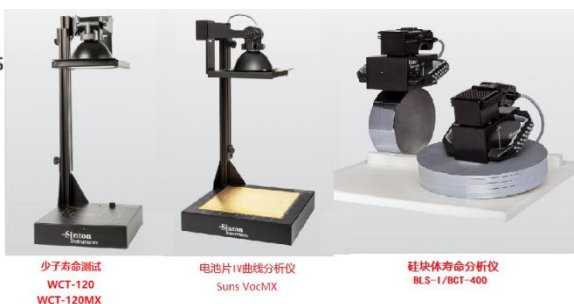




少子寿命测试仪WCT-120MX+Suns VocMX介绍

2026.10

北京、上海办公室/福州办公室：

张有义/YouYi Zhang

邮箱：support@htterui.com

手机：+86-18611956651

台北办公室：

梁子维/Woke Liang

邮箱：service@globalsci.com.tw

手机：+886- 0910111036

HTTR 北京华通特瑞光电科技有 限 公 司

BEIJING HUA TONG TE RUI PHOTON TECHNOLOGY CO., LTD Global Science Instruments Co., Ltd.

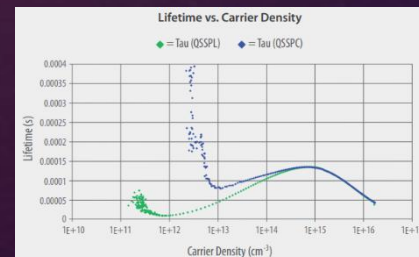
北京华通

GSI 廣 集 企 業 有 限 公 司



SEMI PV13-0211

全球光伏行业标准



HTTR

GSI

北京华通特瑞

台北广集



WCT-120MX
WXT-120PL



Suns VocMX



BCT-400/BLS-I



IL-800

我们提出纳米原子尺度--非平衡条件类费米能级失配 (Quasi Fermi Level Splitting QFLS)关键参数，在实际叠层太阳能电池结构/各个子电池分析辅助以瑞士

Fluxim公司Setfos动太仿直槽坝

20230117英国Oxford大学，Sheffield大学，德国Potsdam大学联合paper：Open – circuit and short – circuit loss management in wide – gap perovskite p – i – n solar cells

Perovskite钙钛矿/晶硅Si叠层太阳能电池设计优化，首先掌握系统性关键因素QFLS Quasi Fermi Level Splitting,减少Voc Loss 。进而Isc最优匹配/稳定寿命增强

20230504 德国HZB， Potsdam大学等联合paper:Inter – face engineering for high – performance， triple – halide perovskite – silicon tandem solar cells 32. 5%

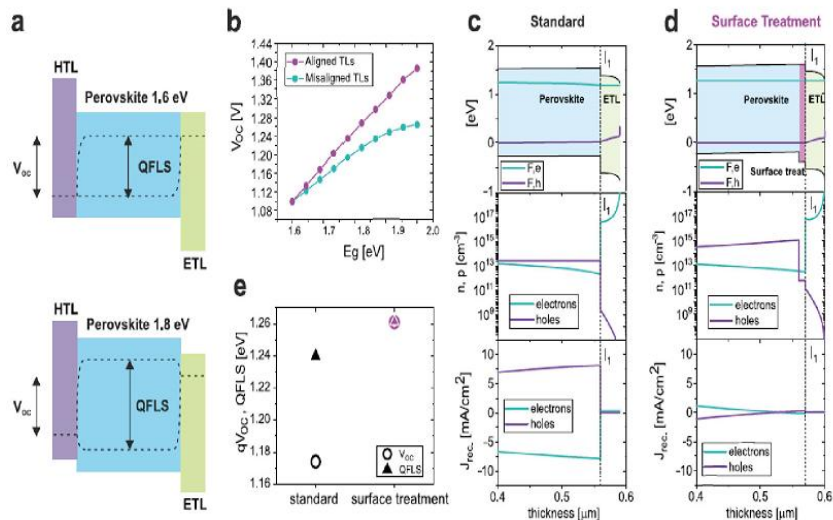
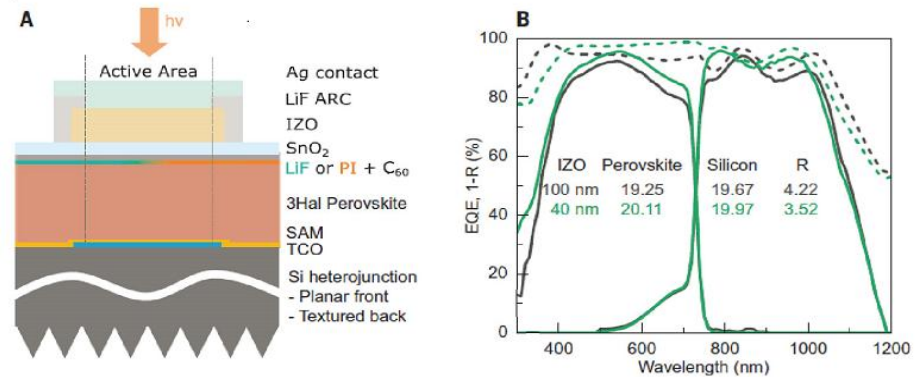


Table S1. PLQY and QFLS obtained from PL measurements on three different device configurations.

Sample	PLQY (QFLS)		
	No surface treatm.	Surface treatment	
	Reference	LiF	PI
Quartz/Perovskite	3.75e-2 (1.305 eV)	9.94e-2 (1.330 eV)	3.93e-2 (1.306 eV)
Glass/ITO/2PACz/3Hal/Surf.Treatm.	5.43e-3 (1.255 eV)	2.47e-2 (1.294 eV)	4.59e-3 (1.251 eV)
Glass/ITO/2PACz/3Hal/Surf.Treatm./C ₆₀	2.66e-4 (1.177 eV)	2.34e-3 (1.233 eV)	8.04e-3 (1.265 eV)
Glass/ITO/Me4PACz/3Hal/Surf.Treatm.	4.10e-2 (1.308 eV)	-	2.75e-2 (1.270 eV)
Glass/ITO/Me4PACz/3Hal/Surf.Treatm./C ₆₀	2.43e-3 (1.175 eV)	-	9.79e-3 (1.297 eV)

Fig. 1 | Drift – diffusion simulations with SETFOS.



多功能有机光电量测系统,整合稳态、瞬态以及交流阻抗多种量测技术,是OLED、钙钛矿/晶硅叠层电池,PeQD-X研究人员最佳的量测工具!

- Charge Extraction
- Photo-CELIV
- Capacitance-Voltage
- IMPS / IMVS
- Impedance Spectroscopy
- MELS
- Current-Voltage-Luminance
- Emission Spectrum
- Transient Electroluminescence
- Transient Photocurrent
- Transient Photovoltage
- User-Defined Signals

Paios



我们的光伏PV产业技术全面升级方案:

*** Tandem Soler Cell

模拟优化Tandem结构, 创新功能材料, 加速推进次世代**钙钛矿/晶硅**叠层太阳电池的批量大尺寸商业化。

*** High Efficiency and High Yield

同时从现在光电转换高效率的晶硅光伏行业迈向更精进生产工艺**高良率**的巅峰。

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FCT-650SE



G2V

LED精准可调光谱专属PVK/Si Tandem Soler Cell 分析测量系统
各项光照IV曲线参数量测也包括晶硅lifetime/SunsVoc满足您对叠层电池的需求。



IL-800

线上寿命自动测试系统

硅片在市场上以人民币每片计价, 您认为合理吗? 恰当吗?
为了PV产业总体迈向高效率和高良率可持续发展, 产线选用IL-800自动测试

pve
Photovoltaik
Engineering

www.pv-engineering.de **PVPM1040C**



太阳能模组户外
安装及维运可靠
精确功率测量



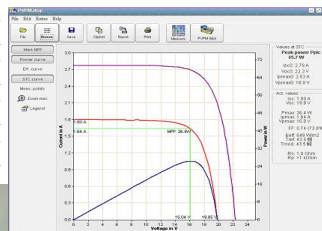
ISET SENSOR



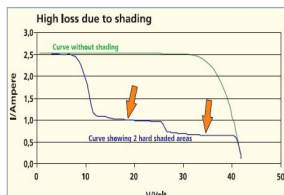
**PVPM1000X
PVPM1040X
PVPM1500X
PVPM1540X**



PVPM1100C



**PVPM系统(与PC连接)
可在线长期监控**



最佳电站入门
多种设计提供
最高性价比之
产品规格

德国Dortmund应用科技大学, Dr. Wagner教授所开发量测技术, 使用 4-wire measurement 搭配相同材质之 ISET SENSOR 减少SR Mismatch, 使得太阳能模块在安装现场可以PVPM系统准确量测 Peak Power PPK, RS, RP及I-V特性曲线包括: Vpmax, Ipmax, Pmax, Voc, Isc, FF, Tmod, Eeff. (精确度<0.08% for I-V, < 5% for Peak Performance, reproducement +/- 2-3%, Accuracy of the a/d converter 0.08% of FSR±1 LSB PVPM系统完全符合STC测试条件, 自动依据 Irradiance/Temp.感测数据, 进行必要修正并以内建LCD显示所有量测结果。PVPM系统可联机PC以软件规划重复多次量测, 以平均取得更精确结果

EmaZys Technologies

HTTR

太阳能电站故障分析仪
Solar PV testing products
Z300 PVT



最佳光伏电站运维工具!

