

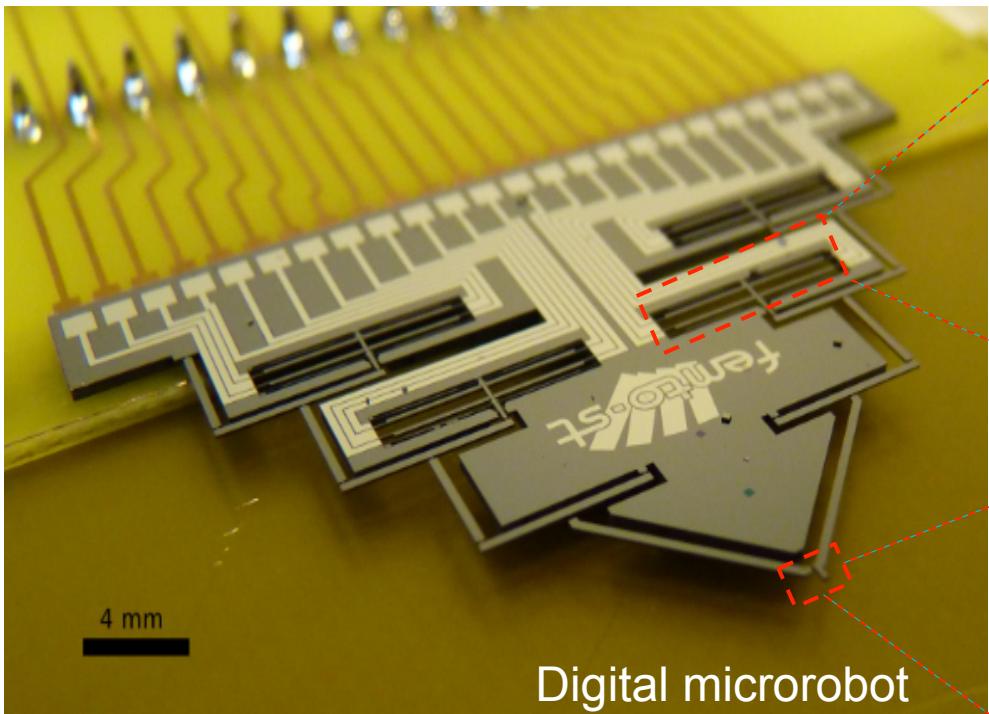


Repeatability and reproducibility analysis of a multistable module devoted to digital microrobotics

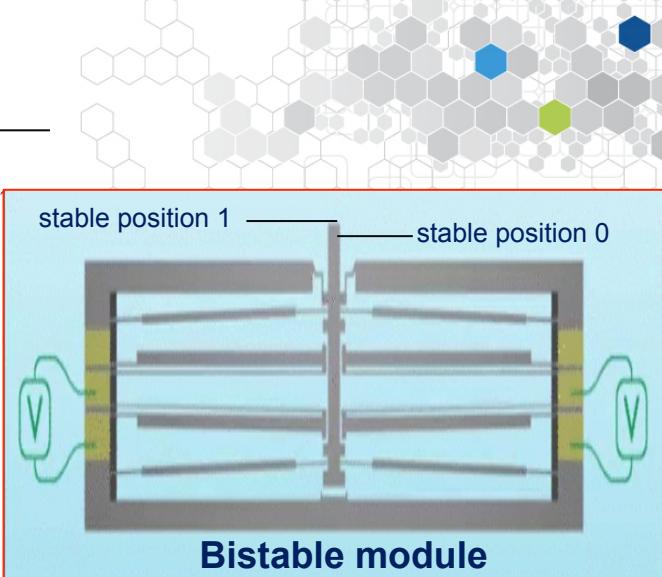
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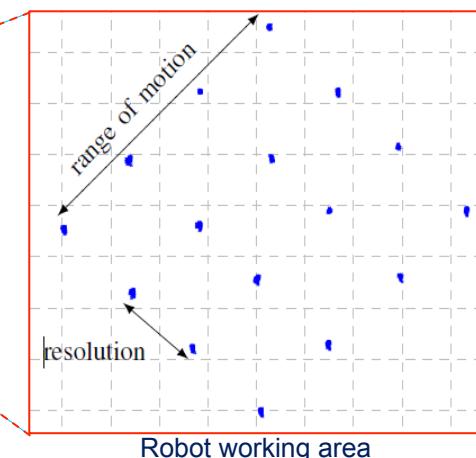
Context and motivation



