A System for measuring Temperature dependent Surface Photovoltage

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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)

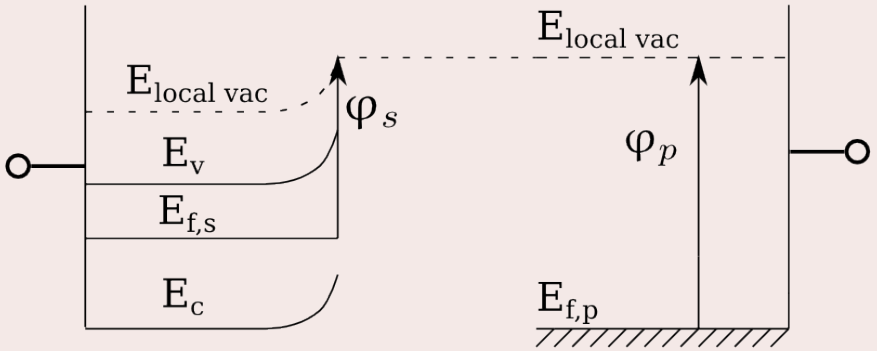
Physical Causes of CPD

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]

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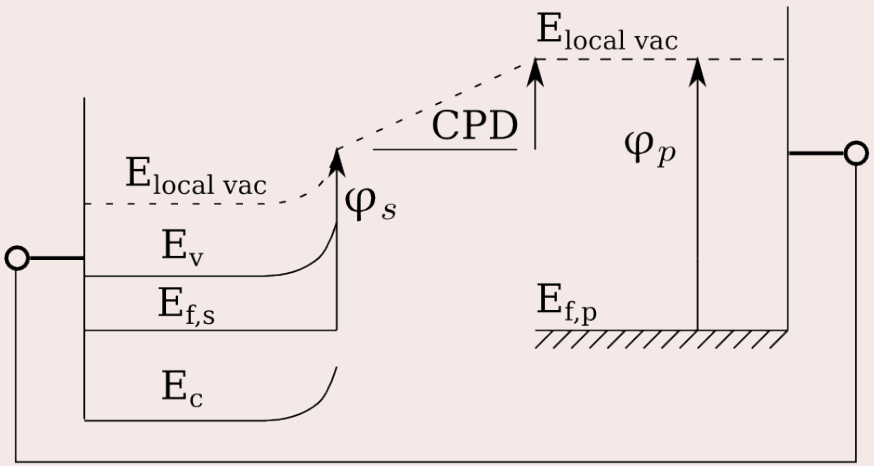

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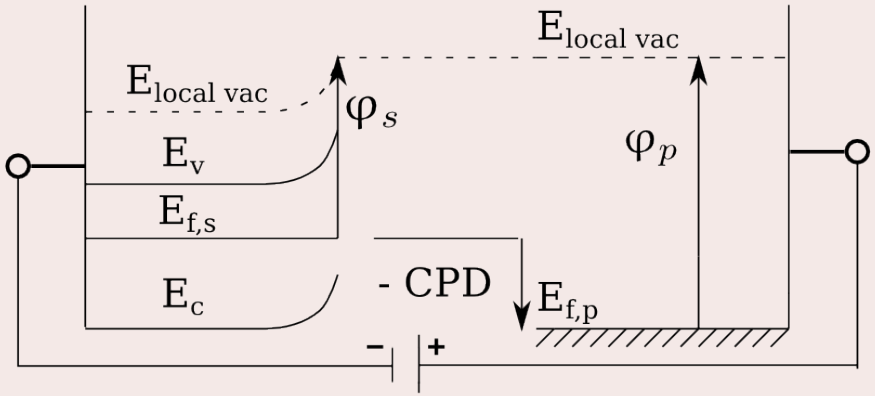


