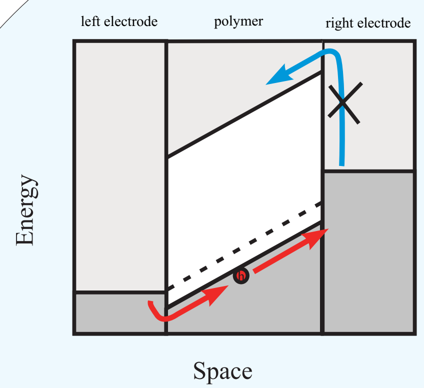
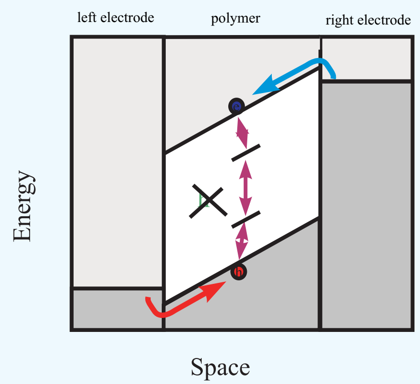
Introduction

LED Performance is limited by:



Absence of carrier balance, for instance minority carriers

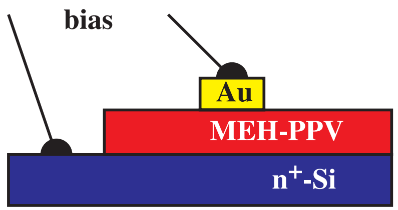
Visible in electrical measurements

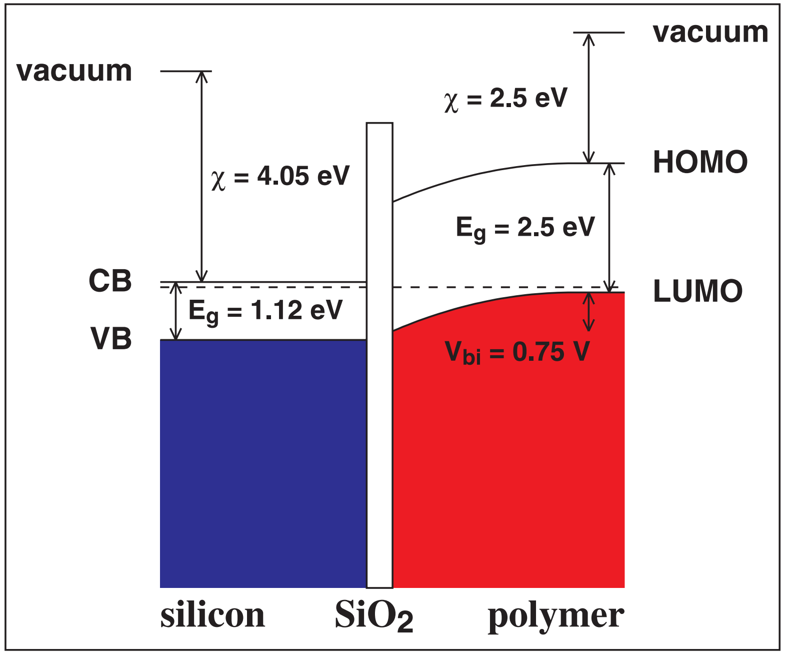


Presence of non-radiating recombination centers.

