

AMANDA – A Materials Acceleration Platform for solution processed semiconductor research

Dr. Jens Hauch / Dr. Misha Sytnik

Helmholtz Institute Erlangen-Nürnberg / Forschungszentrum Jülich

08.02.22 || Jens Hauch || High Throughput Methods in Photovoltaics











What we do....

Photovoltaics

Big Data

Core Competencies

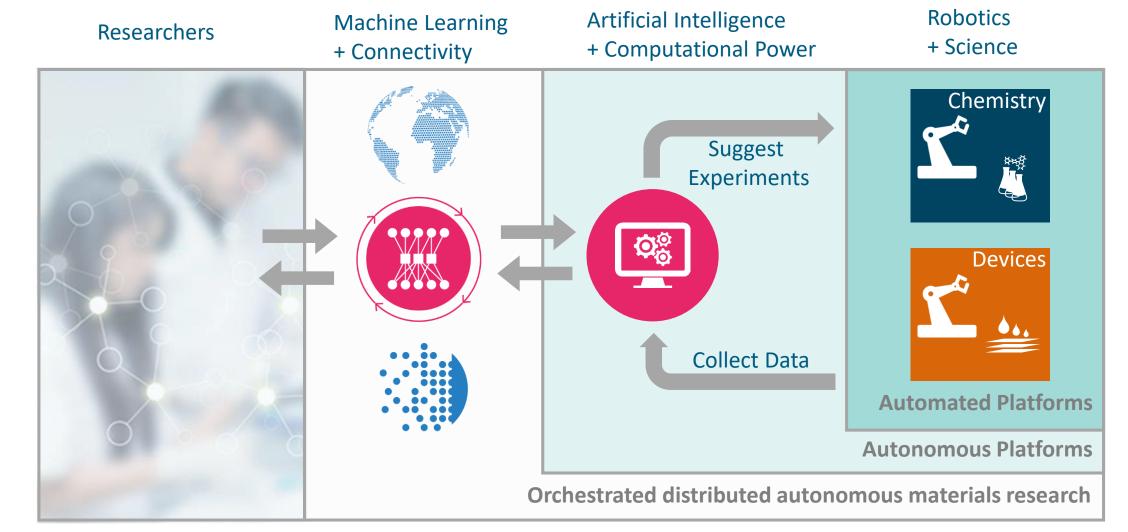
- Physics of Photovoltaics
- PV-Systems & Failure mechanisms
- Materials Science & Development
- Solution processable
 Semiconductors
- Imaging IR Methods

Big Data Methods

- Automation & Robotics
- Artificial Intelligence & Machine Learning
- Data Bases
- FAIR Data