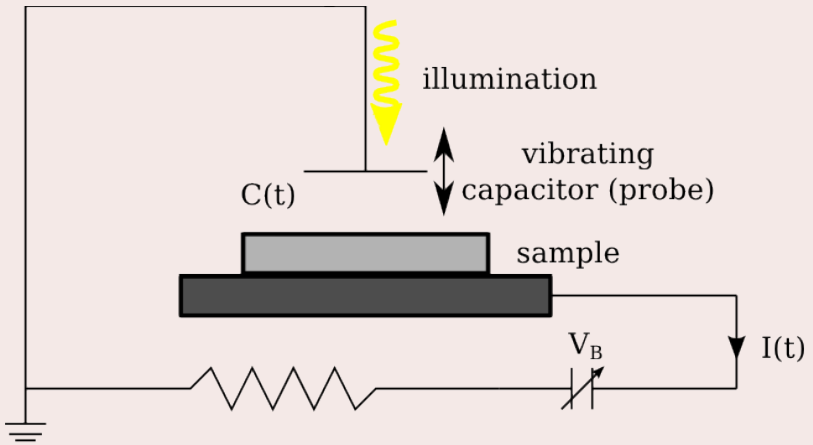
[1]

The Contact Potential Difference (CPD)

Measuring CPD: The Kelvin Probe (KP)

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

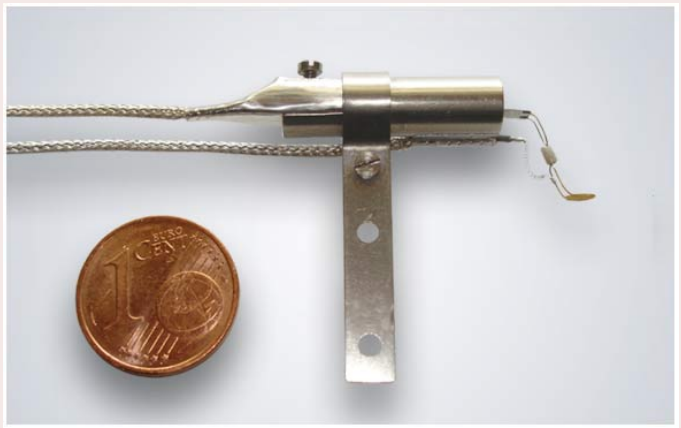
$$I(t) = 0 \quad \text{iff} \quad V_b = -\mathrm{CPD}$$



Established, 'old' KP Systems

Ambient & Glovebox KPs

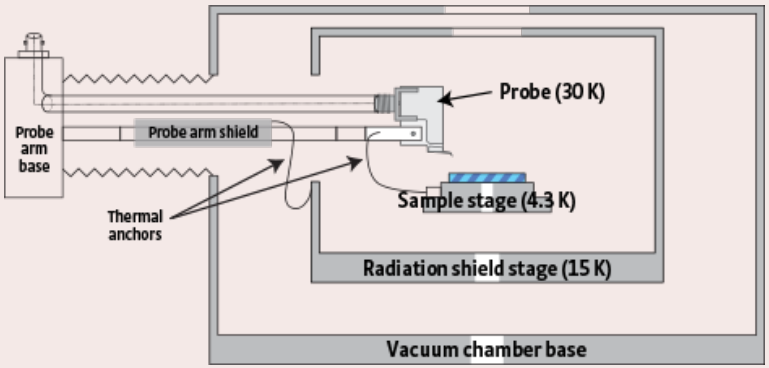
- Besocke KP head & controller
- Humidity controlled ambient
- Glovebox ($<$ 5ppm O_2 & H_2O)
- Xenon lamp & VariAC ($\sim$80 W)
- Illumination is source of heat!



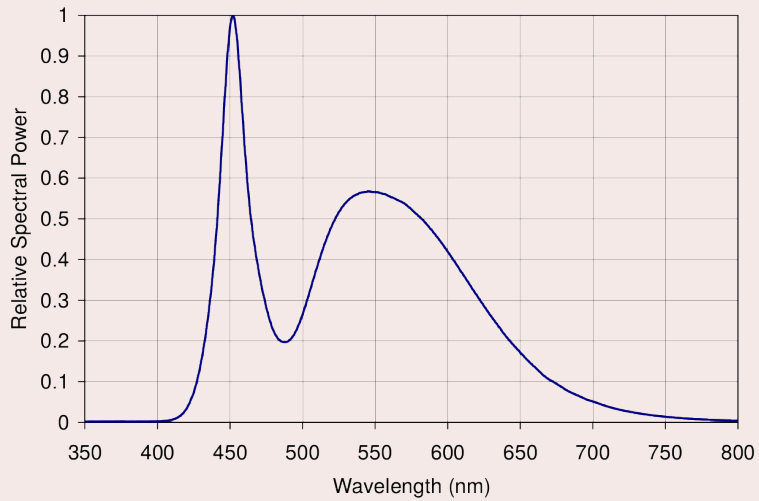
[2]

