

A System for measuring Temperature dependent Surface Photovoltage

by Timo Bretten

Radboud Universiteit Nijmegen

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Outline

Introduction

Theory

The Systems

Experimental

Discussion & Conclusion



Some background. . .

...about my M.Sc. project

- Research carried out in 13/14 at
The Weizmann Institute of
Science
- Project had two parts:
enhancing solar cells & setting
up a new experimental system
- Only part two will be presented



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

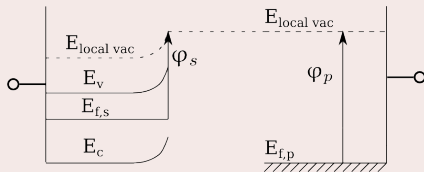
The Contact Potential Difference (CPD)

Physical Causes of CPD

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

$CPD \equiv \varphi_{\text{Probe}} - \varphi_{\text{Sample}}$,
where φ is Work function

Semiconductor-Metal:



[1]

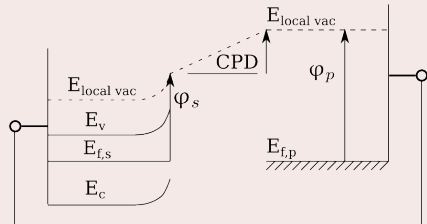
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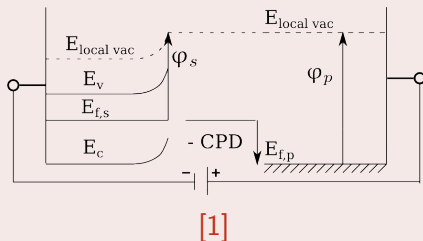
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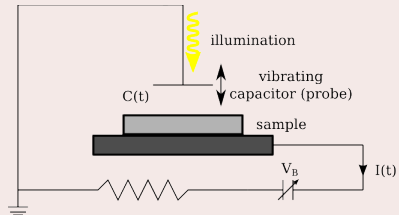


The Contact Potential Difference (CPD)

Measuring CPD: The Kelvin Probe (KP)

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

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



Physical Causes of Surface Photovoltage (SPV)

SPV: CPD in the dark dark vs. light

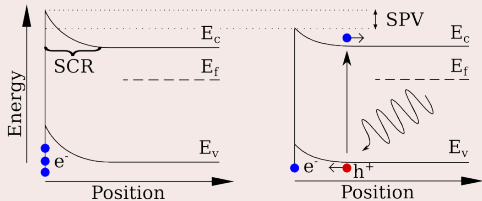
Different surface potentials in light and dark yield SPV:

$$\text{SPV} \equiv \text{CPD}_l - \text{CPD}_d$$

$$\equiv \varphi_{s,d} - \varphi_{s,l}$$

$$\text{SPV}_n > 0$$

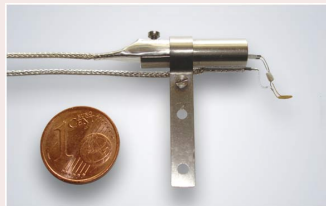
$$\text{SPV}_p < 0$$



Established, 'old' KP Systems

Ambient & Glovebox KPs

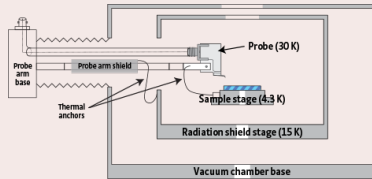
- Besocke KP head & controller
- Humidity controlled ambient
- Glovebox ($< 5\text{ppm O}_2$ & H_2O)
- Xenon lamp & VariAC ($\sim 80\text{ W}$)
- Illumination is source of heat!



