A System for measuring Temperature dependent Surface Photovoltage

by Timo Bretten

Radboud Universiteit Nijmegen

M.Sc. Final Presentation December 10th 2015

Outline

Motivation

The goal of this project is to...

- Use a new experimental Kelvin Probe (KP) system
- Add illumination to 'new' KP
- Compare results from 'new' KP to established, 'old' KPs
  - → Does 'old' & 'new' Contact Potential Difference (CPD) agree?
  - → Does 'old' & 'new' Surface Photovoltage (SPV) agree?
- Ultimately measure temperature dependent Surface Photovoltage (SPV(T)) with the new system

The Contact Potential Difference (CPD)

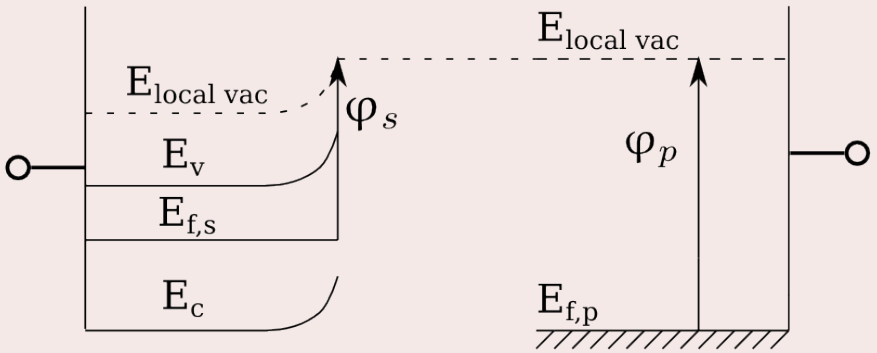
Physical Causes of CPD

The CPD is the difference in local vacuum levels, here defined as:

$$\text{CPD} \equiv \varphi_{\text{Probe}} - \varphi_{\text{Sample}},$$

where φ is Work function

Semiconductor-Metal:



[1]

The Contact Potential Difference (CPD)

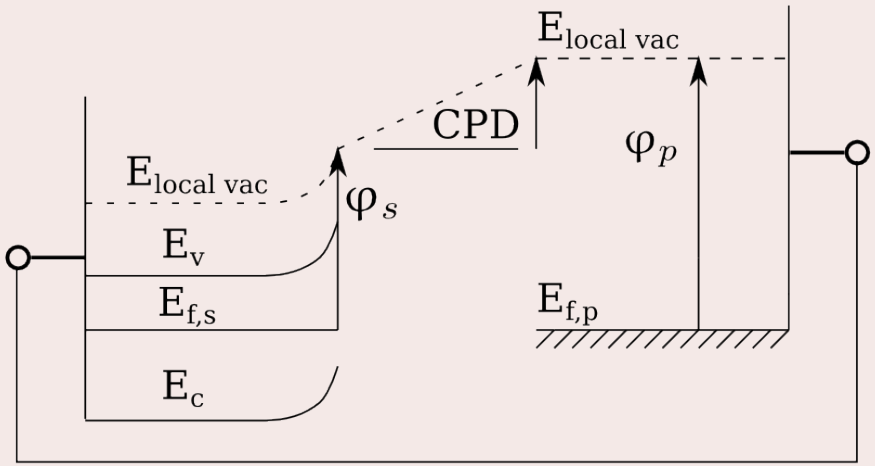
Physical Causes of CPD

The CPD is the difference in local vacuum levels, here defined as:

$$\text{CPD} \equiv \varphi_{\text{Probe}} - \varphi_{\text{Sample}},$$

where φ is Work function

Semiconductor-Metal:



[1]

The Contact Potential Difference (CPD)