Virtual Access Platform for Materials Discovery



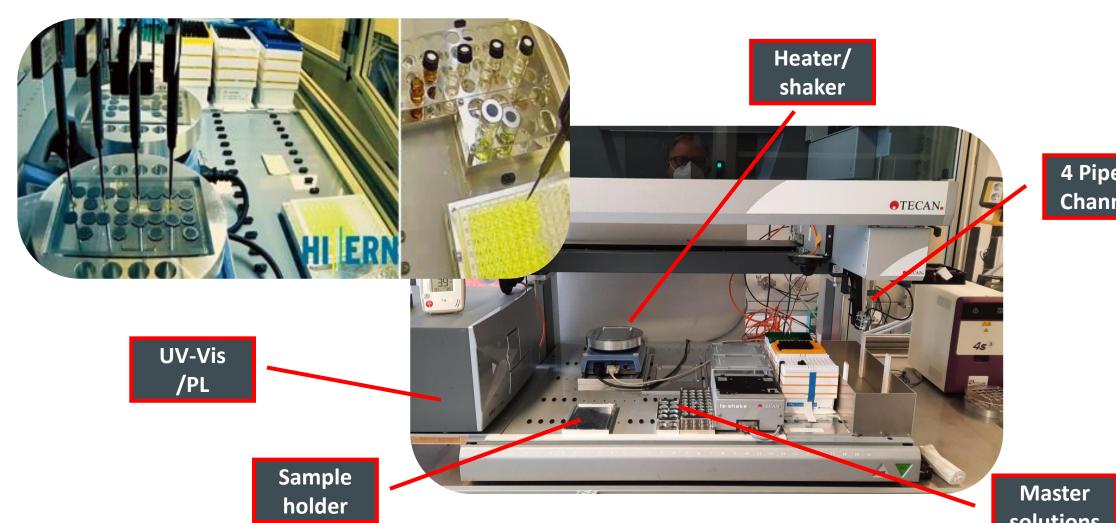


10x Acceleration of the discovery of complex functional materials





Automated Pipetting System and Spectrometer => Synthesis and Drop-casting



4 Pipette Channels

solutions

Automated Synthesis and Characterization of

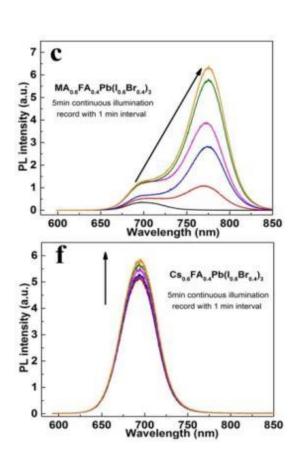


Daravekitae

ADVANCED ENERGY MATERIALS



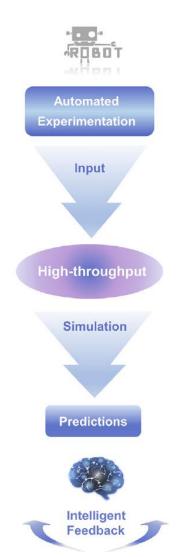
Pristine	Doping content (at.%)	0	10	20	30	40	50	60	70	80	90	100
MAPbI ₃ -	MAPbBr ₃	770	764	730	714	690	659	632	609	589	569	545
		1.00	0.93	1.78	0.53	0.49	0.49	1.66	3.89	2.95	0.88	5.62
		1.49	1.51	1.59	1.68	1.76	1.77	1.85	1.93	1.99	2.02	2.18
	FAPbBr ₃	772	766	714	711	679	660	625	609	594	574	550
		1.00	0.84	4.37	0.02	4.72	19.59	2.26	3.64	1.32	1.59	7.98
		1.50	1.51	1.58	1.68	1.76	1.80	1.91	1.96	2.01	2.07	2.16
	FAPbl ₃	762	763	775	776	777	778	781	795	798	793	787
		1.00	1.24	1.24	2.06	1.68	2.59	3.15	12.50	11.85	18.05	6.45
		1.50	1.50	1.50	1.48	1.47	1.47	1.46	1.46	1.46	-	-
	CsPbI ₃	763	757	762	756	754	750	746	745	-	-	-
		1.00	1.68	1.65	1.85	1.30	1.72	0.65	0.31	-		- 2
		1.50	1.52	1.53	1.53	1.54	1.54	1.55	1.56	-		- 5
	MAPbBr ₃	785	779	770	745	709	687	660	641	624	608	544
		1.00	2.01	2.31	3.79	0.97	0.89	0.29	0.42	0.20	0.14	1.53
		-	1.52	1.53	1.60	1.73	1.77	1.79	1.82	1.91	1.97	2.16
	FAPbBr ₃	786	784	764	743	704	680	656	639	612	580	549
FAPbl ₃		1.00	2.21	4.98	2.28	1.81	0.66	0.58	0.65	0.38	0.06	1.11
		-	1.53	1.55	1.65	1.74	1.81	1.85	1.89	1.95	2.05	2.17
	CsPbI ₃	787	781	777	783	790	801	-	-	-	-	2
		1.00	2.33	4.06	1.95	0.75	0.84	-	-	-	-	
		-	2	122		- 33	25	-	-	2	-	23
CsPbl _{3áá}	MAPbBr ₃	-	8	75	661	660	659	650	615	590	555	543
		2	2	120	0.72	0.73	0.93	0.67	0.32	0.37	0.09	1.00
		8	-	(18)	1.74	1.75	1.76	1.80	1.80	1.85	2.06	2.17
	FAPbBr ₃	-	2	V=	753	720	715	685	651	621	571	546
		-	+	+	7.10	7.92	4.85	1.37	0.21	0.25	0.34	1.00
		-	7.5	(5)	1.65	1.74	1.76	1.80	1.90	1.93	2.08	2.16
	FAPbBr ₃	540.1	540.3	540.5	540.5	540.6	540.7	540.7	540.7	541.1	549.2	550.3
MAPbBr ₂		1.00	1.06	3.59	7.42	2.60	3.18	2.14	1.25	1.53	2.49	1.97
3		2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.19	2.19	2.19