- 快速! 60s完成组串测试
- 精准! 诊断偏差 不超过一块组件
- 定位! 线缆断点, 绝缘不良点, Bypass Diode短路/断路故障点
- 监控! 查找不定时发生故障

新技术:

最先采用IS (阻抗分析) 测试光伏组件/阵列

WCT-120MX&Suns-VocMX



WCT-120MX

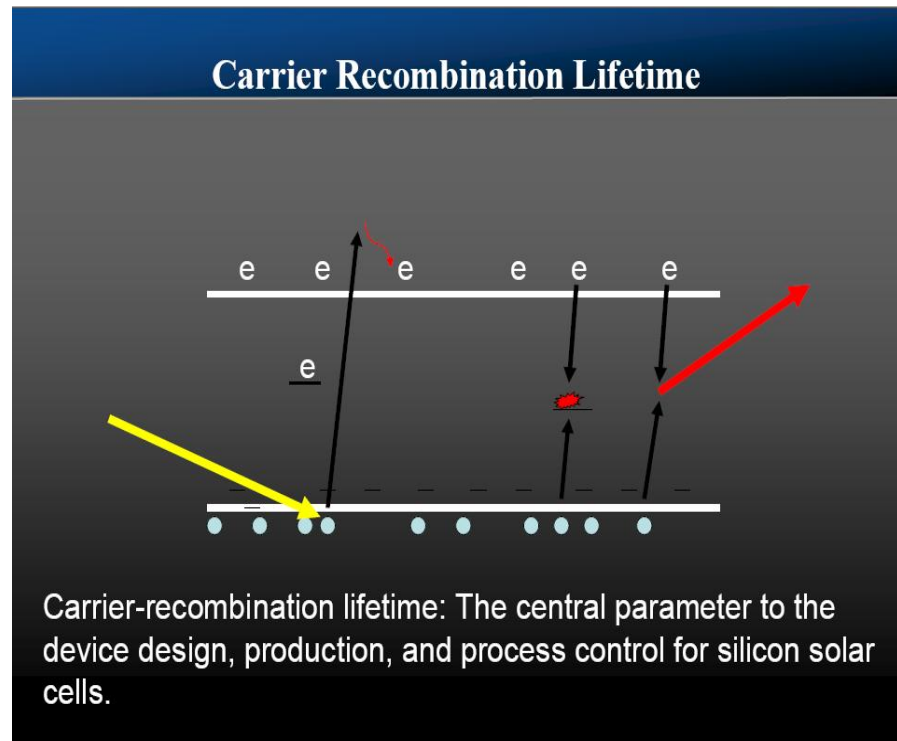


Suns VocMX

Lifetime 原理

载子寿命 (τ) :

- 过剩载流子的平均复合时间
- 决定扩散长度 $L = \sqrt{D\tau}$
- 高效率需要高寿命



寿命量测的目的

- 晶体生长后：监控原料污染的过程，坩埚的污染，生长条件不良。
- 切片之后：保证硅片质量为了出售或购买。
- 掺杂剂扩散后：监测掺杂剂扩散的质量，检查化学污染，确认体积寿命，估算最终的太阳能电池效率。
- 氮化物沉积：监测氮化物质量，优化烧结参数和表面钝化质量。
- R&D：用于表征散装寿命和表面钝化。输入数据用于单元设计和过程优化。

什么影响体寿命

- 金属杂质：Fe，Cr，Al，Au，Cu等。

可以从原料，坩埚，气体污染，化学污染。

其他缺陷：在硼CZ中，B：O对，氧析出

结晶缺陷：位错，晶界

什么决定量测寿命

- 体寿命
- 表面复合
- 硅片厚度
- 掺杂-扩散区域复合
- 在硅片或者硅块过剩载子的扩散

量测寿命=?

量测得到的lifetime并不是Si材料真实的体寿命，而是Si材料的有效寿命 effective lifetime:

1) 形成PN结前

$$\frac{1}{\tau_{eff}(\Delta n)} = \frac{1}{\tau_{bulk}(\Delta n)} + \frac{S_{front}(\Delta n) + S_{back}(\Delta n)}{W}$$

少子寿命大小主要与存在于材料内部的各种复合有关:

1) **Auger recombination**: Characterized by the Auger lifetime ζ_{Auger} . The Auger lifetime depends only on the doping type and concentration in a wafer, and the injection level, or excess carrier concentration Δn

2) 形成PN结后

$$\frac{1}{\tau_{eff}(\Delta n)} = \frac{1}{\tau_{bulk}(\Delta n)} + \frac{J_{oe front} + J_{oe back}}{qn_i^2 W} [N_A + \Delta n]$$

2) **radiative recombination**: Characterized by the radiative lifetime ζ_{Rad} . The radiative lifetime also depends on the doping type and concentration in a wafer, and the injection level, or excess carrier concentration Δn , but is almost always much larger than the Auger lifetime, meaning the radiative lifetime can be neglected.

3) **SRH recombination**: characterized by the SRH lifetime ζ_{SRH} . It is determined by how many impurities and defects are present in the sample, their recombination 'strength' (energy levels and capture cross sections), and the doping and injection level.

4) **surface recombination**: Often characterized as the surface recombination velocity S (units cm/s), rather than as a lifetime value

5) **emitter recombination**: Characterized by a saturation current density J_0 . This parameter actually represents the combined effects of Auger, SRH and surface recombination in the highly-doped region

$$\frac{1}{\tau_{bulk}} = \frac{1}{\tau_{Auger}} + \frac{1}{\tau_{Rad}} + \frac{1}{\tau_{SRH}}$$

Measurement Methods Of Lifetime

1) 基于光电导技术测量方法: PCD

瞬态光电导: TPCD

稳态光电导: SSPCD

准稳态光电导: QSSPCD

2) 基于表面光电压技术测量方法: SPV

3) 调制自由载流子吸收测量方法: MFCA

4) IR载流子浓度成像技术测量方法: CDI

5) 光束诱导电流测量方法: LBIC

6) 电子束诱导电流方法: EBIC

基于光电导方法量测少子寿命

稳态光电导：SSPCD

瞬态光电导：TPCD

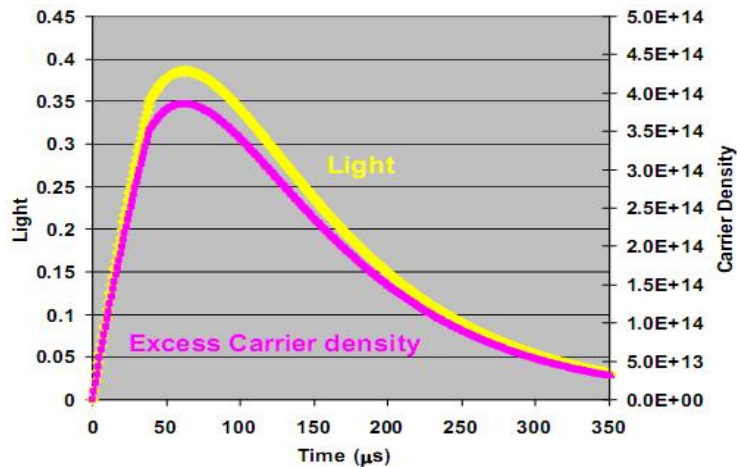
准稳态光电导：QSSPCD

Steady-State Excess Carrier Lifetime



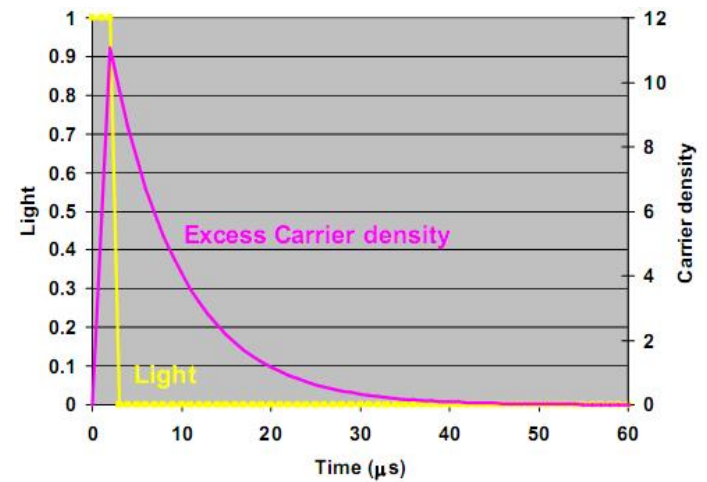
$$\tau_{eff}(\Delta n) = \frac{\Delta n}{G}$$

Generalized Quasi-Steady-State Excess Carrier Lifetime



$$\tau_{eff}(\Delta n) = \frac{\Delta n(t)}{G(t) - d\Delta n(t)/dt}$$

Transient Excess Carrier Lifetime



$$\tau_{eff}(\Delta n) = -\frac{\Delta n(t)}{d\Delta n(t)/dt}$$

Measurement software Analysis Mode

The procedure in the Quick Start guide describes a Quasi-Steady-State lifetime measurement using the Generalized (1/1) analysis. This is the most robust and widely applicable measurement type. As a recommendation, for lifetimes less than 200 μ s, the Generalized (1/1) analysis mode is recommended. For lifetimes greater than 200 μ s, the Generalized (1/64) analysis mode, with a transient flash is recommended. If, however, the lifetime is greater than approximately 800 μ s, it is often better to perform a measurement in the Transient analysis mode.