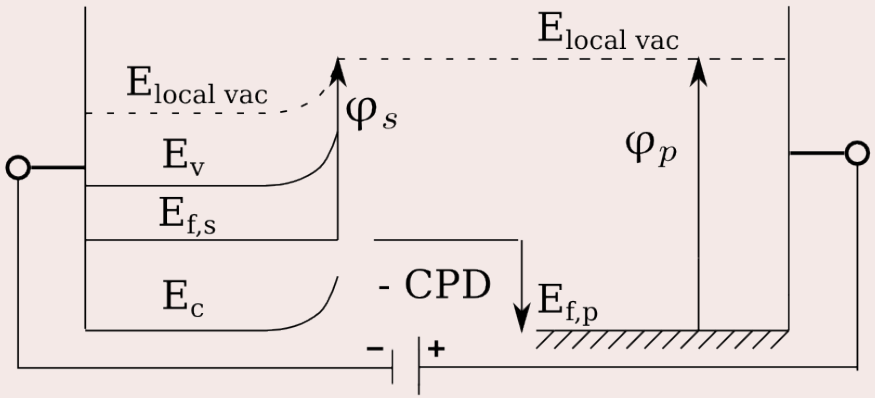
Physical Causes of CPD

The CPD is the difference in local vacuum levels, here defined as:

$$\text{CPD} \equiv \varphi_{\text{Probe}} - \varphi_{\text{Sample}},$$

where φ is Work function

Semiconductor-Metal:



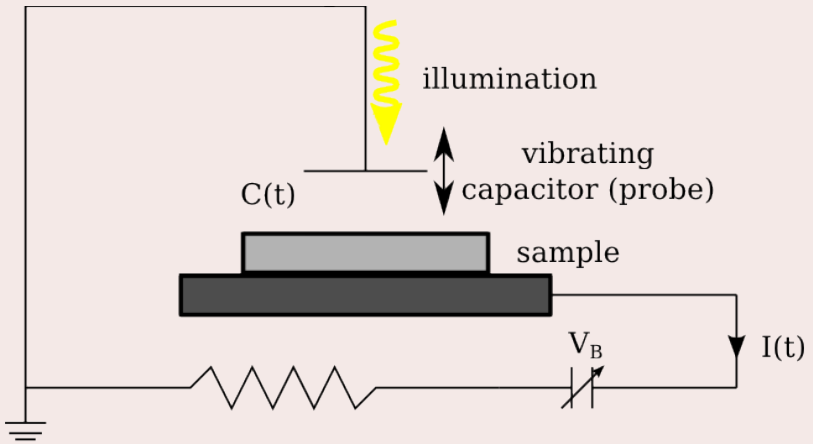
[1]

The Contact Potential Difference (CPD)

Measuring CPD: The Kelvin Probe (KP)

$$I(t) = \frac{dQ}{dt} = (\mathrm{CPD} + V_b)\frac{dC}{dt}$$

$$I(t) = 0 \quad \text{iff} \quad V_b = -\mathrm{CPD}$$

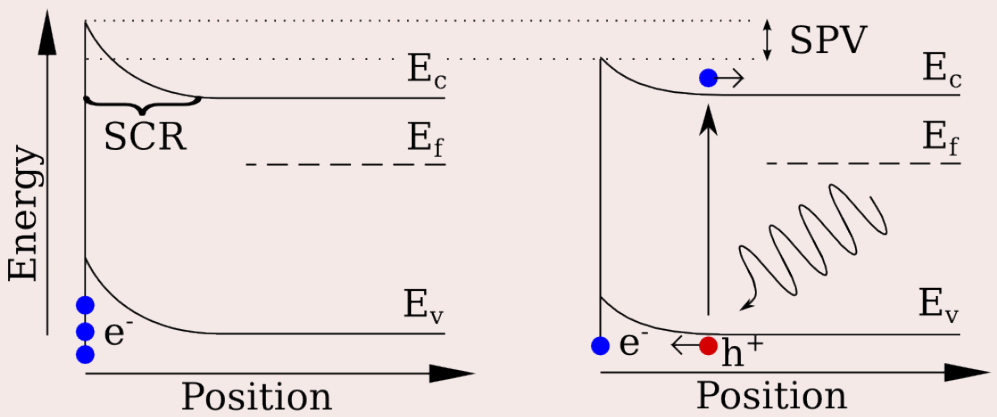


Physical Causes of Surface Photovoltage (SPV)