Study with: DLTS

Schottky Device Structure





- thickness 1 m
- silicon: electron injector
  gold: hole injector
- very thin oxide layer (< 30 Å) to make an MIS tunnel diode

Device DC Characteristics

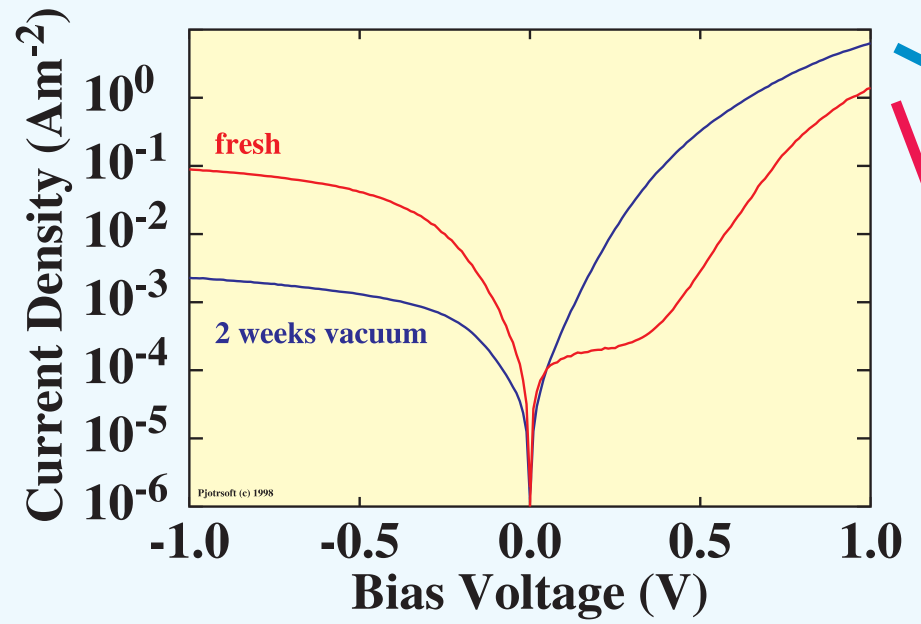
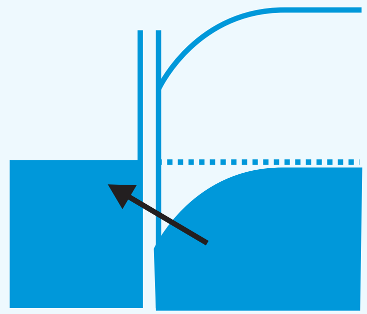
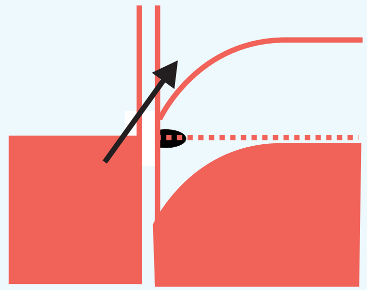


Figure 3a: Typical IV curves at 300 K before (red) and after two weeks in vacuum (blue).



Removal of interface states makes it a majority-carrier device



Fermi level pinning by interface states makes it a minority-carrier device

AC Characteristics

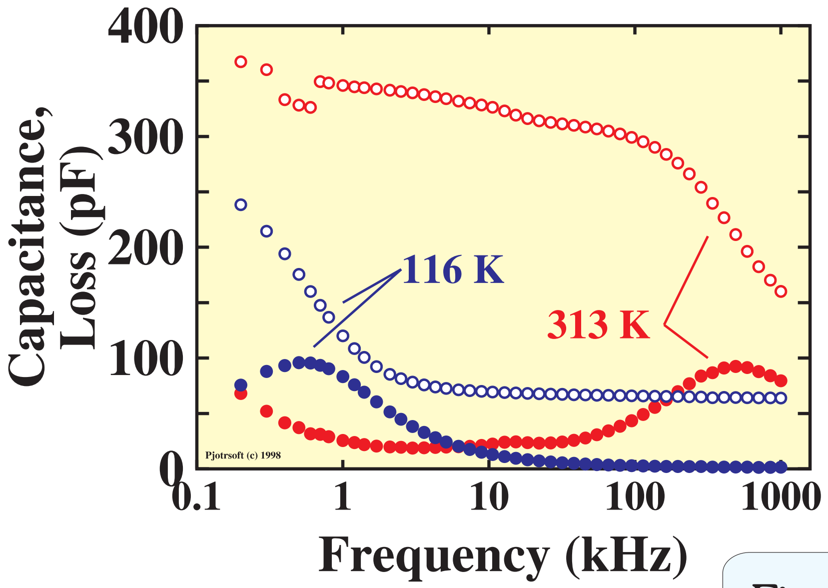
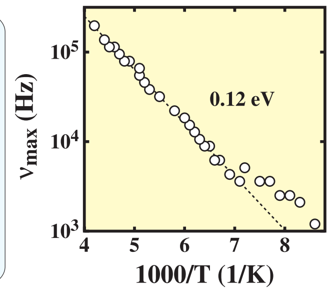