Illumination mode	Analysis Type	Lifetime range
Quasi-Steady-State (flash setting 1/1 for old hardware configurations, TTL for hardware configurations with Quantum flash parts, and N/A for hardware configurations found in this manual)	QSS Generalized (1/1)	< 200 μ s < 200 μ s
Transient (flash setting 1/64 for old hardware configurations, TTL for hardware configurations with Quantum	Transient Generalized (1/64)	> 800 μ s > 200 μ s and < 800 μ s

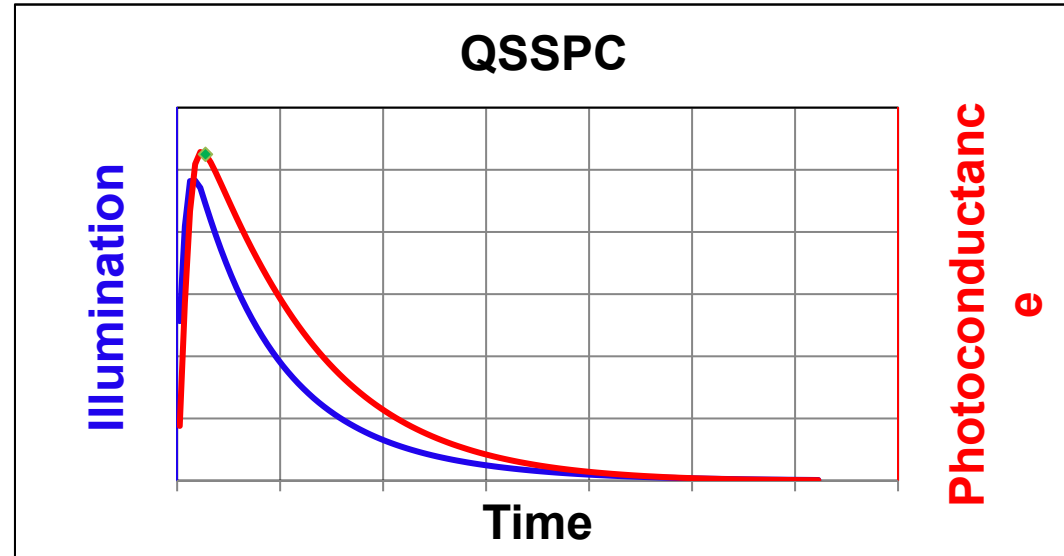
Measurement Theory - QSS

- Quasi-Steady-State (QSSPC):

$$\tau_{QSS} = \frac{\Delta n(t)}{G(t)}$$

$$\tau_{flash} \gg \tau_{Si}$$

- Flash decay time (200Ws mode) is $\sim 2\text{ms}$
- Suitable for lifetimes less than $200\mu\text{s}$



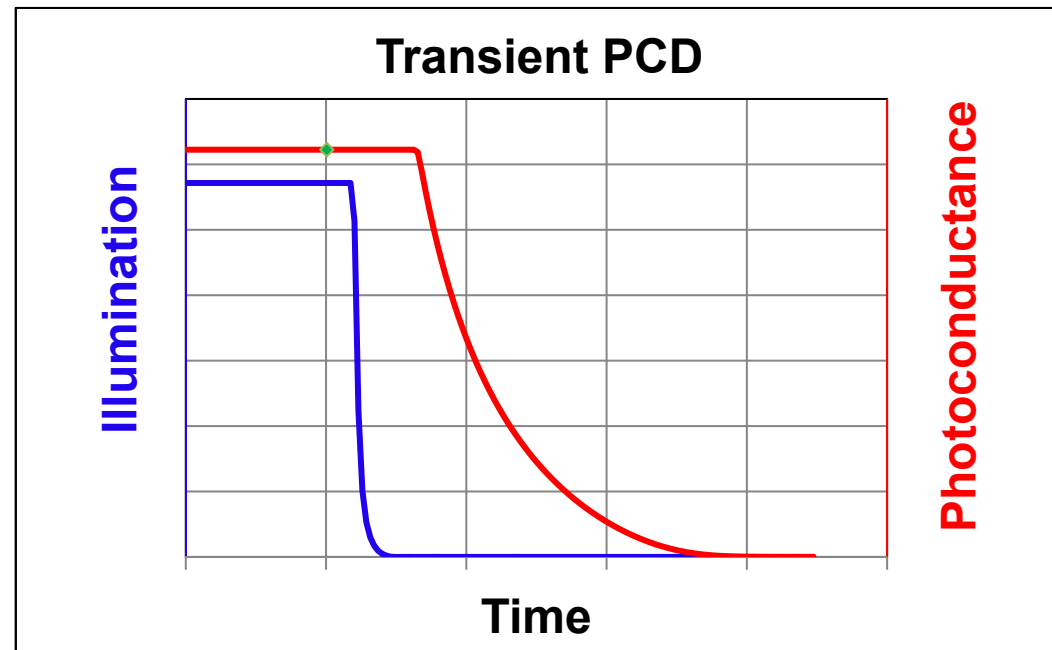
- Requires estimate of photogeneration (G) in sample
- G calculated from reference cell signal

Measurement Theory - Transient

- Transient PCD:

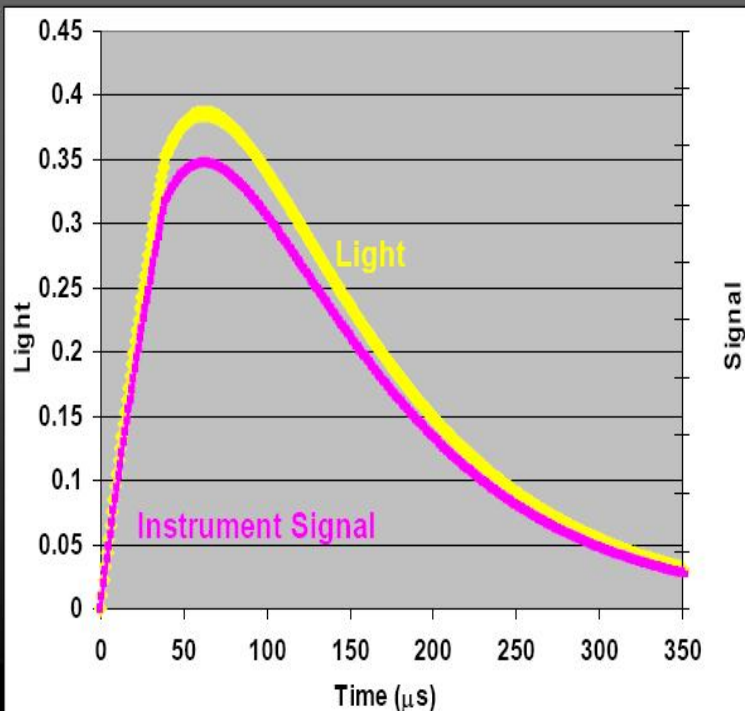
$$\tau_{trans} = \frac{-\Delta n}{d\Delta n/dt}$$

- Xenon flash cutoff time $\sim 40\mu\text{s}$
- Suitable for lifetimes greater than $100\mu\text{s}$



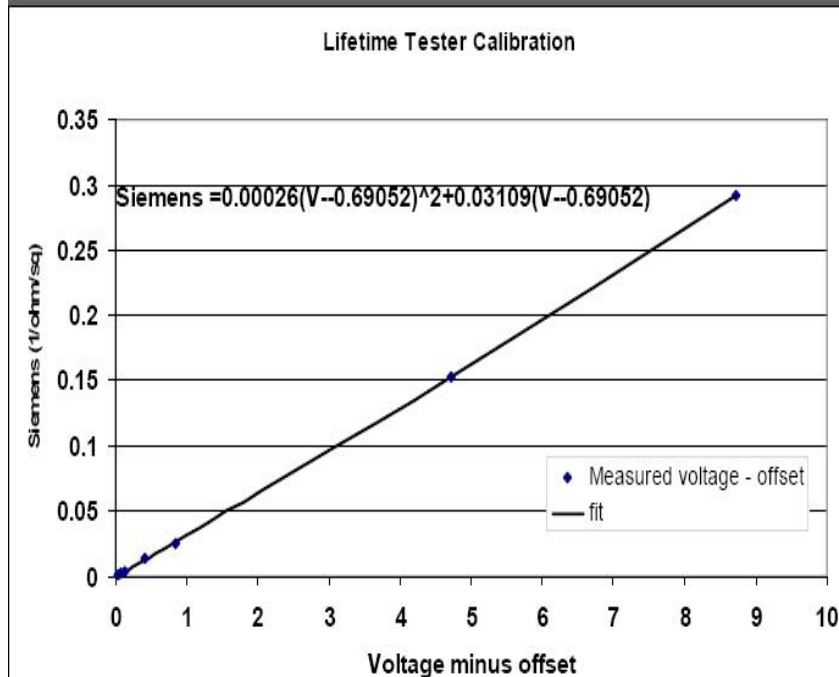
WCT-120 Measurement Process

Step 1: Take data.