'New' System: Cryostat with a KP

Lakeshore Cryostat with Mc Allister KP & LED illumination



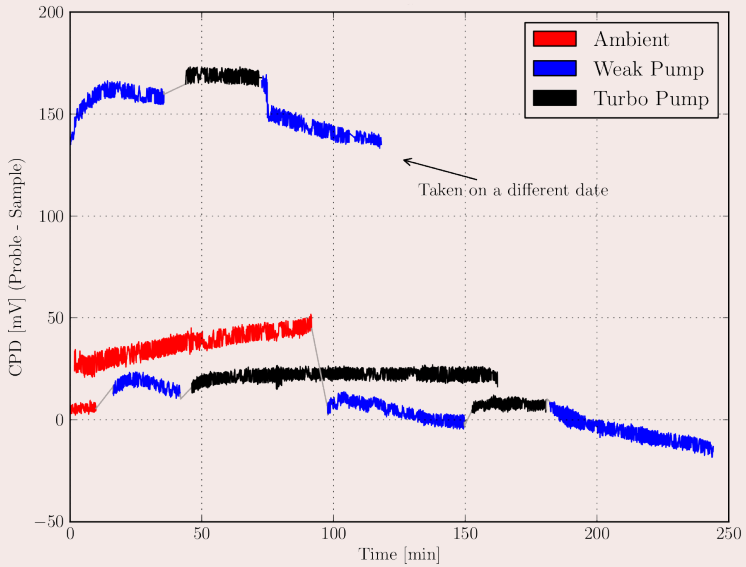
[3]

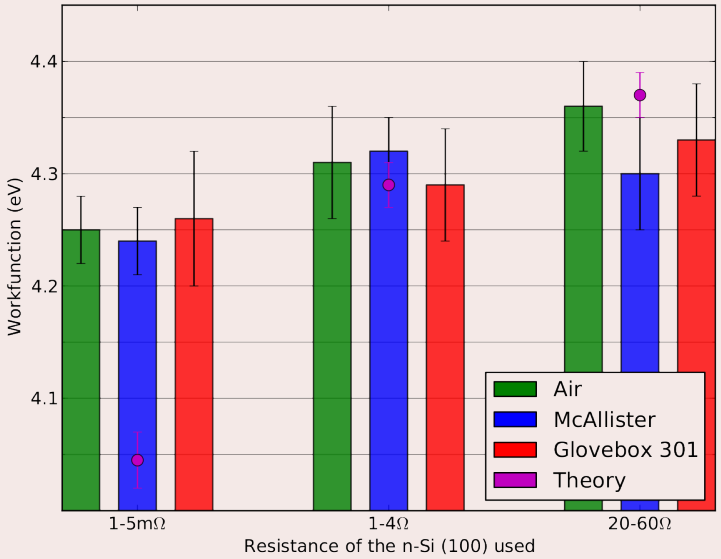


[4]

Checking against Established Systems

Behaviour at Room Temperature





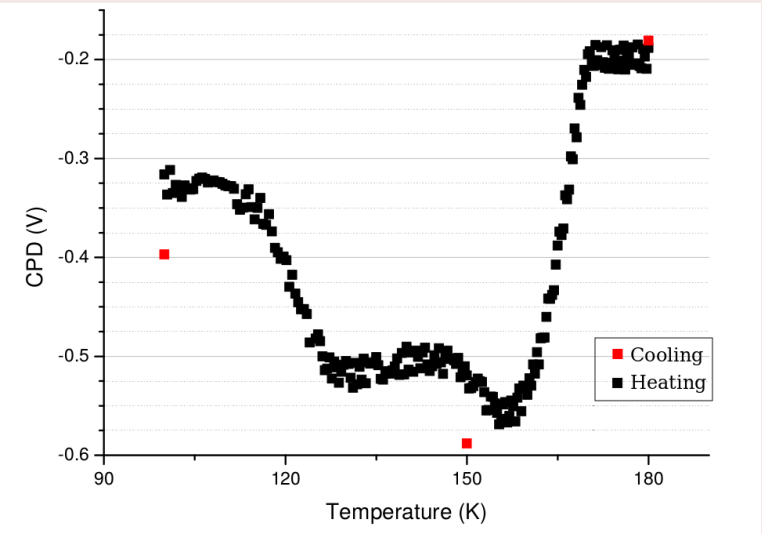
'Jumps' probably due to movement of probe head