Figure 4a: Spectra of capacitance (open circles) and loss (full circles) of the device at RT (red) and 116 K (blue). The cut-off frequency drops from 500 kHz to 500 Hz; the AC probing of 1 kHz is adequate for most temperatures.

Figure 4b: Position of the loss-tangent (loss/capacitance) as a function of temperature revealing an activation energy of E_a = 0.12 eV.



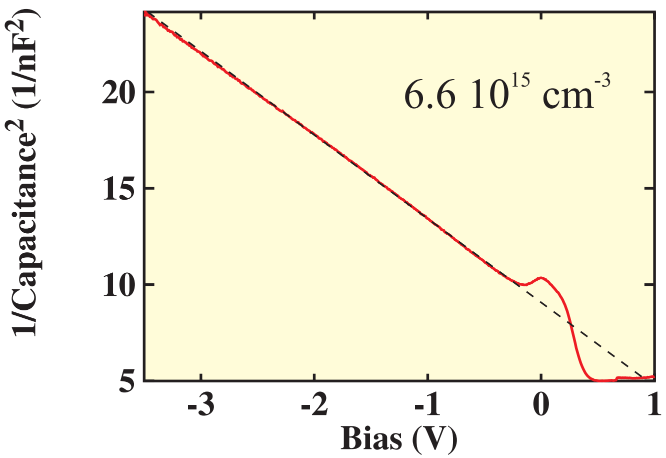
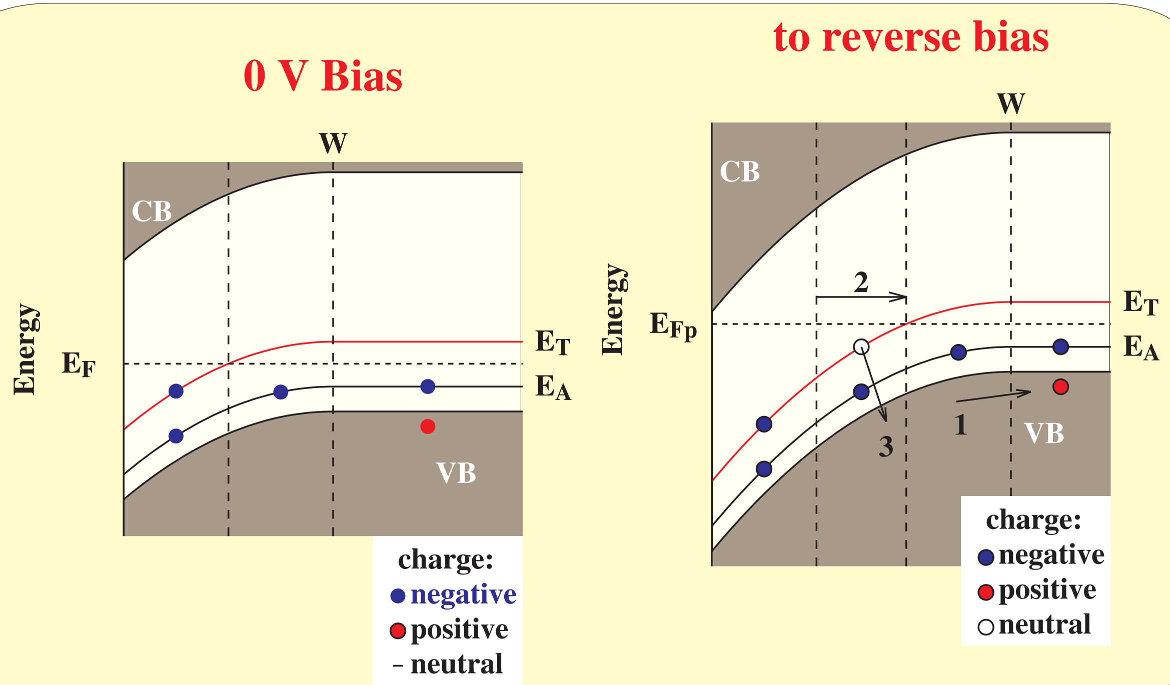