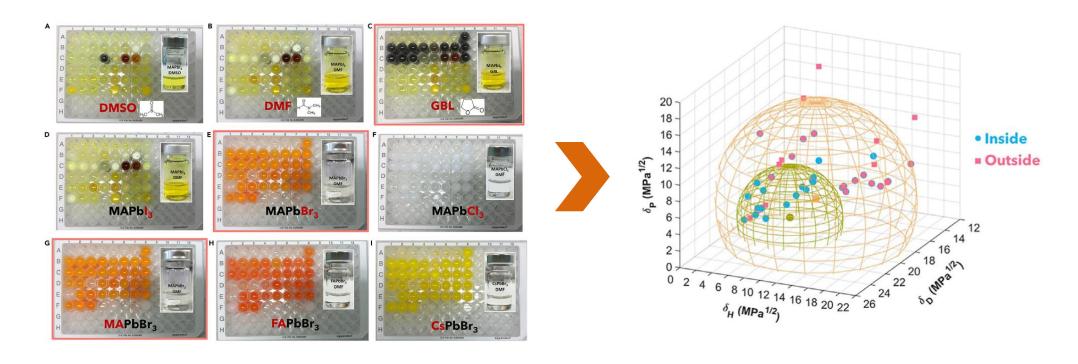


- Synthesis in 96-Well-Plates
- Charakterization in solution









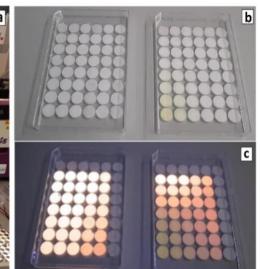
- Utilization of an automated platform for solvent engineering
- Combination of measurements and simulation
- Determination of Hansen Parameters to determine solvent space
- Creation of antisolvent database

Gu et al., Robot-Based High-Throughput Screening of Antisolvents for Lead Halide Perovskites, Joule (2020), https://doi.org/10.1016/j.joule.2020.06.013

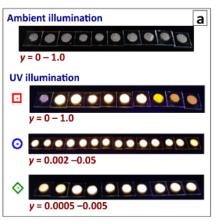


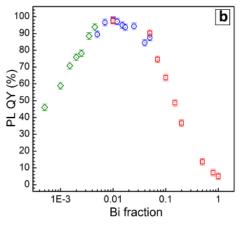


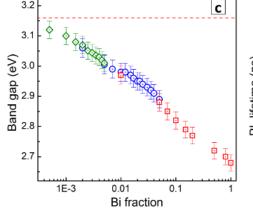


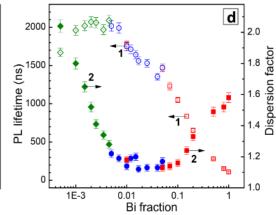


- Low temperature automated synthesis $Cs_2Ag_xNa_{1-x}Bi_yIn_{1-y}Cl_6 \text{ (CANBIC) lead-free PSKs}$
- Variation of Bi content by 4 orders of magnitude
- Discovery of ~100% PLQY
- Charge carrier lifetimes of up 2μs