Digital microrobot



Bistable module



Advantages:

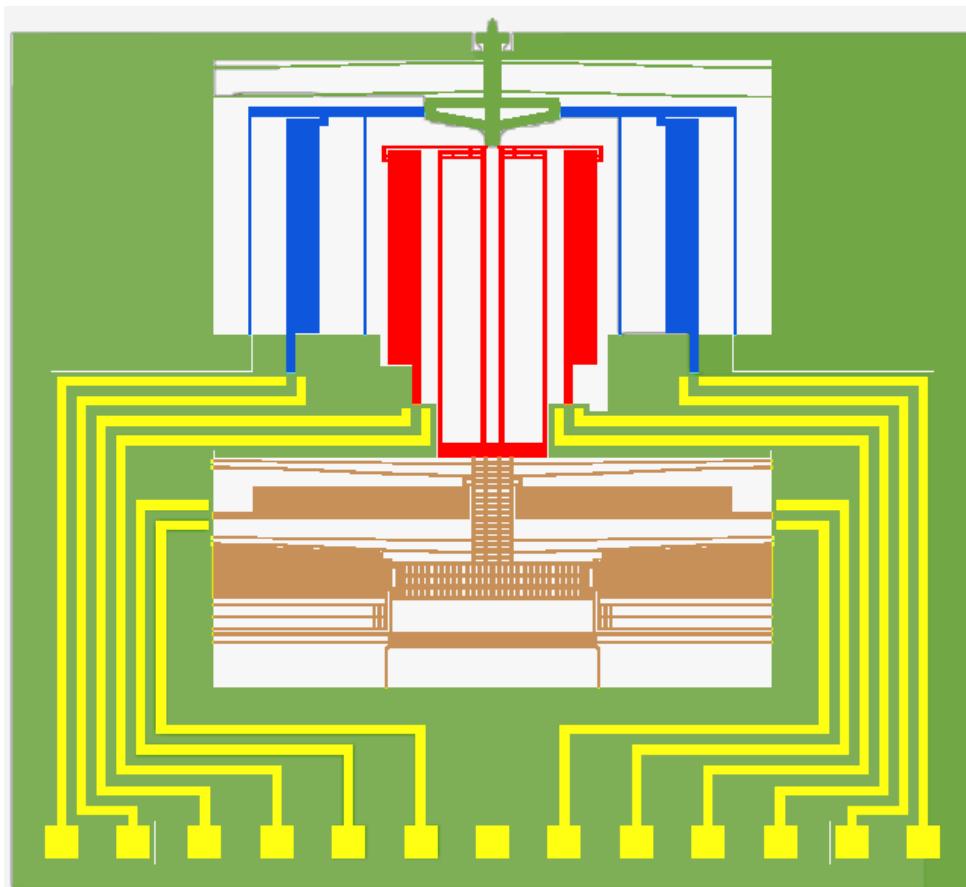
- Open loop control
- Low energy consumption
- Mechanical stability
- Flat actuator
- Adapted to confined environment (SEM, TEM)...

Limitations:

- Only two stable positions
- A bit large structure

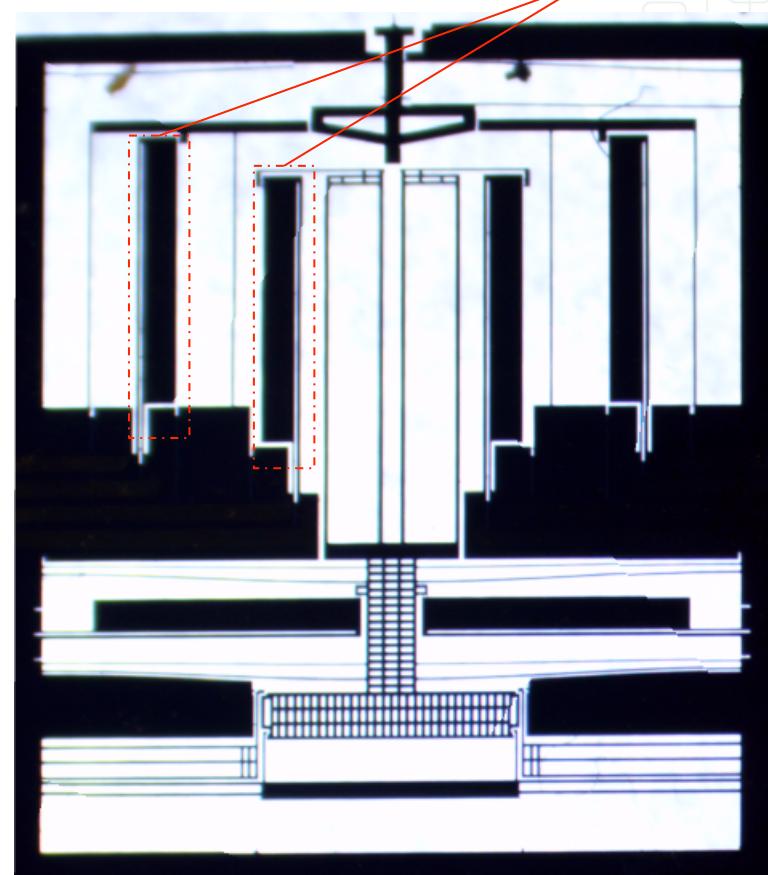
Multistable architecture

- Compact architecture with 13 stable positions (from 0 to 12)
- Three subsystems (U-shaped electrothermal actuators + flexible structures)