Figure 4c: Typical Mott-Schottky plot at 1 kHz, revealing an ionized acceptor concentration of 6.6 10^{15} cm^{-3}

DLTS in a nutshell



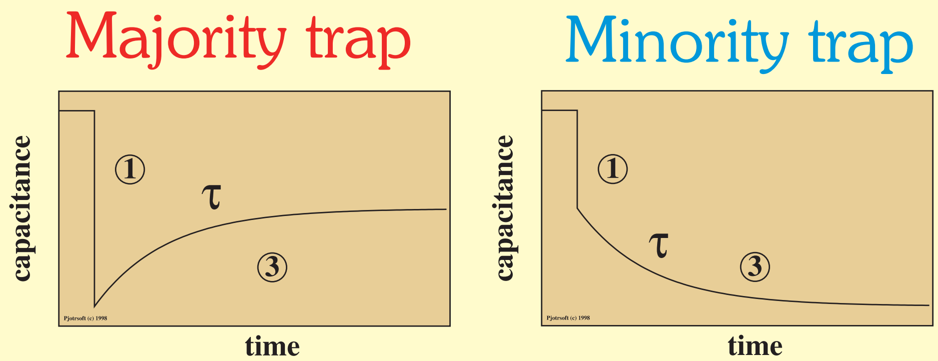
$C = \ A/W$

Upon change of voltage:

1: free carriers flow out fast.
  increase W, decrease C

2: crossing point shifts
  (non thermal equilibrium)

3: holes are slowly emitted
  - increase space charge density
  - decrease W
  - increase C



The speed depends on the trap depth:

$1/\ = T^2 \exp(-E_a/kT)$

The sign depends on the type (majority/minority)

