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中科院物理所铜锌锡硫硒薄膜太阳能电池新世界纪录

太阳能电池大规模应用和光电转换效率提升具有重要的国家能源战略和经济价值。铜锌锡硫硒(CZTSSe)太阳能电池是一种重要的新型无机薄膜太阳能电池，具有材料组成元素丰度高、环境友好、成本低、产业技术兼容等诸多优势，且具有最大的效率提升空间，是清洁能源研究领域的重要方向。提高CZTSSe太阳能电池效率是现阶段该领域发展的核心，是国内外团队共同追求的目标。中国科学院物理研究所/北京凝聚态物理国家研究中心清洁能源实验室孟庆波团队自2016年以来开展CZTSSe薄膜太阳能电池研究。通过对CZTSSe材料和器件更深入的物理和化学认识，该团队在过去数年已经取得了诸多进展。先后报道了CZTSSe电池电荷损失和缺陷性质分析、环境友好水溶液体系金属-分子配位调控、薄膜分层结晶和生长模式调控、体相缺陷协同调控等系列成果(Adv. Mater. 2022, 10.1002/adma.202202858；Adv. Energy Mater. 2021, 11, 2102298；Nano Energy, 2020, 76, 105042；Sci. Bull. 2020, 65, 738；Nano Energy 2020, 89, 106405；Joule, 2020, 4, 472)。

最近，该团队在高效率CZTSSe薄膜太阳能电池研究方面再次取得重要进展，获得了13.6%的电池认证效率。该成果刷新了CZTSSe电池效率世界纪录，并被著名太阳能电池专家 Martin Green教授主编的国际权威电池效率统计表“Solar cell efficiency tables (Version 60)”收录。

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检测结果/说明：
Results of Test and additional explanation.

1 标准测试条件 STC Standard Test Condition (STC)：

总辐照度 Total Irradiance：1000 W/m²

被测电池温度 Temperature：25.0 ℃

光谱分布 Spectral Distribution：AM1.5G

2 STC 条件下测量数据

Measurement Data under STC

正扫 Forward Scan

测试次数 Test Times	I_{sc}（mA）	V_{oc}(V)	I_{MPP}(mA)	V_{MPP}(V)	P_{MPP}(mW)	FF(%)	η（%）
1	9.629	0.5359	8.609	0.4192	3.609	69.94	13.56
2	9.627	0.5365	8.618	0.4188	3.609	69.88	13.56
3	9.629	0.5377	8.626	0.4185	3.610	69.72	13.57
平均值 Average Value	9.628	0.5367	8.618	0.4188	3.609	69.85	13.56

反扫 Reverse Scan

测试次数 Test Times	I_{sc}（mA）	V_{oc}(V)	I_{MPP}(mA)	V_{MPP}(V)	P_{MPP}(mW)	FF(%)	η（%）
1	9.626	0.5378	8.563	0.4227	3.620	69.93	13.60
2	9.627	0.5396	8.571	0.4218	3.615	69.59	13.59
3	9.626	0.5372	8.563	0.4215	3.609	69.79	13.56
平均值 Average Value	9.626	0.5382	8.566	0.4220	3.615	69.77	13.58

失配因子 Mismatch factor: 1.011

图1. 电池效率认证报告

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SHORT COMMUNICATION

PROGRESS IN PHOTOVOLTAICS WILEY

Solar cell efficiency tables (Version 60)

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图2. 电池效率统计表“Solar cell efficiency tables (Version 60)”文章信息。

There are three new results in Table 2 (one-sun 'notable exceptions'). An efficiency of 25.3% is reported for a large-area (268-cm^2) n-type silicon cell with polysilicon on thin-oxide rear contact (aka TOPCon) fabricated by JinkoSolar[34] and measured by the Institute für Solarenergieforschung (ISFH). Using the amorphous-silicon/silicon heterojunction (HJT) approach, an efficiency of 25.5% is reported for another large-area (274-cm^2) gallium-doped p-type silicon cell fabricated by LONGi and again measured by ISFH. LONGi is reported as being convinced that this p-HJT cell route still has great potential for further development. An efficiency of 13.6% was measured for a 0.27-cm^2 $Cu_2ZnSnS_xSe_{4-x}$ (CZTSSe) cell[37] by the Institute of Physics (IOP), Chinese Academy of Science (CAS) and measured by NPVM.