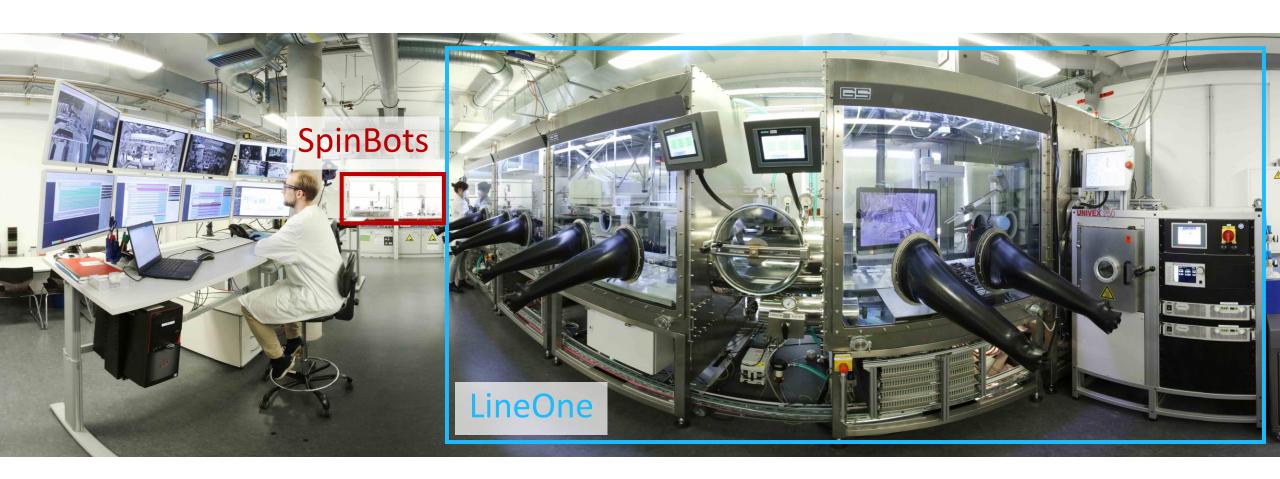






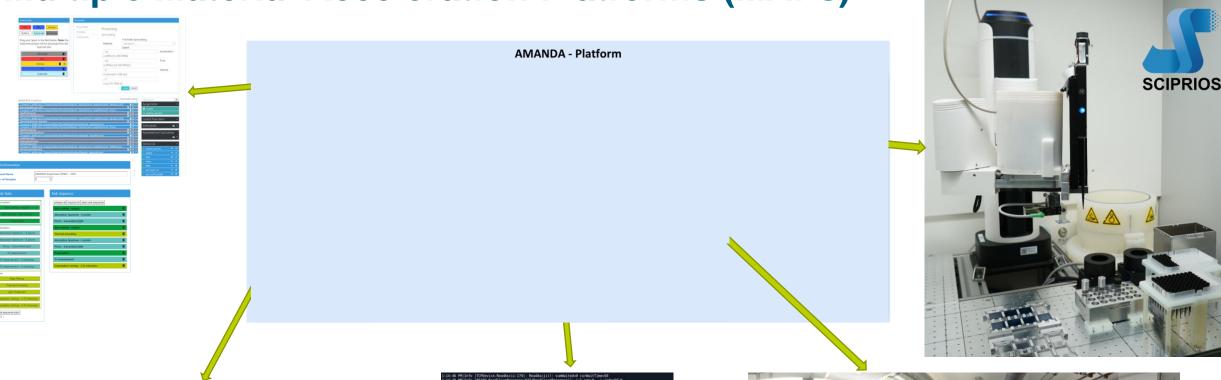






The AMANDA Platform – a System for Controlling Multiple Material Acceleration Platforms (MAPs)