DLTS Results

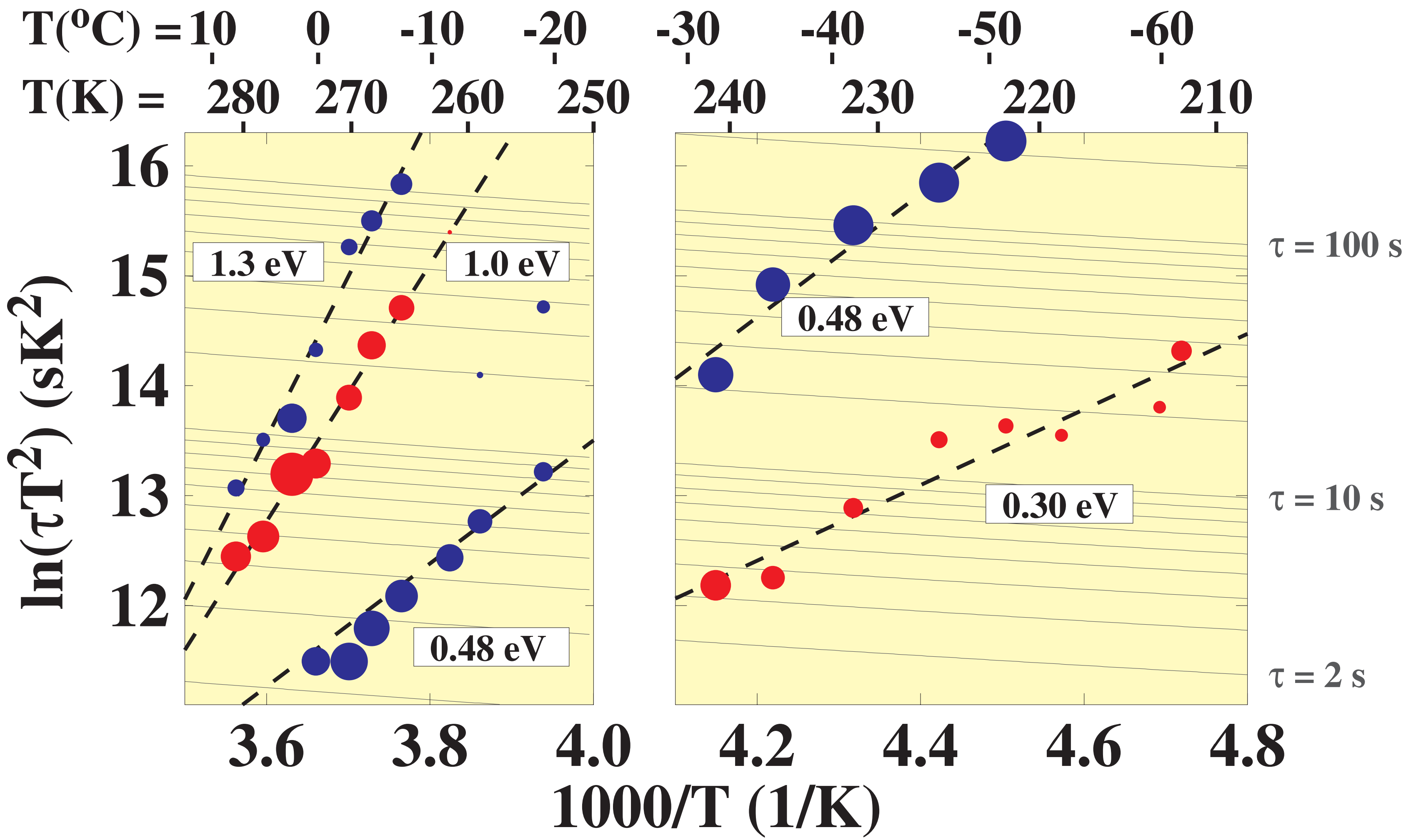


Figure 6: Decay times as a function of temperature for two runs. Red circles denote majority-type transients, while blue circles indicate minority type trap levels The area of each point is proportional to the transient amplitude (x5 in right plot). From this plot the trap level depths E_a can be determined.

DLTS summary

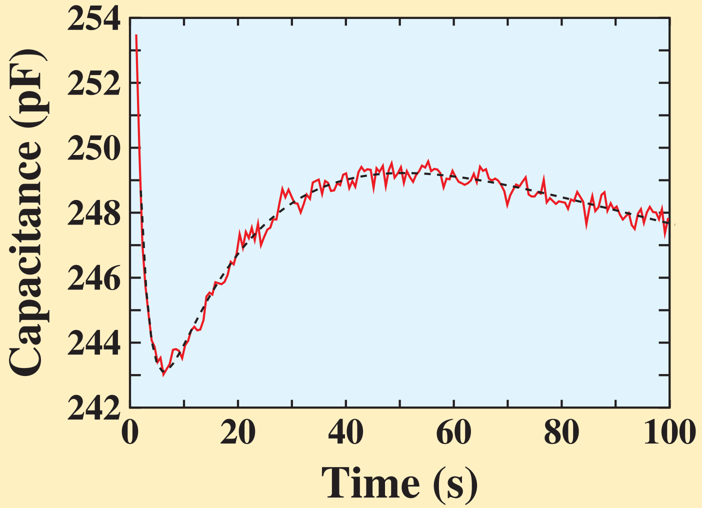


Figure 7a: An example of a complex capacitance transient that reveals three trap levels: a fast and a slow minority-carrier trap and, in between, a majority carrier trap. The transient was recorded at 5 °C after switching the voltage from 0 V to 1.4 V.