图3. “Solar cell efficiency tables (Version 60)”中对中科院物理所取得新电池效率的描述。

TABLE 2 'Notable exceptions' for single-junction cells and submodules: 'Top dozen' confirmed results, not class records, measured under the global AM1.5 spectrum (1000 Wm^{-2}) at 25°C (IEC 60904-3: 2008 or ASTM G-173-03 global)

Classification	Efficiency (%)	Area (cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	Fill factor (%)	Test centre (date)	Description
Cells (silicon)							
Si (crystalline)	25.0 ± 0.5	4.00 (da)	0.706	42.7[a]	82.8	Sandia (3/99)	UNSW, p-type PERC[30]
Si (crystalline)	25.8 ± 0.5[b]	4.008 (da)	0.7241	42.87[c]	83.1	FhG-ISE (7/17)	FhG-ISE, n-type TOPCon[31]
Si (crystalline)	26.0 ± 0.5[b]	4.015 (da)	0.7323	42.05[d]	84.3	FhG-ISE (11/19)	FhG-ISE, p-type TOPCon
Si (crystalline)	26.1 ± 0.3[b]	3.9857 (da)	0.7266	42.62[e]	84.3	ISFH (2/18)	ISFH, p-type rear IBC[32]
Si (large crystalline)	24.0 ± 0.3[f]	244.59 (t)	0.6940	41.58[g]	83.3	ISFH (7/19)	LONGi, p-type PERC[33]
Si (large crystalline)	25.3 ± 0.4[h]	268.0 (t)	0.7214	42.07[i]	83.4	**ISFH (11/21)**	**Jinko, n-type TOPCon[34]**
Si (large crystalline)	25.5 ± 0.4[j]	274.3 (t)	0.7476	40.66[i]	83.8	**ISFH (11/21)**	**LONGi, p-type HJT**
Si (large crystalline)	26.6 ± 0.5	179.74 (da)	0.7403	42.5[k]	84.7	FhG-ISE (11/16)	Kaneka, n-type rear IBC[4]
Cells (III-V)							
GaInP	22.0 ± 0.3[b]	0.2502 (ap)	1.4695	16.63[l]	90.2	NREL (1/19)	NREL, rear HJ, strained AlInP[35]
Cells (chalcogenide)							
CdTe (thin-film)	22.1 ± 0.5	0.4798 (da)	0.8872	31.69[m]	78.5	Newport (11/15)	First Solar on glass[36]
CZTSSe (thin-film)	**13.6 ± 0.3**	**0.2661 (ap)**	**0.5375**	**36.18[l]**	**69.8**	**NPVM (5/22)**	**IOP, CAS[37]**
CZTS (thin-film)	11.0 ± 0.2	0.2339(da)	0.7306	21.74[k]	69.3	NREL (3/17)	UNSW on glass[38]
Cells (other)							
Perovskite (thin-film)	25.7 ± 0.8[n,o]	0.09597 (ap)	1.1790	25.80[i]	84.6	**Newport (11/21)**	**UNIST Ulsan[39]**
Organic (thin-film)	18.2 ± 0.2[p]	0.0322 (da)	0.8965	25.72[g]	78.9	NREL (10/20)	SJTU Shanghai/ Beihang U.
Dye sensitised	12.25 ± 0.4[q]	0.0963 (ap)	1.0203	15.17[d]	79.1	Newport (8/19)	EPFL[40]

图4. 最新太阳能电池效率世界纪录统计表“Solar cell efficiency tables (Version 60)”(单结电池部分）给出的太阳能电池性能详细参数和认证机构。