1) 注入光辐照待测物时同时量取raw data

Step 2: Conductance Calibration: Traceable to 4-point-probe



2) 利用标准件校准，把raw data转换为物理量光导-Siemens, 1/ohm/sq)

WCT-120 Measurement Process

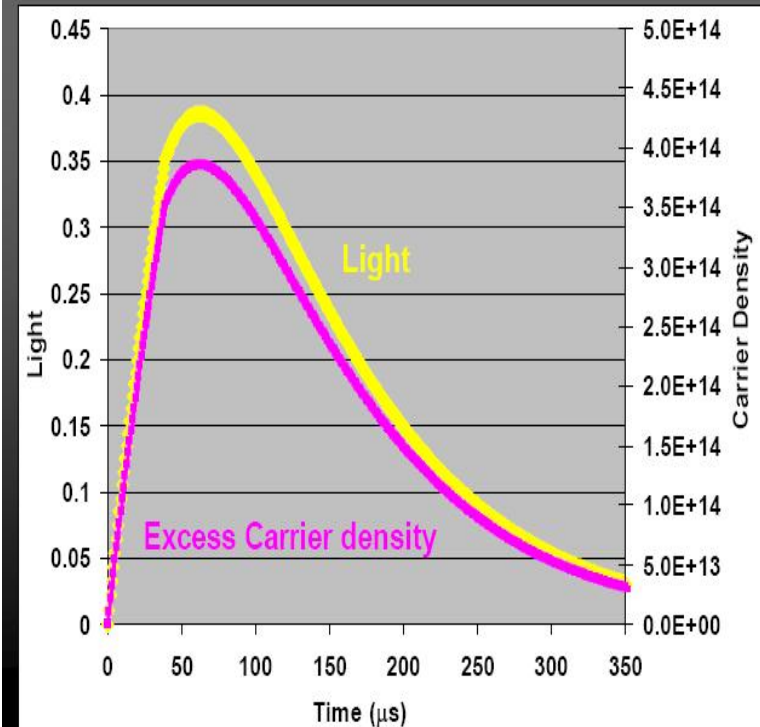
Step 3: Photoconductance & Carrier Density

- The mobility equation converts the conductivity to an average carrier density.

$$\Delta n = \frac{\Delta \sigma}{qW(\mu_n(\Delta n, N_A) + \mu_p(\Delta n, N_A))}$$

3) 利用载子移动率，背景杂质浓度及光导公式计算过剩载子浓度与时间及光强光系

Step 4: Carrier density vs. time & light.



4) 计算所得到的载子寿命VS载子浓度

Comparing with other methods

Method	How is excess carrier density sensed?	Issues: Pros / Cons
RF-QSSPC	Eddy current sensing of Photoconductance Conversion to Δn using known mobility function	Simple calibration that is valid for a wide range of samples. Real, physical lifetime result. Requires mobility and photo-generation calculation or measurement. Low resolution
RF Transient	Eddy current sensing of Photoconductance. Conversion to Δn using known mobility function.	Simple calibration. Measures real, physical lifetime. Can be subject to trapping and DRM artifacts at low carrier density.
μ -PCD / MDP	Microwave reflectance or absorption sensing of photoconductance.	High-resolution mapping capability. Non-linear detection of photoconductance in some injection-level or dopant ranges, skin-depth comparable to sample thickness in some cases. DRM and trapping artifacts at low carrier density. Does not measure physical parameter.

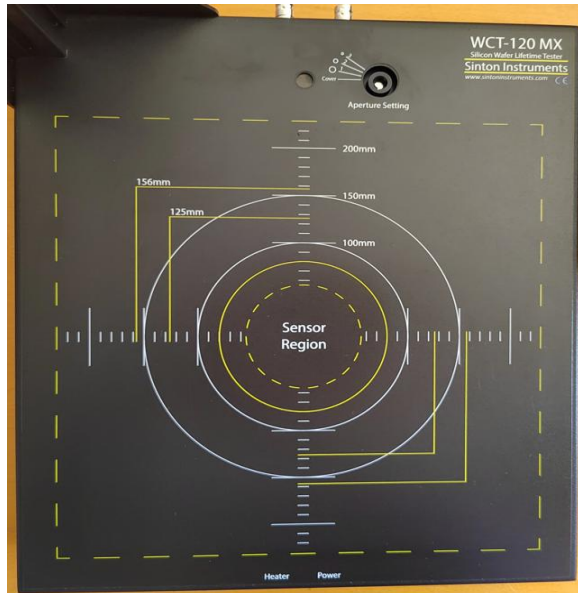
Microwave- PCD

- Microwave Sensor:
 - Short wavelength illumination (905nm)
 - Sensor is non-linear and not calibrated
- PV9 Standard:
 - “Therefore, this test method does not purport to measure excess carrier lifetime...” (SEMI PV9-1110, www.semi.org)
 - “...the result of this test method is not a real physical property of the test specimen...” (SEMI PV9-1110, www.semi.org)
 - “The method is not suitable for measurements in bricks or ingots where the decay time is greater than 10 μ s due to the diffusion of carriers into the material beyond the measurement depth of the microwaves used” (SEMI PV9-1110, www.semi.org)

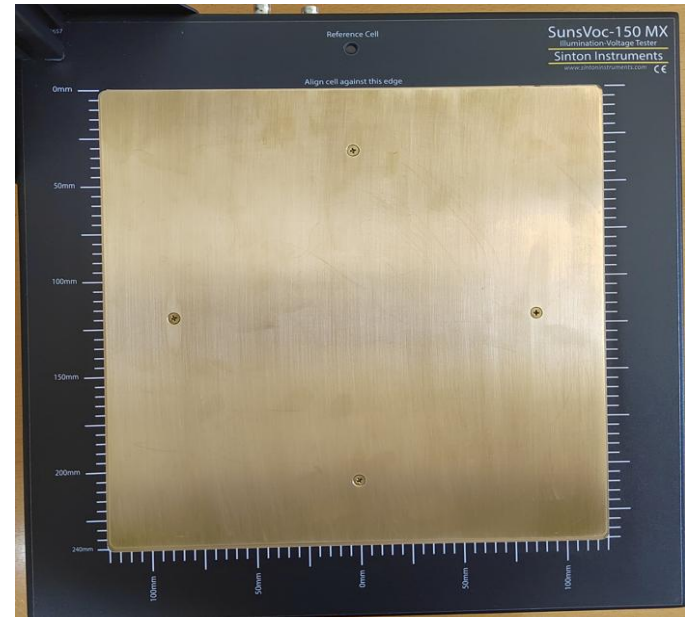
Comparison Chart

Feature/Parameter	Eddy Current QSSPC, Transient PCD	Microwave uPCD, QSS-uPCD
Measurement Area 测试面积	Area Average(10-40mm)	1mm
Sensor Depth Sensitivity 测试深度	3000um	100-1000um
Illumination Wavelength 光源波长	> 1000nm (effective)	905nm(typical)
Illumination Absorption Depth 光源吸收深度	100-5000um	30um
Lifetime Measurement Range (Bulk Samples) 寿命测试范围（硅棒/硅块）	0.1us-15000us	<10us
Sensor Saturation Lifetime (Unpassivated Bulk Samples) 传感器饱和和寿命（未钝化的硅棒/硅块）	>10000us	~8us
Calibrated Conductance Sensor 校准的电导传感器	✓	—
Real, Physical Parameter Measurement 物理参数量测	✓	—
Injection Dependent Lifetime Measurement 有注入浓度的寿命量测	✓	—
Calibrated Emitter Saturation Current (Joe) Measurement 校准的发射极饱和和电流量测	✓	—
Extensive Technical Research Database for PV industry PV行业大量的技术研究数据库	✓	—
Accurate Measurement without Surface Passivation 未经表面钝化的量测精度	✓	—
Results Reproducible and Comparable Between Users 测试结果可再现可比较	✓	—
Designed For PV Industry 为PV产业设计	✓	—