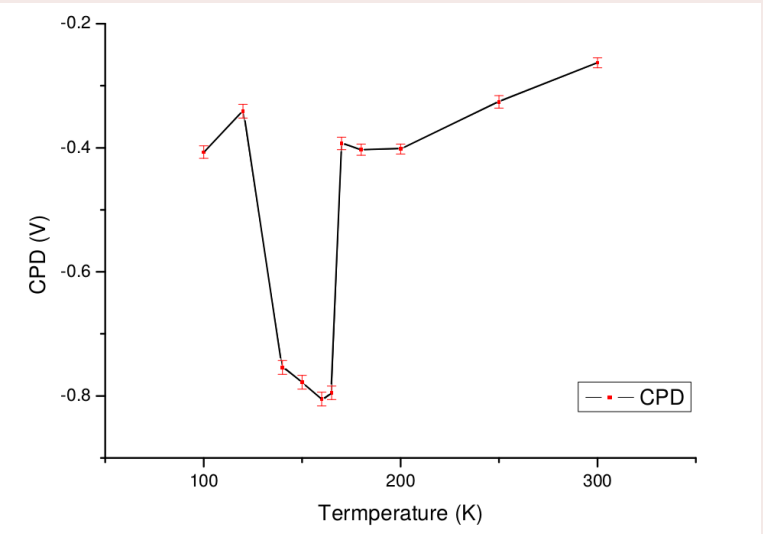
Excellent agreement between systems

Temperature Dependent CPD in W:VO_2

Temperature Sweep and precise Measurement

Samples supplied by M. Nakano, RKIEN



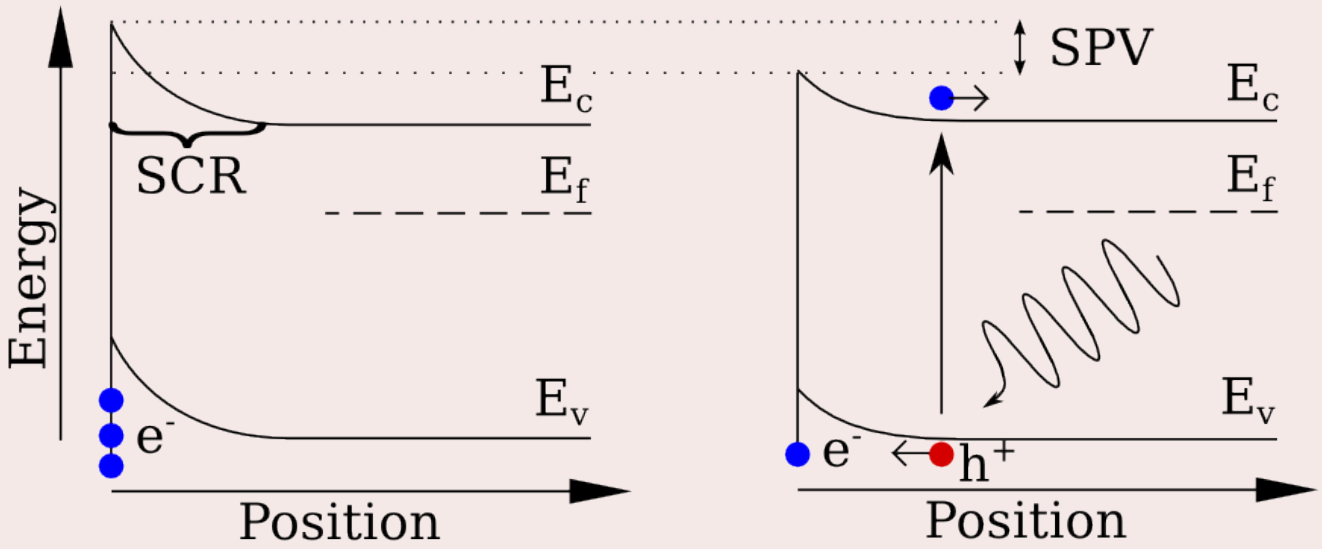


Curious behaviour in the range 120 K to 160 K, far below T_{MI}
Effect of substrate?