SPV: CPD in the dark dark vs. light

Different surface potentials in light and dark yield SPV:

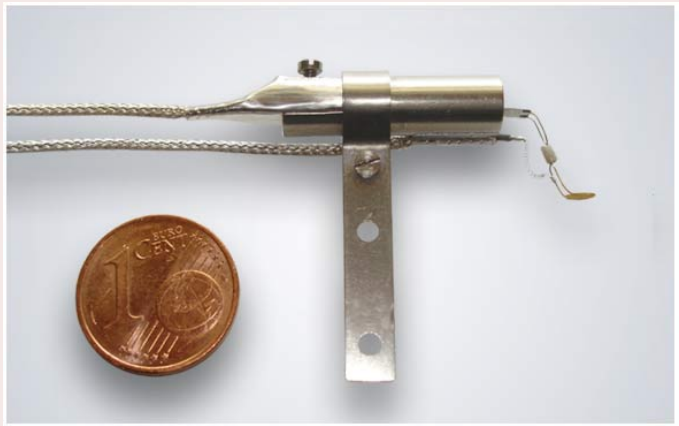
$$\begin{aligned} \mathrm{SPV} &\equiv \mathrm{CPD_l} - \mathrm{CPD_d} \\ &\equiv \varphi_{s,d} - \varphi_{s,l} \\ \mathrm{SPV_n} &> 0 \\ \mathrm{SPV_p} &< 0 \end{aligned}$$



Established, 'old' KP Systems

Ambient & Glovebox KPs

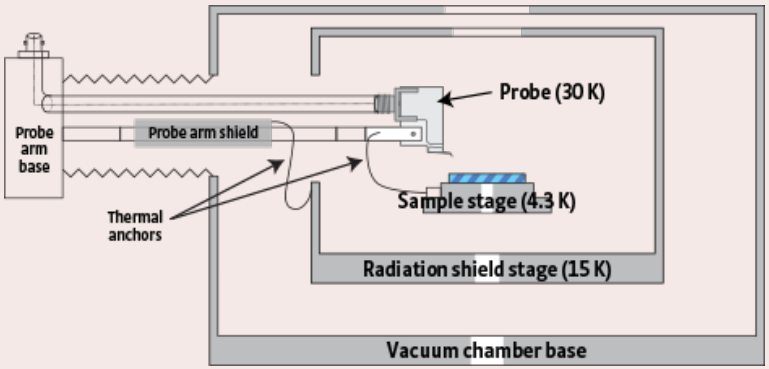
- Besocke KP head & controller
- Humidity controlled ambient
- Glovebox (< 5ppm O_2 & H_2O)
- Xenon lamp & VariAC ($\sim$80 W)
- Illumination is source of heat!



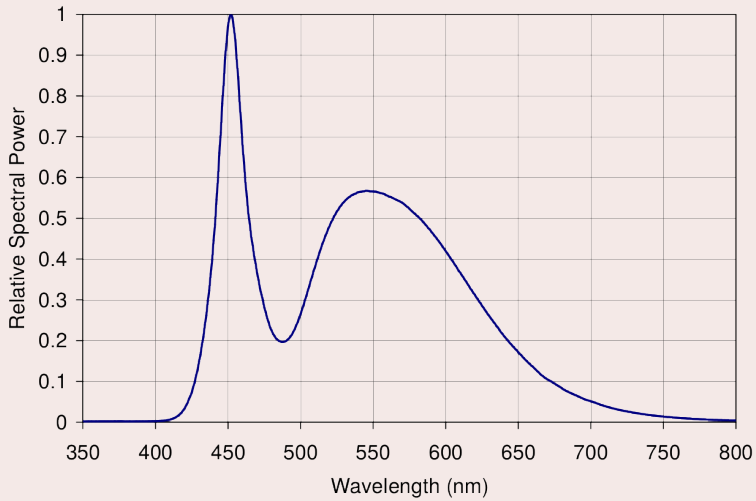
[2]