硬件部分



WCT-120MX stage



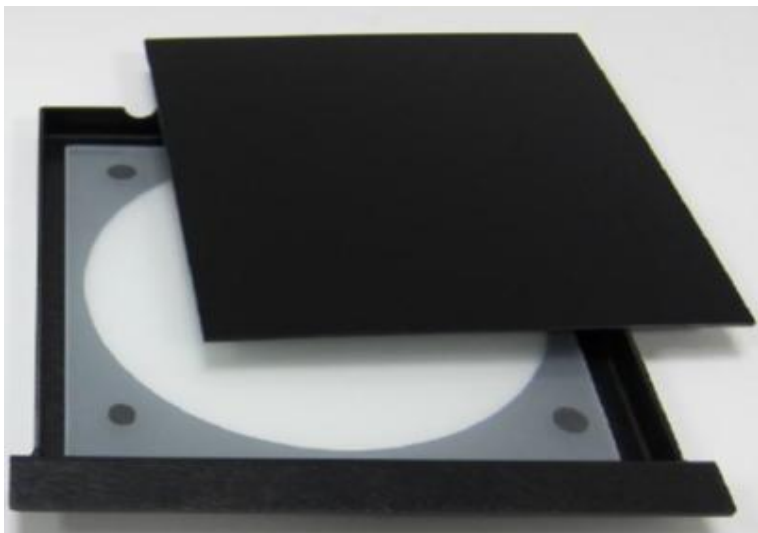
Suns-VocMX stage



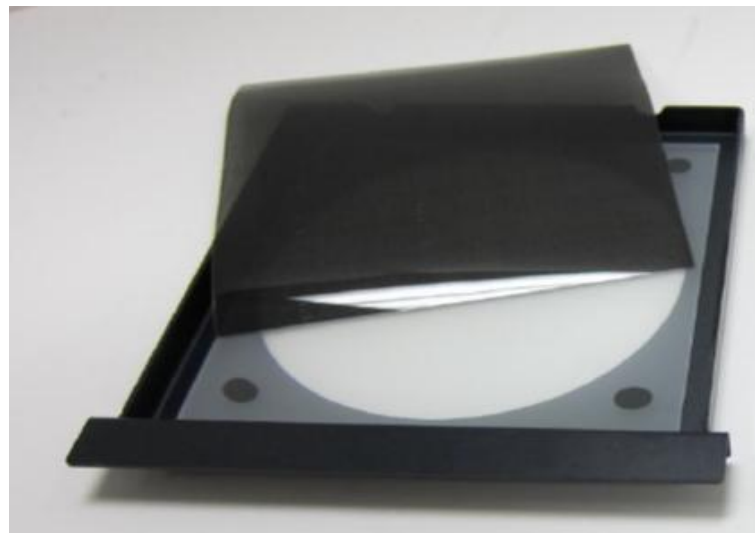
WCT-120MX flash head



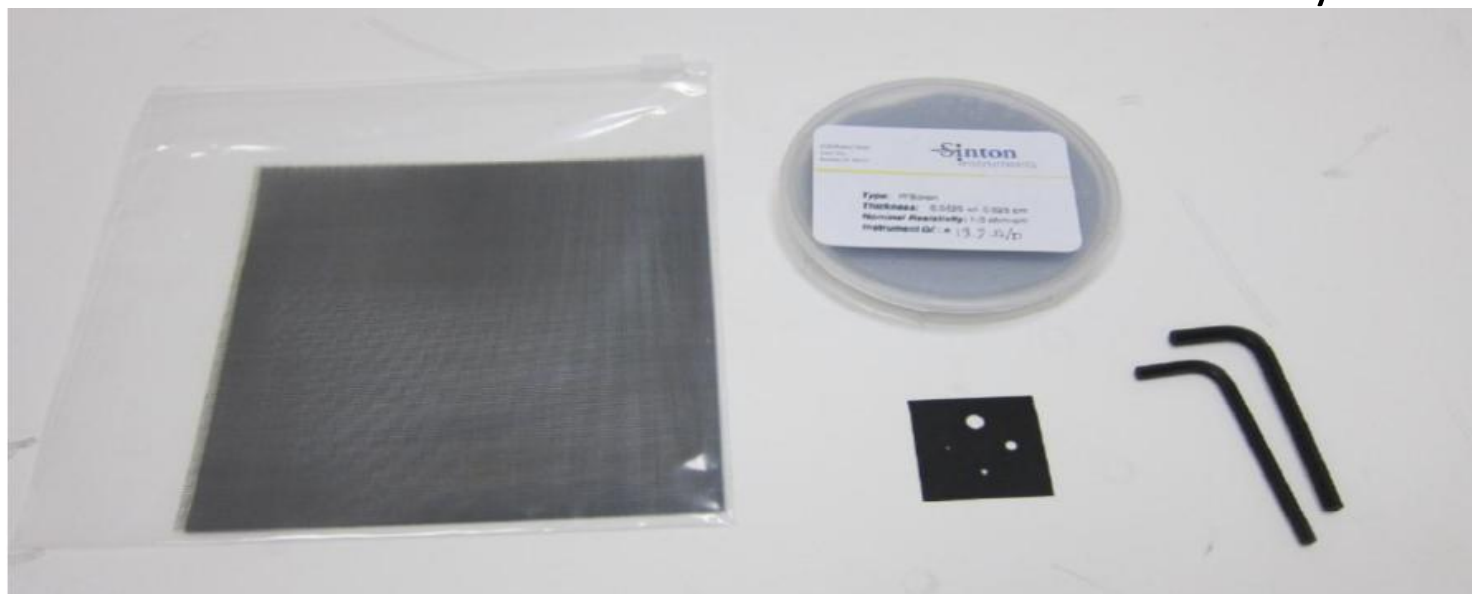
Suns-VocMX flash head



WCT-120 flash tray (IR pass filter)



Suns-voc flash tray (ND filter)



ND Filters, Reference Cell Aperture, Allen Keys, Reference Wafer



Signal connector box



National instrument cable 68 pins



Ref (red) , PC (blue) , Trigger cables (green)



Needle Probe (red) , Thermocouple Cable (yellow) , DIN Heater Cable (white) (Suns-Voc only)



FPS-300 Power supply

68-pin National Instruments Cable to Signal connector box



WCT-120软件部分



1、按钮：

Zero Instrument: 在量测或重新打开软件时进行设备归零，能够重置电导校准的基准电压

Measure Sample: 调整DAQ输入范围（ZOOM In/Out）

Generate SEMI PV13 Report: 生成PDF报告，在报告工作表中

Log to Summary: 将量测结果发送到同一个摘要文件

Save Graph Data to Text File : 将图表数据转化成Txt文件

Rescale Graph:重新绘制寿命与载子浓度关系图

2、样品参数

Sample Name: 设置为“true”，Excel文件名称将以Sample Name为命名

Resistivity: 电阻率

Substrate Type: 选择p型或n型

3、分析参数

optical constant: 0.7 as cut wafer, 1.0 AR coating wafer。

Lifetime Specified MCD (cm-3): p型用 1×10^{15} ，n型用 5×10^{14}

Jo Specified MCD:指定少数载流子浓度下的饱和电流密度。

Bias Light: 偏置光，用来补偿trap捕捉效应。

Analysis mode: QSS, Transient,generalized(1/1), generalized(1/64)