ID	Product ID	Measurement Type	Time start	Time end	Name		
						⊘ Filter	
							☐ Add
36995	7831	IV	2021-08-25 20:51:04	2021-08-25 20:51:55	36995	VIEW IV	3
36996	7802	Absorption	2021-08-25 20:53:42	2021-08-25 20:53:42	36996	VIEW ABS	S, 8
16997	7832	IV	2021-08-25 20:52:43	2021-08-25 20:53:33	36997	VIEW IV	S. 8
6998	7833	IV	2021-08-25 20:54:13	2021-08-25 20:55:03	36998	VIEW IV	B, 8
86999	7803	Absorption	2021-08-25 20:56:44	2021-08-25 20:56:44	36999	VIEW ARS	8, 8
17000	7834	IV	2021-08-25 20:55:43	2021-08-25 20:56:34	37000	VIEW IV	S, 8
7001	7835	IV	2021-08-25 20:57:13	2021-08-25 20:58:04	37001	VIEW IV	B , A
17002	7804	Absorption	2021-08-25 20:59:44	2021-08-25 20:59:44	37002	VIEW ABS	8, 8
17003	7805	Absorption	2021-08-25 21:02:43	2021-08-25 21:02:43	37003	VIEW ABS	S, 8

1:14:46	PHIInfo	TCPDevice.ReadAscii:179 - ReadAscii(): sumMaited-0 curWaitTime-50
1-14-46	PHITnfo	ITCPDevice ReadAscii:179 - ReadAscii(): sumMaited=50 curMaitTime=60
		TCPDevice ReadAscii:179 ReadAscii(): sumMaited=110 curWaitTime=72
		TCPDevice.ReadAscii:179 - ReadAscii(): Summaited=182 curMaitTime=86
		PF400.ReadCleanResponse:633 ReadCleanResponse(): i=1 sep=0 -> indexOf=0
1:14:40	LW(TUIO	(PP400.MeaditeanNesponse:033[NeaditeanNesponse(): 1=1 Sep=0 -> Indexio(=0 ionse=0 169.994 90 183.999 180.802 87.532 723.856
	resp	GU26-6 103.33-8 30 193.333 190.005 81.335 153.930
1:14:46	PMIInfo	PF400, MoveAxisToPositionSingle:423 Axis 2 changed from 80 to 90.
1:14:46	PHIInfo	ITCPDevice.ReadAscii:179 - ReadAscii(): sumMaited-8 curMaitTime-50
1:14:46	PHIInfo	IPF400.ReadCleanResponse:633IReadCleanResponse(): i=1 sep=0 -> indexOf=0
	resp	onse=8 169.994 98 183.999 188.001 87.532 723.856
	Design to	TCPDevice ReadAscii:1791- ReadAscii(): sumMaited-0 curMaitTime-50
		PF400.ReadCleanResponse:633 ReadCleanResponse(): i=1 sep=0 -> indexOf=0
1.14.40		ionse=0 169.994 90.001 183.999 180.001 87.532 723.856
	resp	0036-0 109.994 90.001 183.999 180.001 87.532 /23.856
		TCPDevice.ReadAscii:179 - ReadAscii(): sumMaited=0 curWaitTime=50
1:14:47		PF400.ReadCleanResponse:633 ReadCleanResponse(): i=1 sep=0 -> indexOf=0
	resp	ionse=0 169.994 90 183.999 188.602 87.532 723.856
-14-47	mil Tofo	TCPDevice.ReadAscii:179 - ReadAscii(): sumMaited=0 curMaitTime=50
		PF400.ReadCleanResponse:633 ReadCleanResponse(): i=1 sep=0 -> indexOf=0
		ionse=8 169.994 98 183.998 188.802 87.532 723.856
	mara-d-	Device.SendCurrentDeviceState:205 Current state of device 'pf400-box3' changed to 'Ready'.
1:14:47	HWI TULO	WaitDevice.WaitForMinutes:40 Wait - Waited 3 of 20 minutes.
		TCPDevice.ReadAscii:179 - ReadAscii(): sumMaited=0 curWaitTime=50
1:14:47	MH IULO	PF400.ReadCleanResponse:633 ReadCleanResponse(): i=1 sep=0 -> indexOf=0
	resp	onse=0 169.994 90 183.999 180.001 87.532 723.856
	PMIDebus	olSequencePlanControl.SendChangedSequenceStep:501 Status of step 'uL-id-3116' of sequence plan ins
1:14:47	PHIInfo	[Device SetCurrentStatus:135 Status of device 'pf400-box3' changed to 'Connected'.
	PM Debug	SequenceControlFlowExecution.EvaluateSequencePlanStep:137 Execute step 'NEW Step': Token - Relea
	PM Debug	SequencePlanControl.SendChangedSequenceStep:501 Status of step 'ui-id-3138' of sequence plan ins
1:14:47	PM Info	Device.SetCurrentStatus:135 Status of device 'Token' changed to 'Active'.
		SequencePlanControl.SendChangedSequenceStep:501 Status of step 'ui-id-3118' of sequence plan ins
1:34:47	PMI Info	Device.SetCurrentStatus:135 Status of device 'Token' changed to 'Connected'.
		SequenceControlFlowExecution.EvaluateSequenceSubroutineElement:501 Start subroutine TVmeasureme
1 14:47	DM Desburg	SequencePlanControl_SendChangedSequenceStep:S01 Status of step 'ui-id-3128' of sequence plan ins
	THE DELICE	Information and the Continue Continue of the C