‘New’ System: Cryostat with a KP

Lakeshore Cryostat with Mc Allister KP & LED illumination



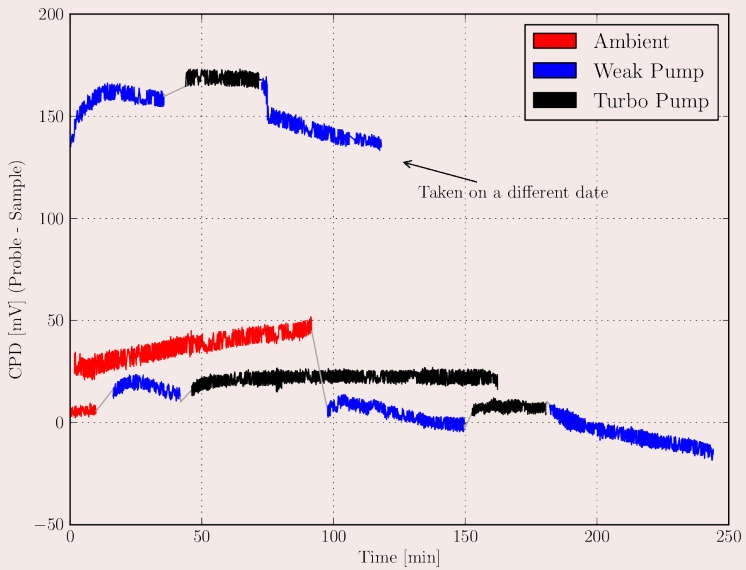
[3]

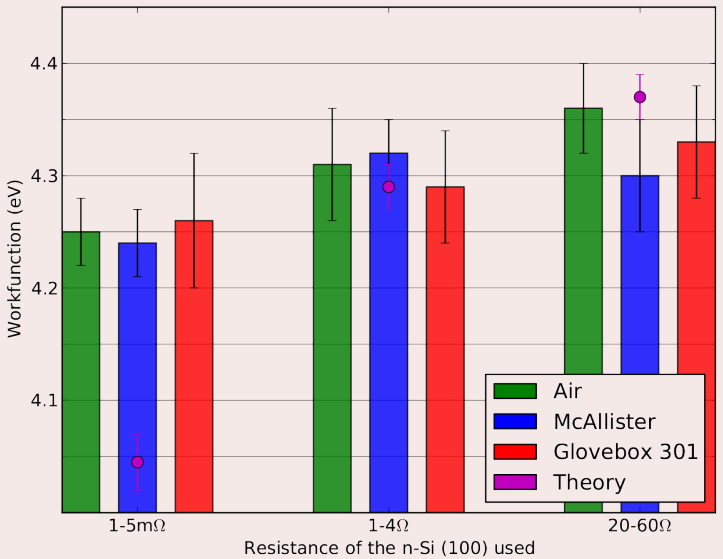


[4]