4、量测结果

Lifetime at Spec. MCD (μs): 瞬态（量测寿命与估计的体寿命相同）、准稳态（量测寿命小于估计的体寿命）

Total Sheet Resistance(Ω/sq):方块电阻值

Measured Resistivity($\Omega\text{-cm}$):电阻率

J_0 at 25°C (A/cm^2):饱和电流密度

Estimated Bulk Lifetime (μs): 估计体寿命

J_0 Fit R_2 -给线性回归方程拟合优度来进行最佳的 J_0 拟合

Lifetime at Implied V_{mp} (μs): 最大功率点对应的少子寿命值

Min and Max MCD (cm^{-3}): 指定载子浓度在这两值之间

Bias point CD (cm^{-3}): 偏置光相对应的载流子浓度

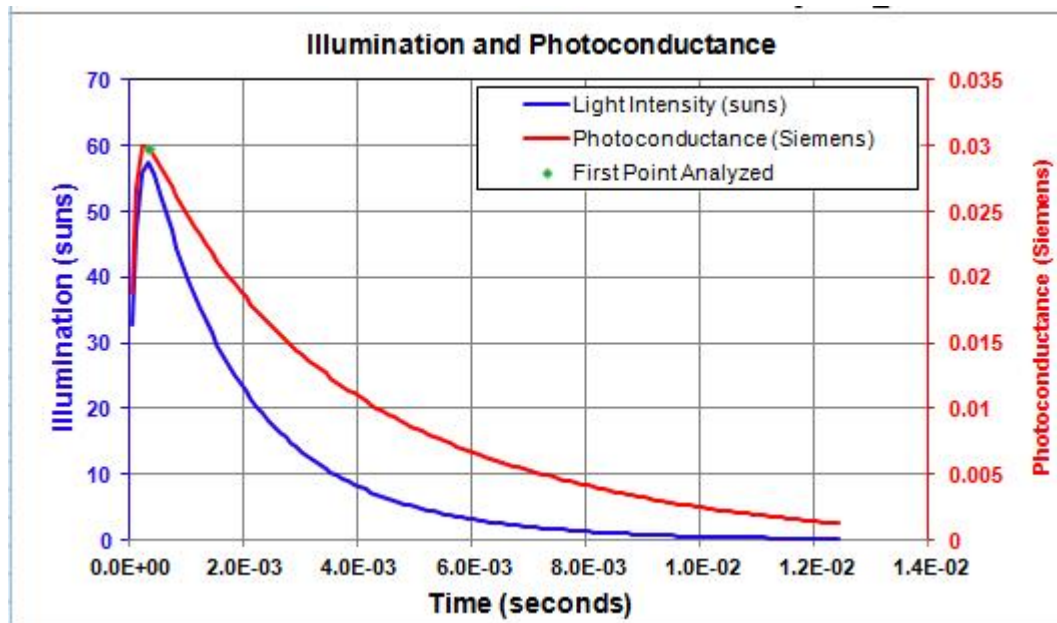
Trap Density (cm^{-3}): 偏置光相对应的陷阱密度近似值

Doping (cm^{-3}): 通过电阻率和掺杂类型得出

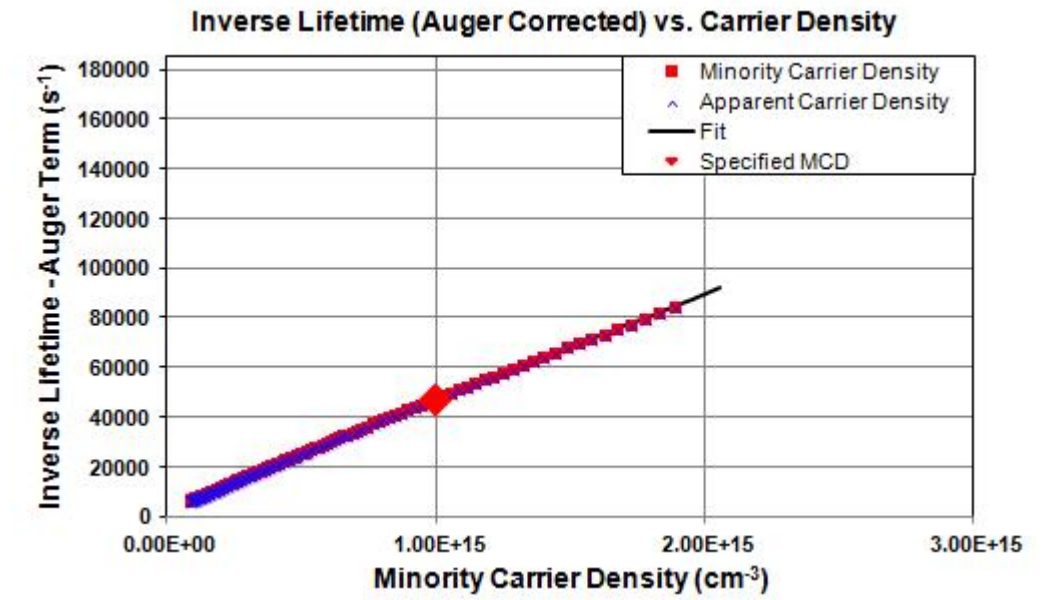
1Sun Implied V_{oc} (V):1Sun下的 V_{oc}

Implied FF(%): 填充因子

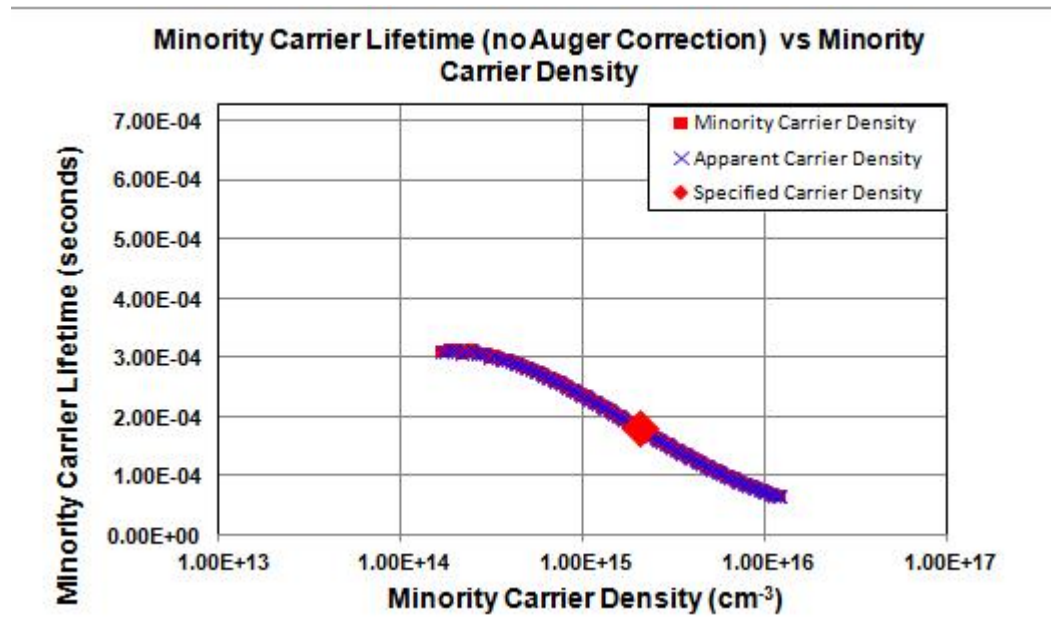
测量曲线的解释



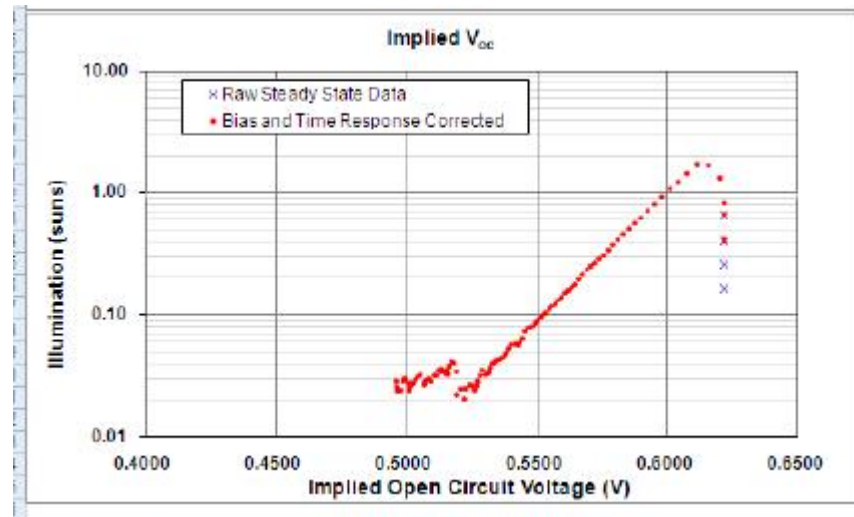
此图为raw data随着时间的变化图。红色：光电导（单位西门子），蓝色：光强度



此图为lifetime的倒数（俄歇复合被剔除）和过剩载流子浓度之间的关系图



少子寿命（俄歇复合没有被修正）与过剩载流子的浓度之间的对应关系



Implied V_{oc} 与辐照强度之间关系

The implied V_{OC} is calculated via the expression:

$$V_{oc} = \frac{kT}{q} \ln \left(\frac{np}{n_i^2} \right)$$

SunsVoc 软件部分



1、按钮

Measure Sample – 此按钮用来开始一次 Suns-Voc 量测， 点击此按钮后会跳出输入样品名字窗口（此窗口可以在设定面板进行设定在量测时不跳出）， 点击 “OK”后即触发一次量测， 点击 “cancel”取消此次量测。

Load Recipe – 导入配置文件（recipe field）

Save Recipe – 保存配置文件（recipe file） .

Load Result –导入量测结果进行重新分析， 软件的执行程序可以安装在其他电脑中并工作在模拟模式， 模拟模式下的软件可以用来导入量测结果并对量测结果进行再分析。

Save Result – 保存量测结果。

Save Graph Data to Text File – 将图形数据(lifetime vs. MCD and Implied Voc保存成txt格式文件。

Log to Summary –量测后点击此按钮会将主要量测参数保存在Summary文件中， 此功能只在auto summary功能被取消掉才使用。

Cancel Routine – 按此按钮则取消此次量测

Log In As Admin – 登录管理， 可以设定密码。 默认没有密码

Lock Software – 锁定软件， 直到下次登录后

Tool Status – 状态栏， 显示设备状态

Loaded Recipe – 显示目前使用的配置文件

Error Description – 显示软件报警信息， 一些常见报警信息如下

Re-zero Instrument – 此报警信息表明设备已经超过24小时没有进行

Zero Instrument操作或者空气电压的基线已经超出了正常范围。处理此报警信息需要进行重新 “Zero Instrument” 操作

Saturated Reference Cell – 此报警信息表明用来量测辐照强度的参考电池片被饱和了， 抬高灯头将会减小辐照强度并消除此报警信息， 如果用户需要非常高的辐照强度（由于非常低的少子寿命的样品）， 请参考使用 **reference cell aperture**。

2、样品参数

Batch ID- 批次数列号表明样品是属于哪一批次的，当结果被保存会以 “Batch ID – Sample ID.ltr” 格式保存

Sample ID – 样品ID，当结果被保存会以 “Batch ID – Sample ID.ltr” 格式保存

Comments – 可以书写评论语句在此区域

Jsc (A/cm²) –此值为电池片的电流密度，可以通过独立的IV测试仪测出，或者可以填写一估计值。注意，一般情况下填写估计的标称值即可。

Number of Cells – 即将被量测的电池片的数量

Thickness (cm) – 样品的厚度，单位为cm

Base Resistivity (Ω -cm) –样品的基体电阻率， 此处需要填写精确的电阻率值而不是估计的标称值， 此值主要是用来计算少子寿命。 IV曲线的计算无此值无关。