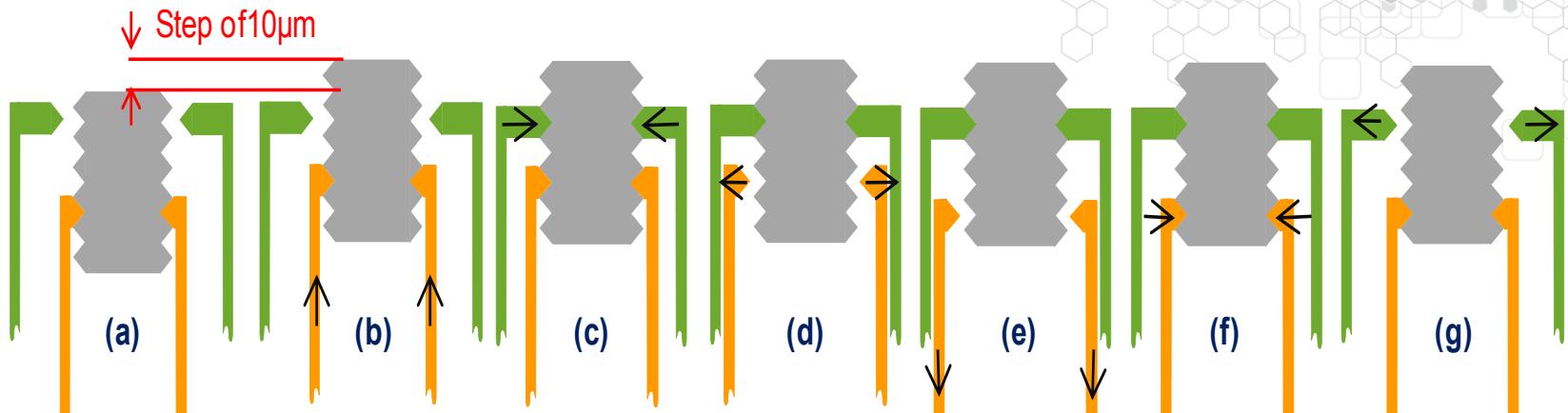
Subsystem 1 Subsystem 2 Subsystem 3

Proposed architecture

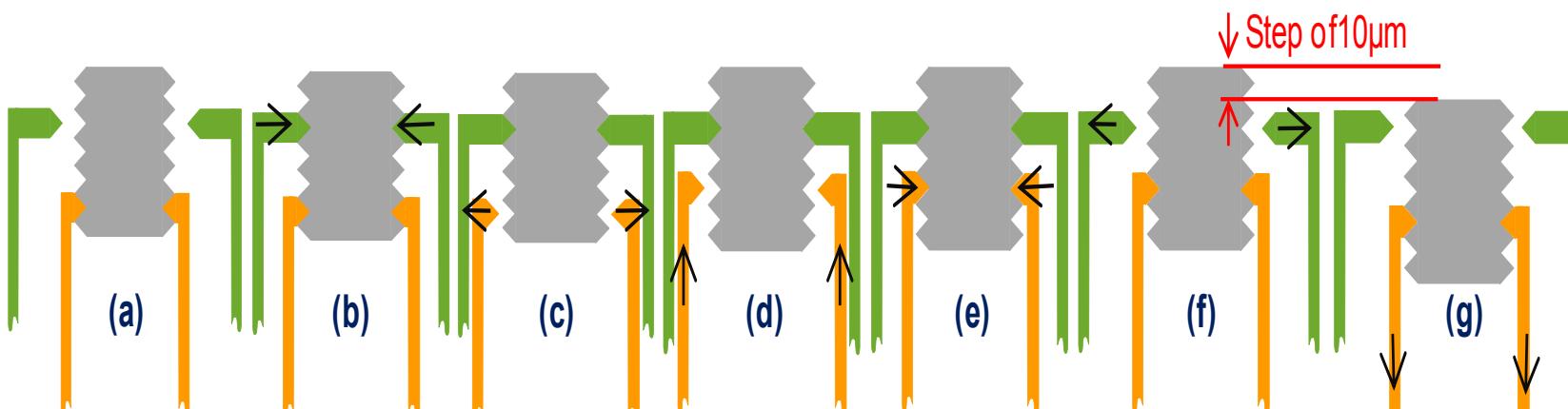


Fabricated module

Functioning principle (step generation)