LineOne – An autonomous fabrication line for solution based solar cells



Box 1: Preparation Box 2: Layer formation & optical characterization Box 3: Device completion and electrical characterization Transport robot Transport robot Sample Storage Thermal annealing Sample Accel-erated Hot plates, tiphandling Evap, **UV-Vis** Inspection lieftime coater racks, sample loading and IV testing spectrometer camera testing holder, vial storage stage holder Pipetting robot **Manual Preparation** Preparation Preparation

Features

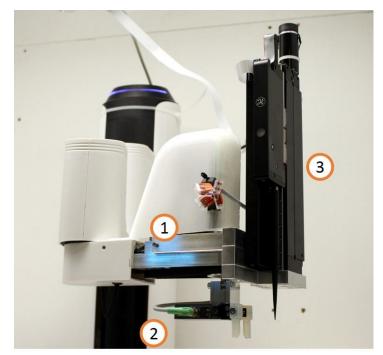
- Fully automated OPV manufacturing and characterization including:
 - Solution preparation
 - Spin coating
 - Thermal annealing
 - Thermal evaporation
 - Optical absortion measurement
 - Electrical characterization
 - Accelerated lifetime testing
- Operating in inert atmosphere
- High flexibility in process design
- In-line ML integration



Thermal evaporator



Spinbot – A Fully Automated Spin Coating Setup



Scara-Robot (1), Gripper (2), pipetting channel (3)