Sample Type –样品的基底的类型（P 或者 N），用来计算掺杂浓度和迁移率。

Analysis Mode – 此处可以选择分析模式 Generalized 模式和 QSS 模拟， Generalized 模式应该用在有高电容效应的晶硅电池片上， 其他材料可能会需要用 QSS 模式。

3、量测结果

Voc (V) – 1 sun 下的Voc值， 其他设备量测的Voc值与此处量测到的Voc值差主要在于温度的差异。

Pseudo Vmp (V) – 理论上最大功率点处的电压值

Pseudo Jmp (A/cm²) – 理论上最大功率点处的电流值， 此值与填入的Jsc值有关

Pseudo Pmp (A/cm²) – 理论上的最大功率点， 此值与填入的Jsc值有关

PFF – 理论上的电池片填充因子（去除串联电阻的影响）

Pseudo Efficiency – 理论上的电池片效率（去除串联电阻的影响）

Apparent Rs (Ω -cm²) – apparent 的串联电阻

Ideality (n) @ 1 sun – 1 sun条件下的理想因子， 较低的并联电阻会导致较高的理想因子

TIdeality (n) @ 0.1 sun -0.1 sun条件下的理想因子， 0.1sun接近最大功率点。较低的并联电阻会导致较高的理想因子

Voc @ 0.1 sun (V) – 0.1 sun 条件下的Voc
This is the Voc measured at 0.1 sun illumination.

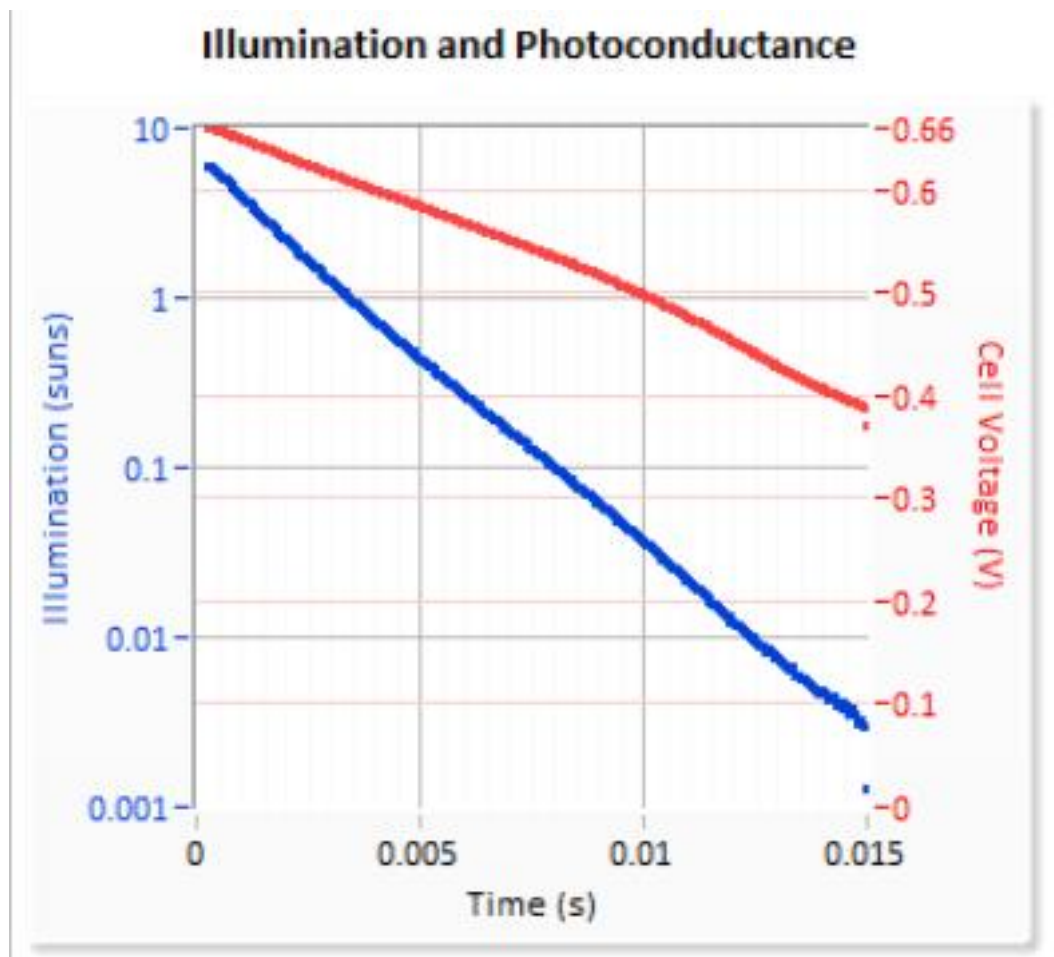
Jo1 (A/cm²) – 双二极管模型中J01

Jo2 (A/cm²) – 双二极管模型中J02

Fitted Rsh (Ω -cm²) – 拟合的并联电阻值.

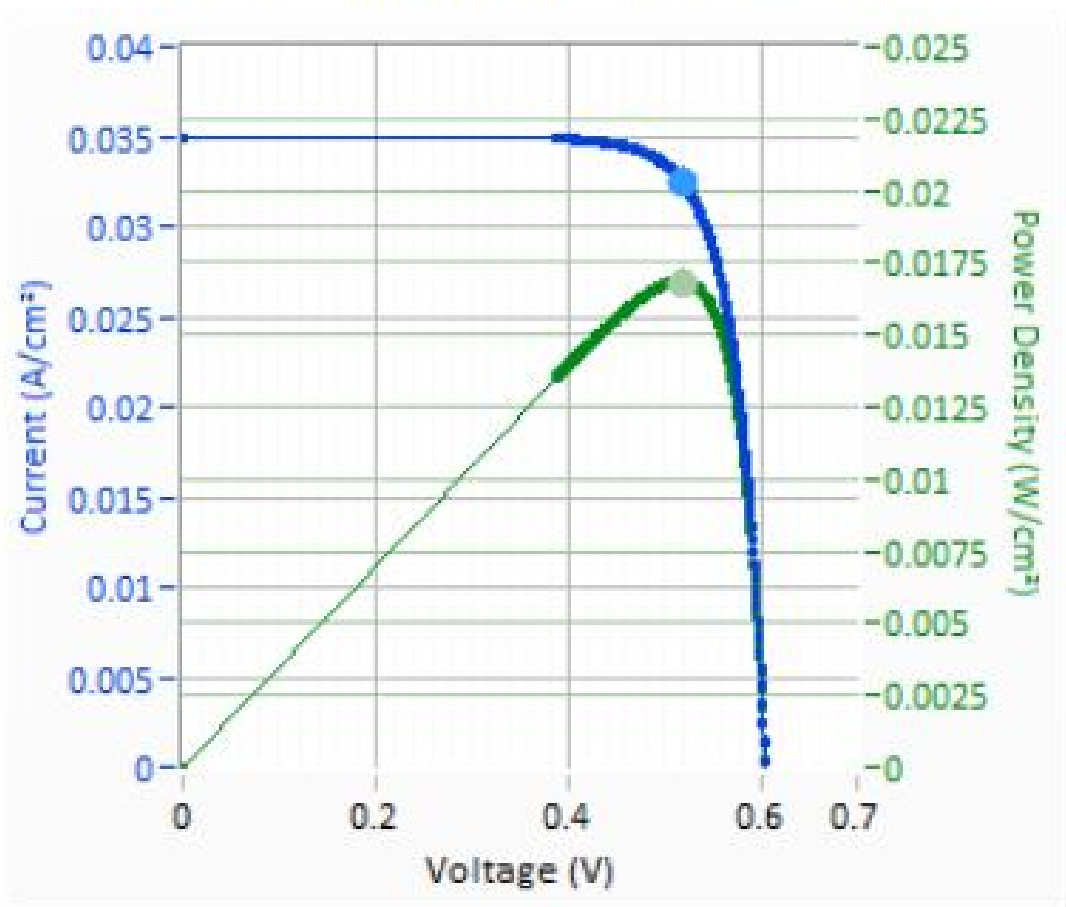
Lifetime @ pVmp (μ s) – 理论上的最大功率点处的少子寿命值