label	*type*	*activation energy*
AF0	acceptor	0.12 eV
AF1	majority	0.30 eV
DF1	minority	0.48 eV
AF2	majority	1.0 eV
DF2	minority	1.3 eV

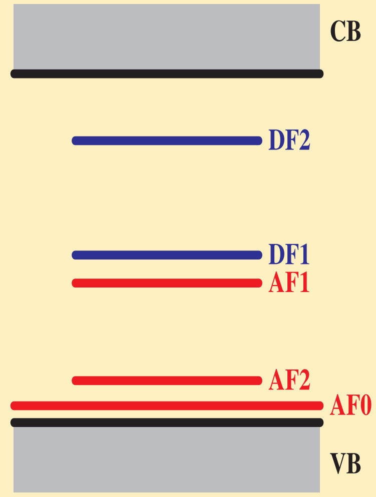


Table 1: Summary of the four trap levels found in DLTS and the acceptor level found in the loss-tangent data.
The figure illustrates the energy position in the forbidden gap of the MEH-PPV.

DLTS: Filling-Pulse-Length Dependence

For single-charge point-defects the amplitude of the transient C(t) depends exponentially on the filling pulse width t (the time spend at 0 V before switching back to 1.4 V), while for multi-charge (extended) defects every charge trapped makes the transient slower. A plot of log [C(oo) - C (t)] vs. t will be a straight line in the former case, while it will bend upwards for the latter.

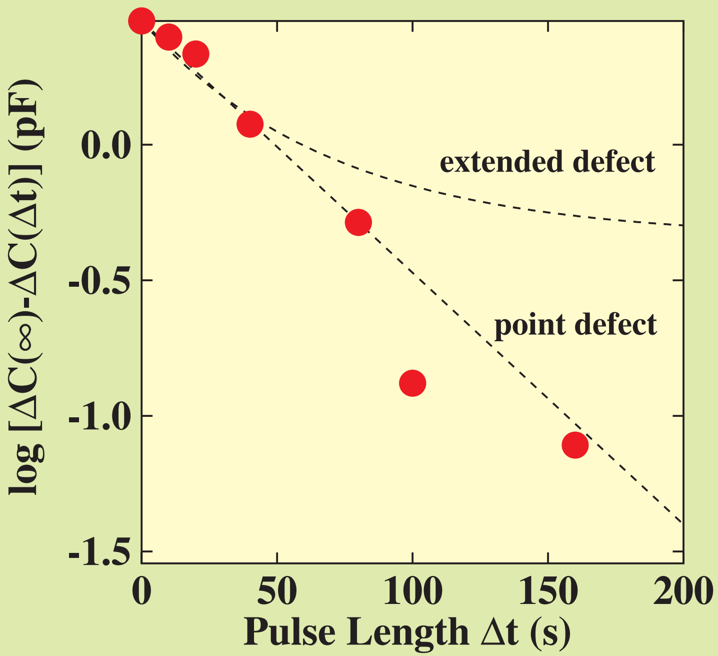


Figure 8: The data in the figure taken at room temperature for the transient amplitude of AF1 show that this trap level originates from a point-like defect.

Conclusions / Summary

- Evidence for minority-carrier injection
- Influence of vacuum conditions
- acceptor level:
    - concentration $N_A = 6.6\ 10^{15}$ cm ^{3}
    - depth: $E_A = 0.12$ eV
- successful DLTS in MEH-PPV!
    - 4 levels found: 2 x majority, 2 x minority trap
    - AF1 is point-like defect

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