Checking against Established Systems

Behaviour at Room Temperature





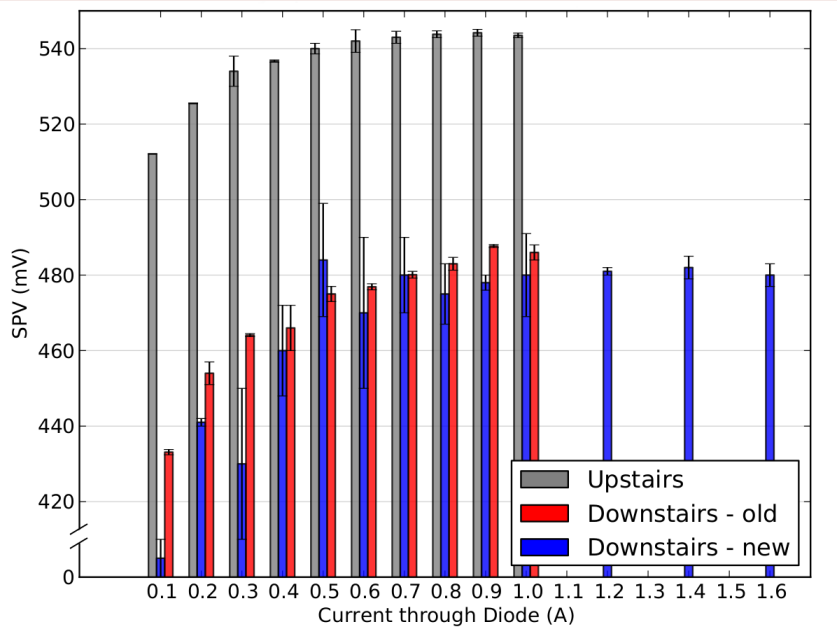
'Jumps' probably due to movement of probe head
Excellent agreement between systems

Checking against Established Systems

Behaviour at lower temperatures and SPV

30 nm AlO_3 on Si,
by plasma-enhanced
atomic layer deposition [5]

- $\varphi_{Si/Alumina}$ at 300 K:
  (4.42 ± 0.03) eV
- $\varphi_{Si/Alumina}$ at 250 K:
  (4.44 ± 0.04) eV

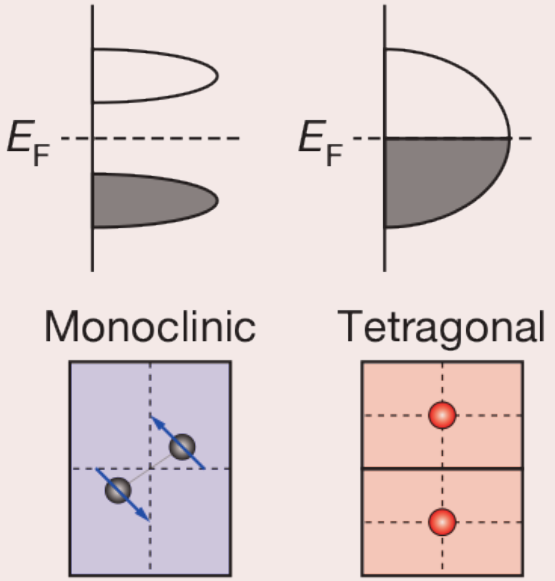


Probably no ice, even on very hydrophilic surface
SPV ∼12 % too low compared to other system and literature ([5]).
Shadows on the sample?

Intermission: Choosing a Model System for SPV(T)

Metal Insulator (MI) Transition in VO_2

- metal at $T > T_{MI}$
- semiconductor at $T < T_{MI}$
- insulator at $T \ll T_{MI}$
- $T_{MI} \approx 270\,\mathrm{K}$ [6] (W-doped)
- $\varphi \approx 5.15\,\mathrm{eV}$ [7] (at RT)
- $\Delta\varphi_{MI} \approx -0.15\,\mathrm{eV}$ [7]
- $\Delta\varphi_{MI} \approx 0.45\,\mathrm{eV}$ [8] (W-doped)