测量曲线的解释

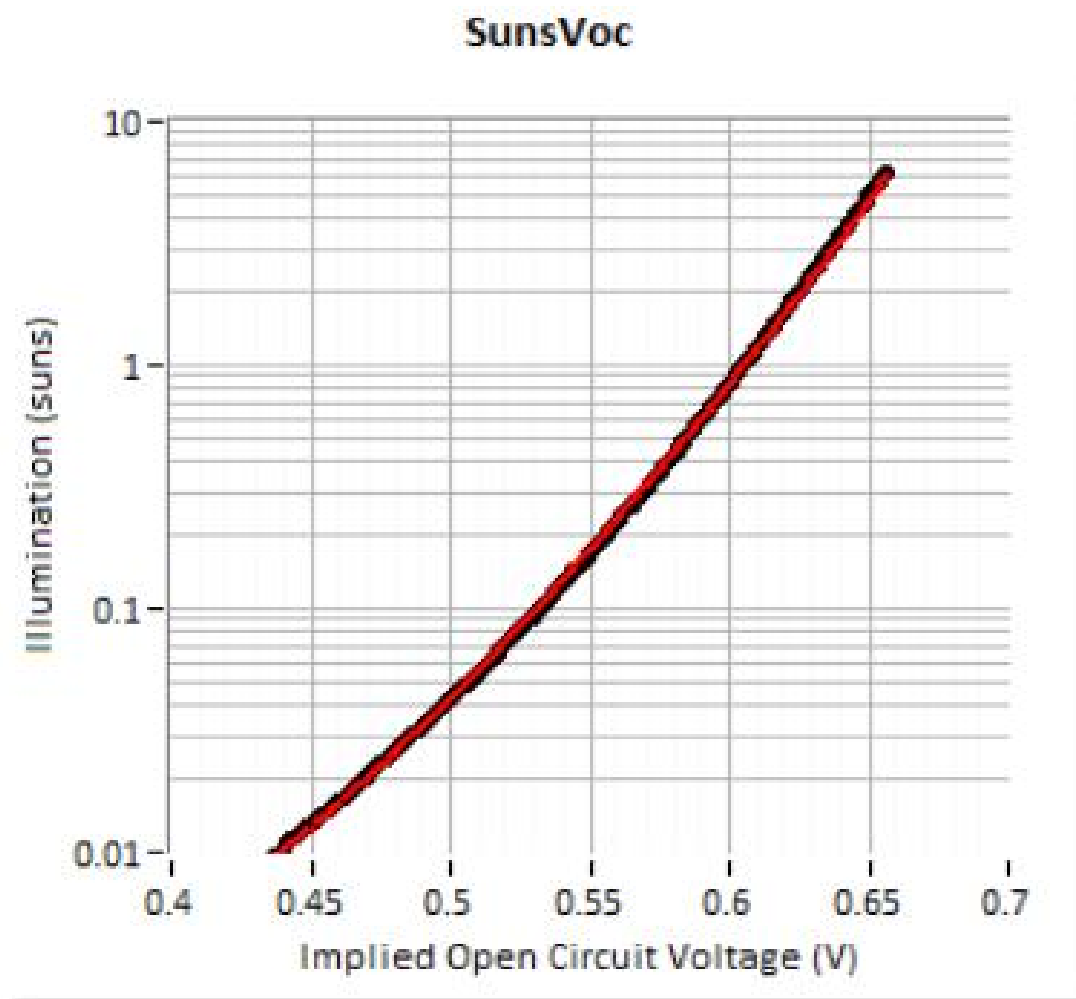


此图为光强度（Suns）以及开路电压（V）随时间变化曲线

Pseudo Light IV Curve (no R_s effect)

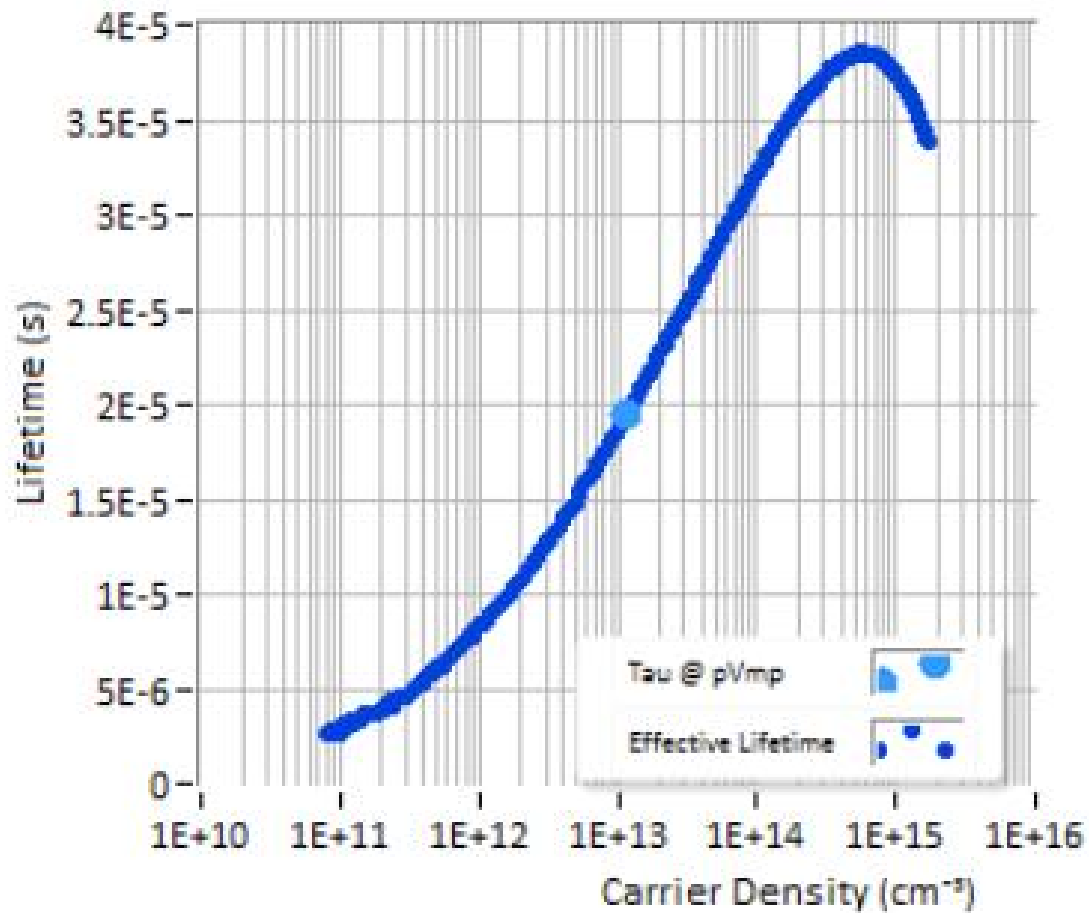


此图为理论IV曲线（不考虑 R_s 影响）和理论功率曲线



此图为量测的 Suns-Voc 曲线和双二极管拟合数据曲线

Lifetime vs. Carrier Density



此图为有效少子寿命 vs MCD 曲线，以及在最大功率点处少子寿命值

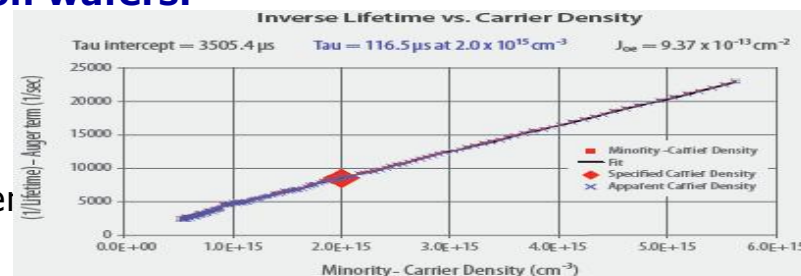


WCT-120MX
少子寿命检测仪

Best available calibrated measurement of carrier recombination lifetime. Widely used for both monocrystalline and multicrystalline silicon wafers.

量测功能:

- Lifetime
- Resistivity
- Emitter saturation current density
- Trap density
- One-sun Voc



Sinton少子寿命分析仪依据校准后的光导变化量及可追溯光强激发条件，量测得到具有物理意义正确数据

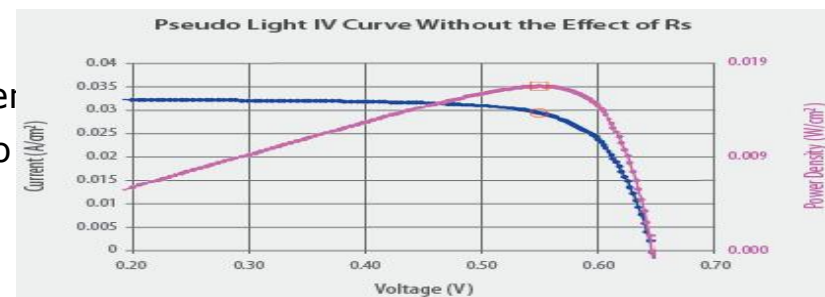


Suns-VocMX
电池片IV曲线分析仪

Perfect for paste-firing optimization and process control. Open-circuit method indicates the upper bound for any solar cell precursors after junction formation.

量测参数:

- Implied I-V curve at open circuit : materials limit to efficiency
- Pseudo-efficiency
- Pseudo-fill-factor
- Two-diode analysis
- Shunt value



Suns-Voc显示光照下的近似IV曲线(不考虑Rs影响)

北京华通特瑞光电科技有限公司

Beijing Hua Tong Terui Photon Technology Co.,Ltd.

谢谢！

北京市朝阳区北辰东路8号汇园国际公寓F座1702室
Rm 1702,Bldg.F.Huiyuan International Apartment No.8,Beichen
E.Rd,Beijing,China 100101
北京办公室联系人：张有义
福州办公室联系人：陈文波
邮箱： support@htterui.com