Intermission: Physical Causes of SPV

Band bending & SPV: dark vs. light

$$SPV \equiv CPD_{light} - CPD_{dark} \equiv \varphi_{s,dark} - \varphi_{s,light}$$



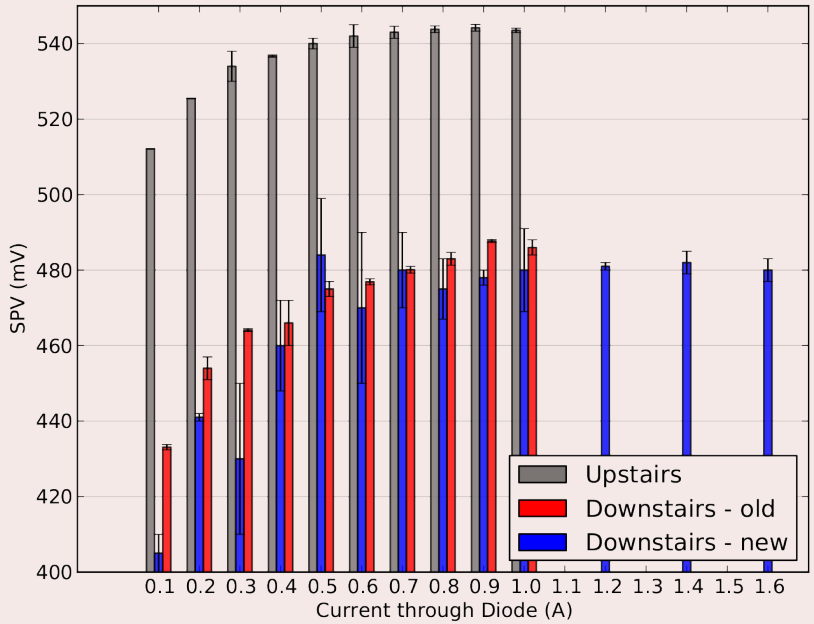
$SPV_{n\text{-}Type} > 0$ $\quad$ $SPV_{p\text{-}Type} < 0$

Checking against Established Systems

Behaviour at lower temperatures and SPV

20 nm Al on Si,
oxidised by plasma

- φ_{Alumina} at 300 K:
  (4.00 ± 0.12) eV
- φ_{Alumina} at 250 K:
  (4.17 ± 0.15) eV

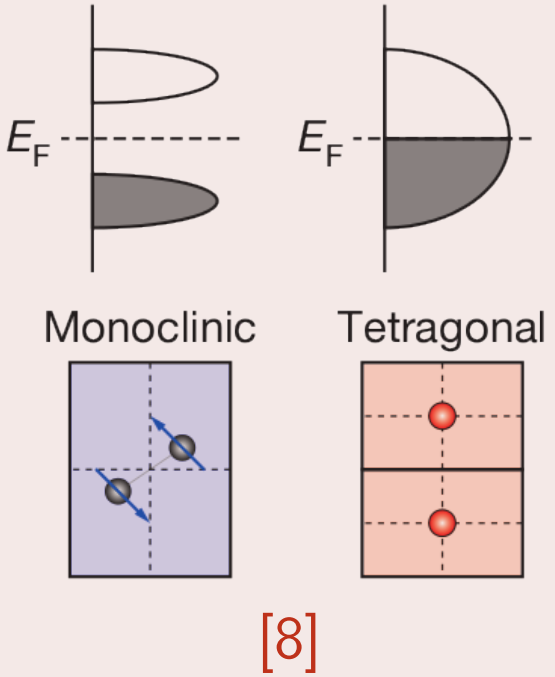


Probably no ice, even on very hydrophilic surface
SPV ∼12 % too low. Shadows on the sample?