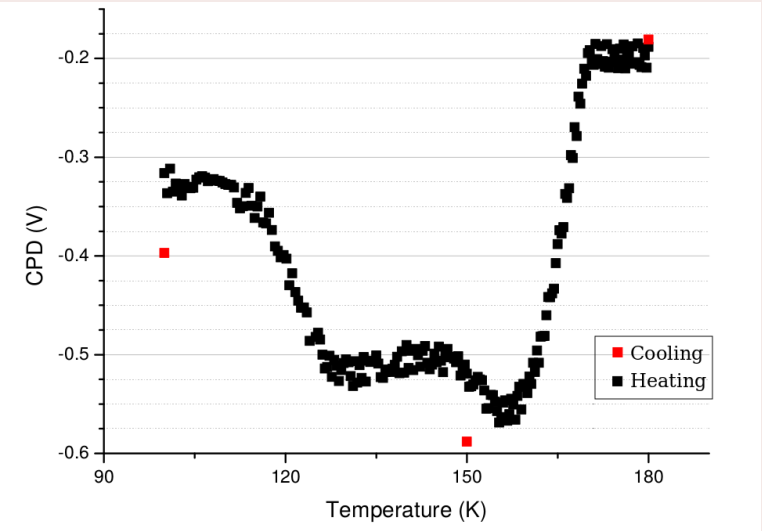


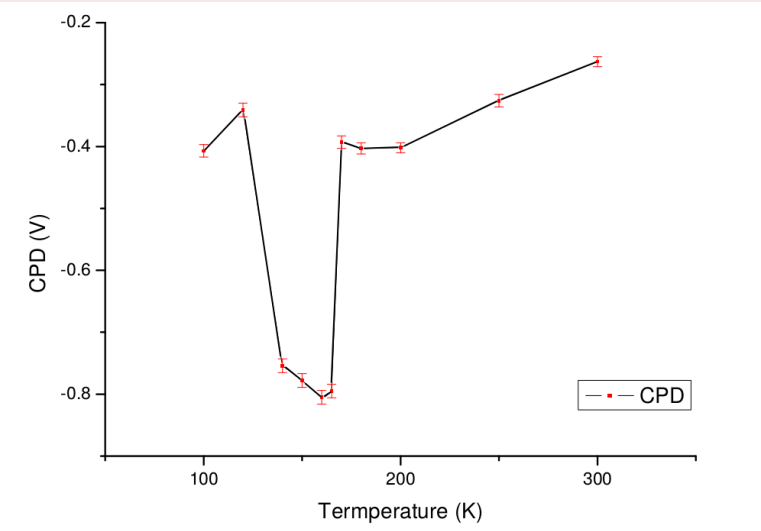
[9]