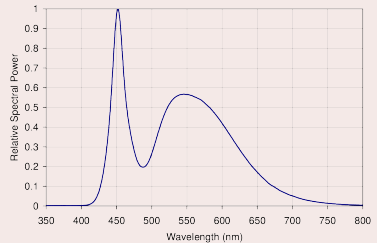
[2]

'New' System: Cryostat with a KP

Lakeshore Cryostat with Mc Allister KP & LED illumination



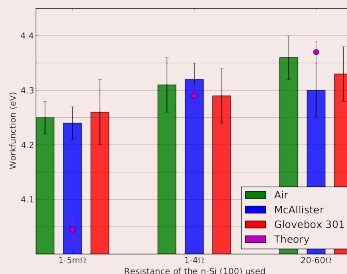
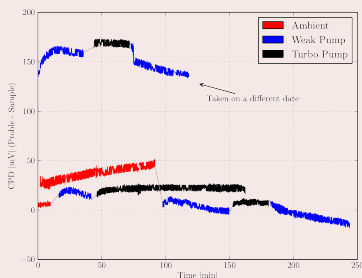
[3]



[4]

Checking against Established Systems

Behaviour at Room Temperature



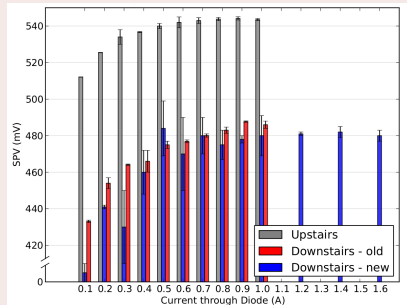
'Jumps' probably due to movement of probe head
Excellent agreement between systems

Checking against Established Systems

Behaviour at lower temperatures and SPV

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

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

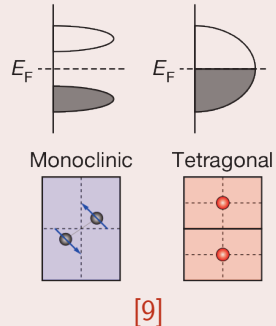


Probably no ice, even on very hydrophilic surface
SPV $\sim 12\%$ too low compared to other system and literature ([5]).
Shadows on the sample?

Intermission: Choosing a Model System for SPV(T)

Metal Insulator (MI) Transition in VO_2

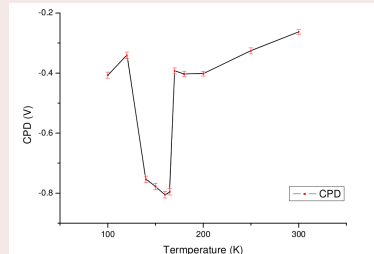
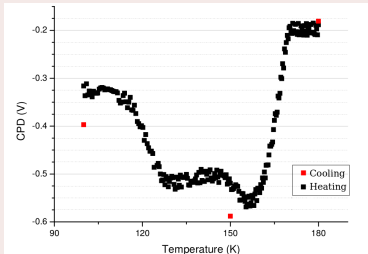
- metal at $T > T_{MI}$
- semiconductor at $T < T_{MI}$
- insulator at $T \ll T_{MI}$
- $T_{MI} \approx 270 \text{ K}$ [6] (W-doped)
- $\varphi \approx 5.15 \text{ eV}$ [7] (at RT)
- $\Delta\varphi_{MI} \approx -0.15 \text{ eV}$ [7]
- $\Delta\varphi_{MI} \approx 0.45 \text{ eV}$ [8] (W-doped)



Temperature Dependent CPD in W:VO₂

Two independent Measurements: Sweep and Stabilise

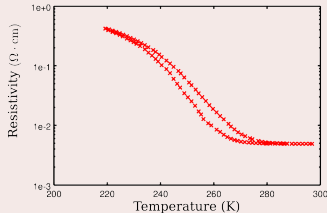
Samples supplied by M. Nakano, RKIEN



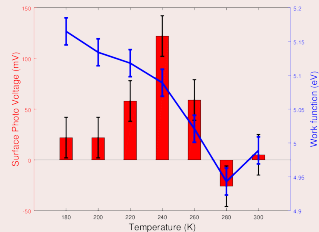
Curious behaviour in the range 120 K to 160 K, far below T_{MI}
Effect of substrate?

Temperature Dependent SPV in W:VO₂

$\rho(T)$ and SPV(T)



Measurement by Nir Kedem



$\rho(T)$ 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 $\sim 12\%$ 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

Acknowledgements

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