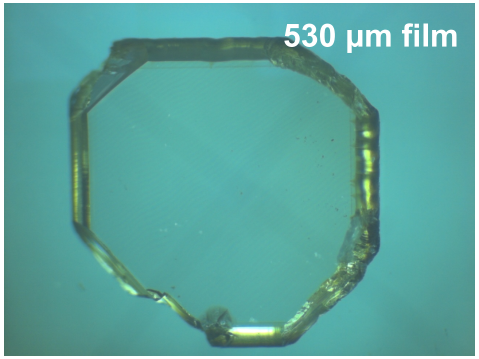


FIG. 1. Shape of the current pulse induced by the drift of holes and plot of the exponential decay on a semi-log scale at room temperature in a 400-μm thick and ⟨110⟩ oriented sample with $E = 10^3$ V/cm.

$$v_s = \left(\frac{K_B\theta_{op}}{2m_0}\right)^{1/2},$$

$$\langle\epsilon\rangle = \tfrac{1}{3}K_B\theta_{op}.$$


530 µm film