Temperature Dependent CPD in W:VO_2

Two independent Measurements: Sweep and Stabilise

Samples supplied by M. Nakano, RKIEN

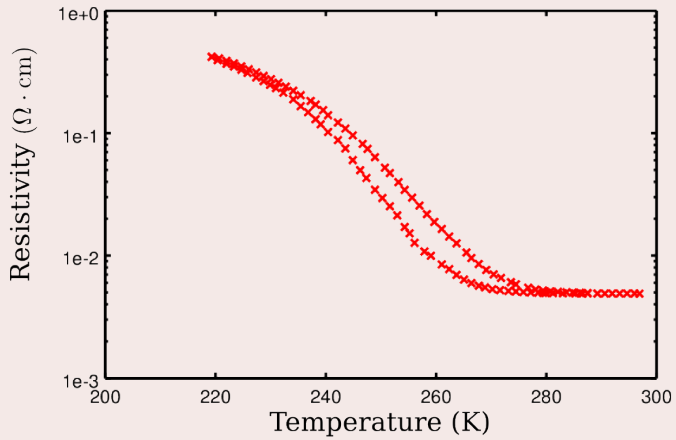




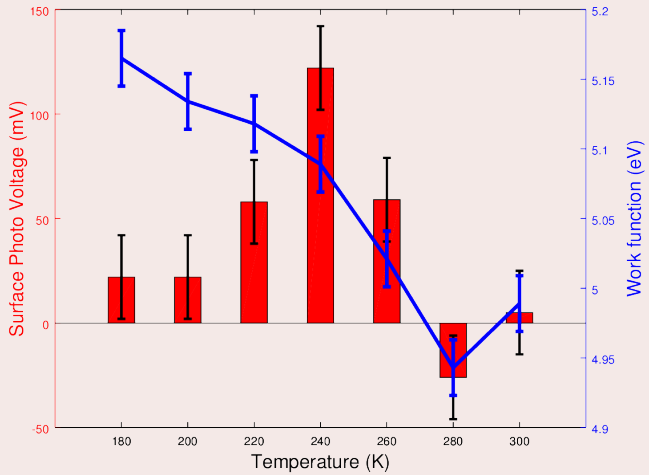
Curious behaviour in the range 120 K to 160 K, far below T_{MI}
Effect of substrate?

Temperature Dependent SPV in W:VO_2

ρ(T) and SPV(T)



Measurement by Nir Kedem



ρ(T) magnitude and T_{MI}-range agrees with literature ([7],[10])
$\Delta\varphi_{MI}$ observed before; direction & magnitude unclear ([6],[8])
Gradual gap opening process $\rightarrow$ appearance of SPV
Sign of SPV identifies sample as n-type $\rightarrow$ W-doping

Discussion & Conclusion

We showed that...

- CPD is in excellent agreement with established systems
- SPV ∼12 % too low. Shadowing?
- CPD(T) reproducible and interesting
- CPD(T) & SPV(T) reasonable

→ Lakeshore + Mc Allister + LED is a viable experimental system for SPV(T)

- System has successfully been used in that configuration since 2014, publication forthcoming [11]

List of References

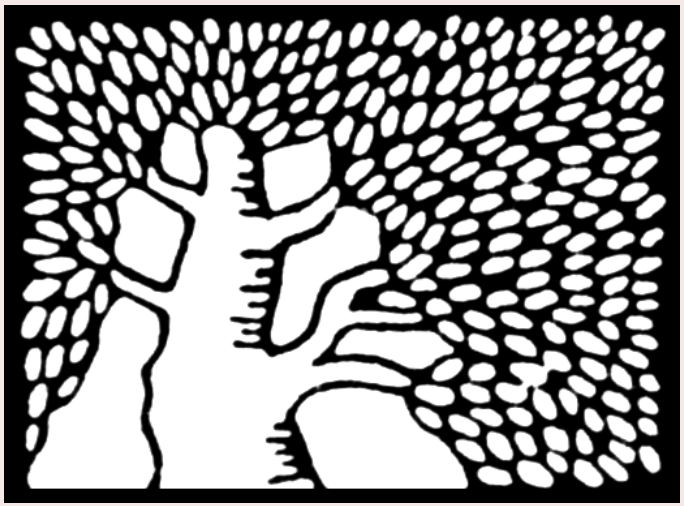
Literature and links

[1] L. Kronik & Y. Shapira *Surf. Sci. Rep.*, **37(1-5)**, 1999
[2] Besocke Website
[3] Lakeshore Website
[4] LEDengin Website
[5] D. Cahen *et al. Appl. Phys. Lett.*, **101**, 2012
[6] K. Shibuya *et al. Phys Rev. B*, **82(20)**, 2010
[7] C. Ko *et al. ACS Appl. Mater. Interfaces*, **3(9)**, 2011
[8] H. Yin *et al. ACS Appl. Mater. Interfaces*, **3(6)**, 2011
[9] M. Nakano *et al. Nature*, **487(7408)**, 2012
[10] K. Shibuya *et al. Appl. Phys. Lett.*, **96**, 2010
[11] D. Cahen *et al. J. Phys. Chem. Lett.*, forthcoming

Some more background...

...about my M.Sc. project

- Research carried out in 13/14 at The Weizmann Institute of Science
- Project had two parts: P(VDF) & SPV(T)
- Only part two was presented



Acknowledgements

Thanks! to...

Prof. David Cahen	for his supervision
Dr. Hugo Meekes	for his spontaneous support
Igal Levine	for keeping me (somewhat) on track
Nir Kedem	for always having an answer