Intermission: Choosing a Model System for SPV(T)

Metal Insulator (MI) Transition in VO_2

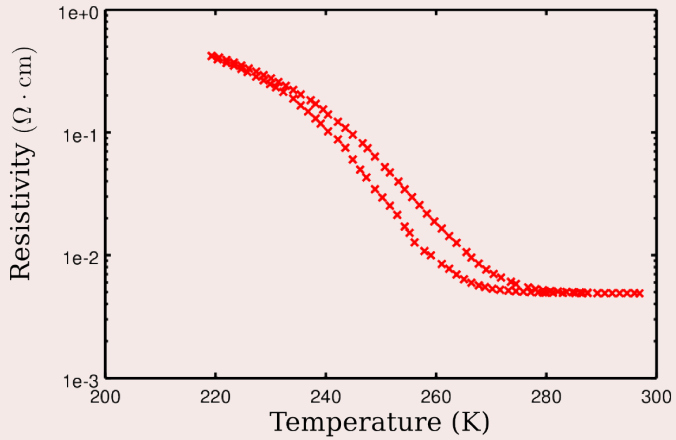
- metal at $T > T_{MI}$
- semiconductor at $T < T_{MI}$
- insulator at $T \ll T_{MI}$
- $T_{MI} \approx 270\,\mathrm{K}$ [5] (W-doped)
- $\varphi \approx 5.15\,\mathrm{eV}$ [6] (at RT)
- $\Delta\varphi_{MI} \approx -0.15\,\mathrm{eV}$ [6]
- $\Delta\varphi_{MI} \approx 0.45\,\mathrm{eV}$ [7] (W-doped)

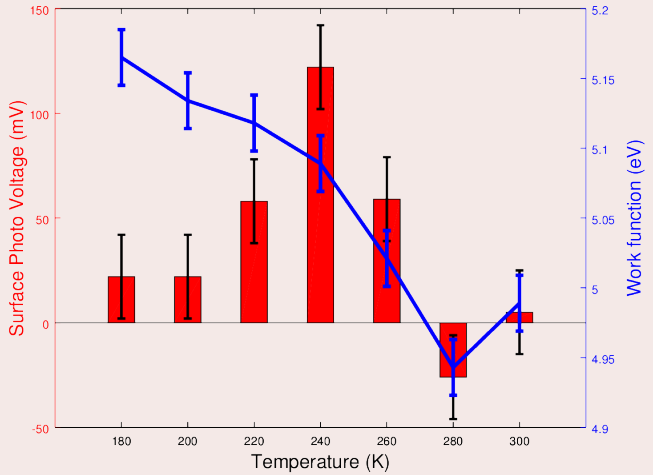


[8]

Temperature Dependent SPV in W:VO_2

ρ(T) and SPV(T)





Measurement by Nir Kedem

SPV identifies W:VO_2 as n-type material (agrees with W-doping)
ρ(T) & transition at the expected temperature ([6],[9])

Discussion & Conclusion

We showed that...

- CPD is in excellent agreement with established systems
- SPV $\sim$12 % too low. Shadowing?
- CPD(T) reproducible and interesting
- $\Delta\varphi_{MI}$ observed before, direction & magnitude unclear
- CPD(T) & SPV(T) reasonable

$\rightarrow$ Lakeshore + Mc Allister + LED is a viable system for SPV(T)

List of References

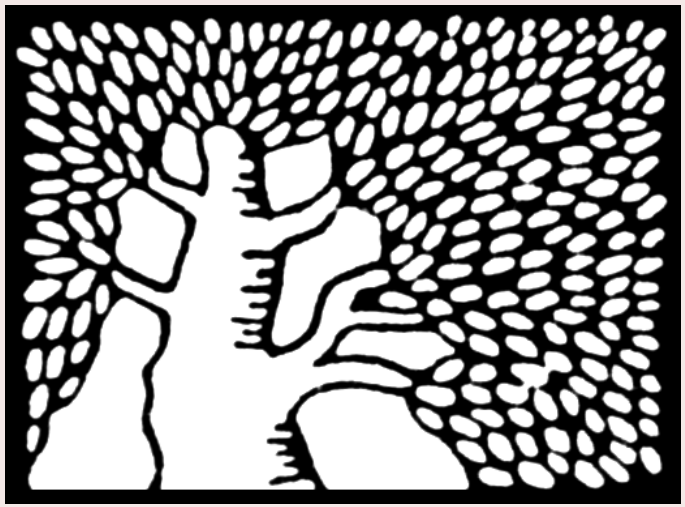
Literature and links

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

Some 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

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Nir Kedem	for always having an answer