Features

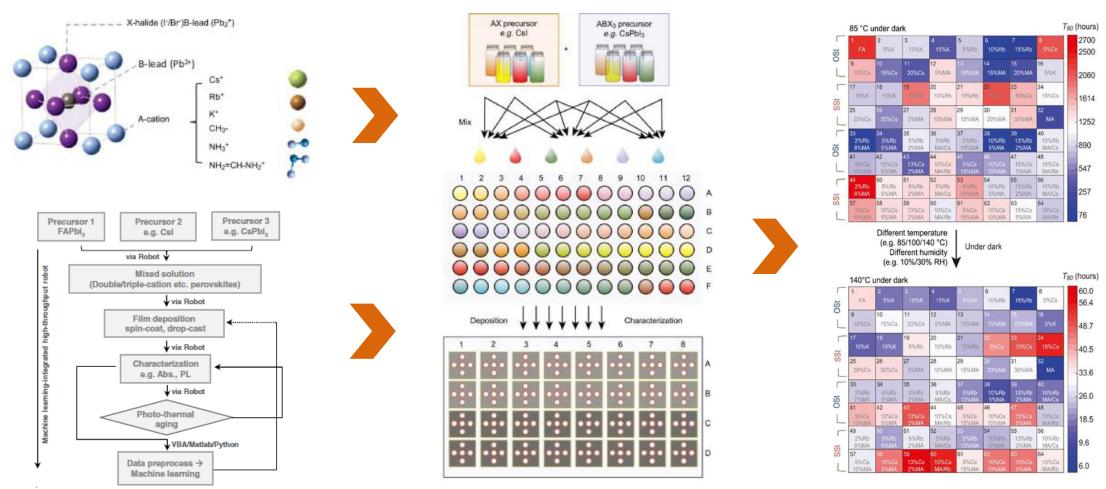
- Sample transport
- Pipetting
- Spincoating
- Thermal annealing







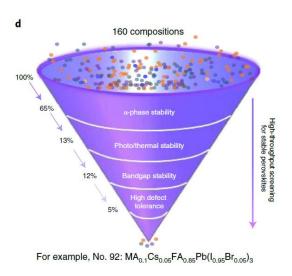


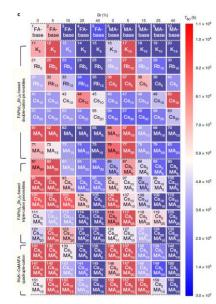


- Testing the effect of various cations of device stability at various temperatures
- Discovery of "stability reversal" for several compositions



Ultrastable Perovskite Solar Cells with 1400hrs stability

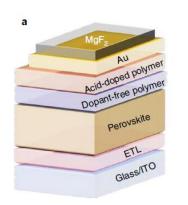


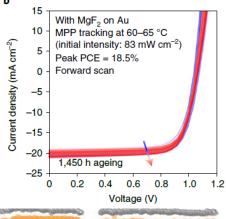


- Stability screening of 160 mixed cation, mixed halide perovskites
- Novel bilayer polymer hole transport layer
- Stabilized top electrode



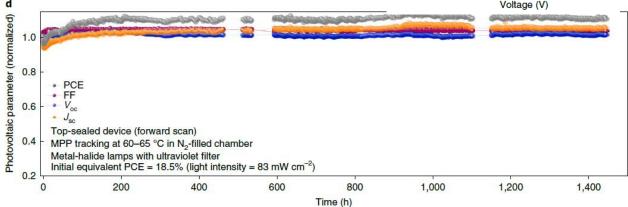








No hysteresis



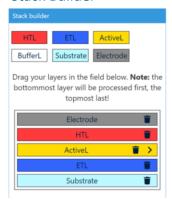




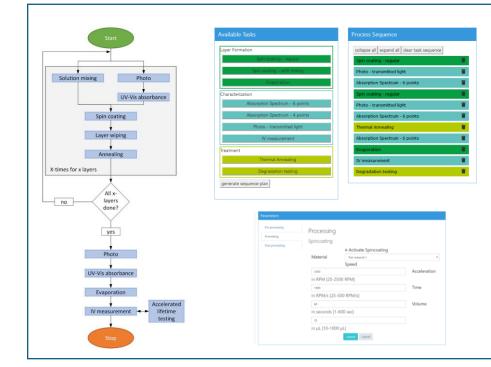




Stack Builder



Process Builder



Sequence Plan Generator





Thank you for your attention!







Funded by the European Union



Contact:

Dr. Jens Hauch - Helmholtz Institut Erlangen-Nürnberg / ZAE Bayern +49 9131 9398 100, j.hauch@fz-juelich.de