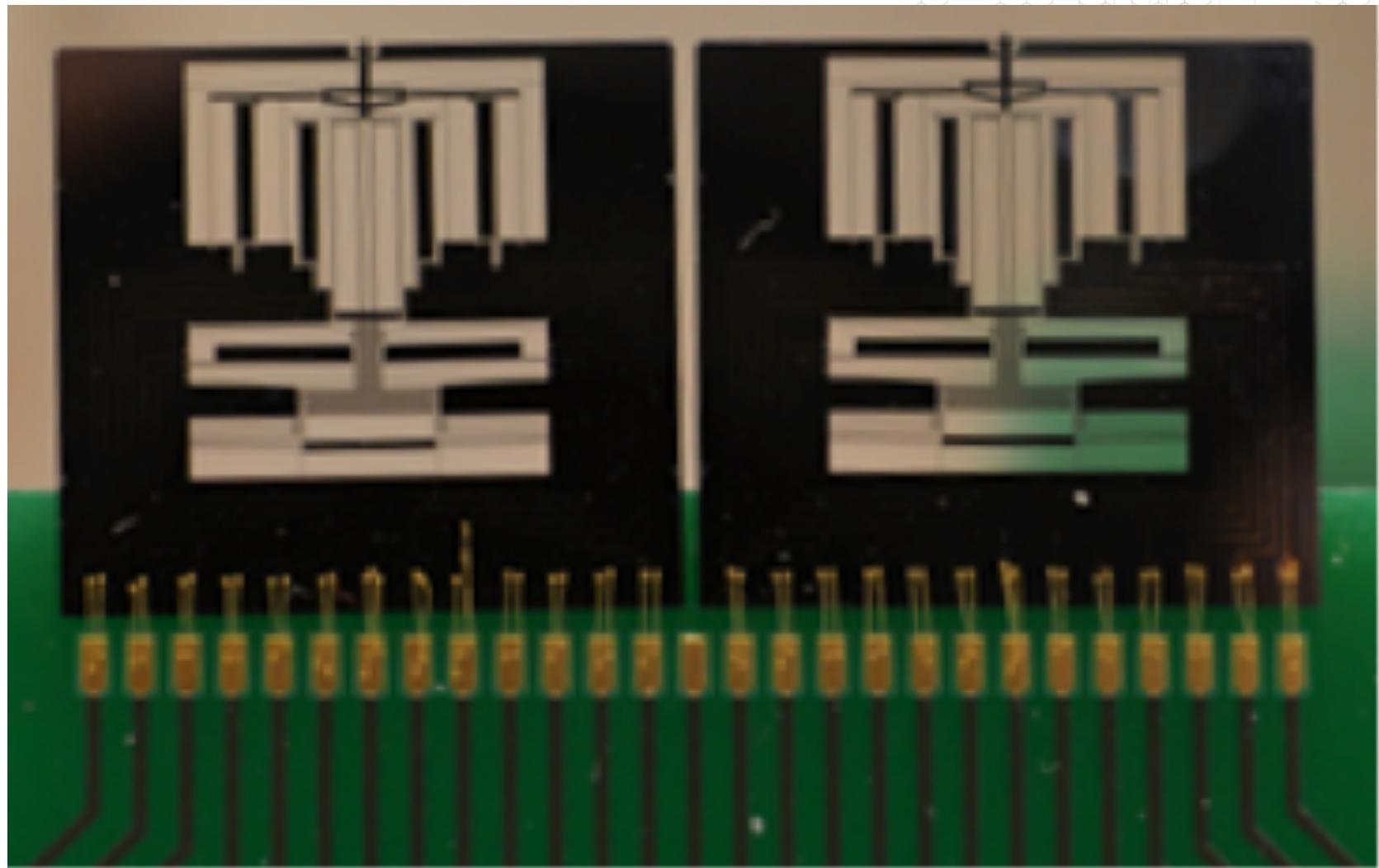


Upward step

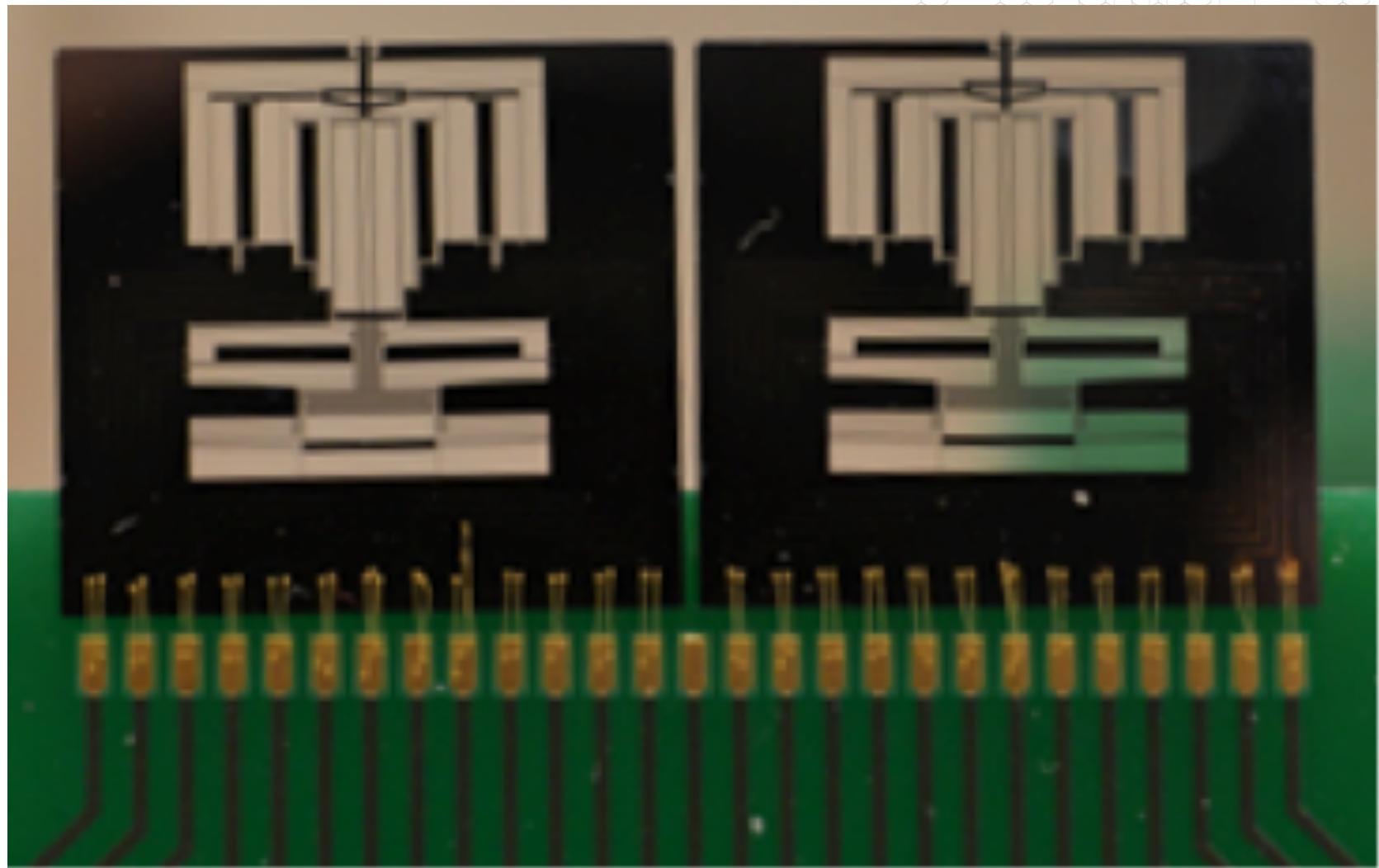


Downward step

Fabricated multistable



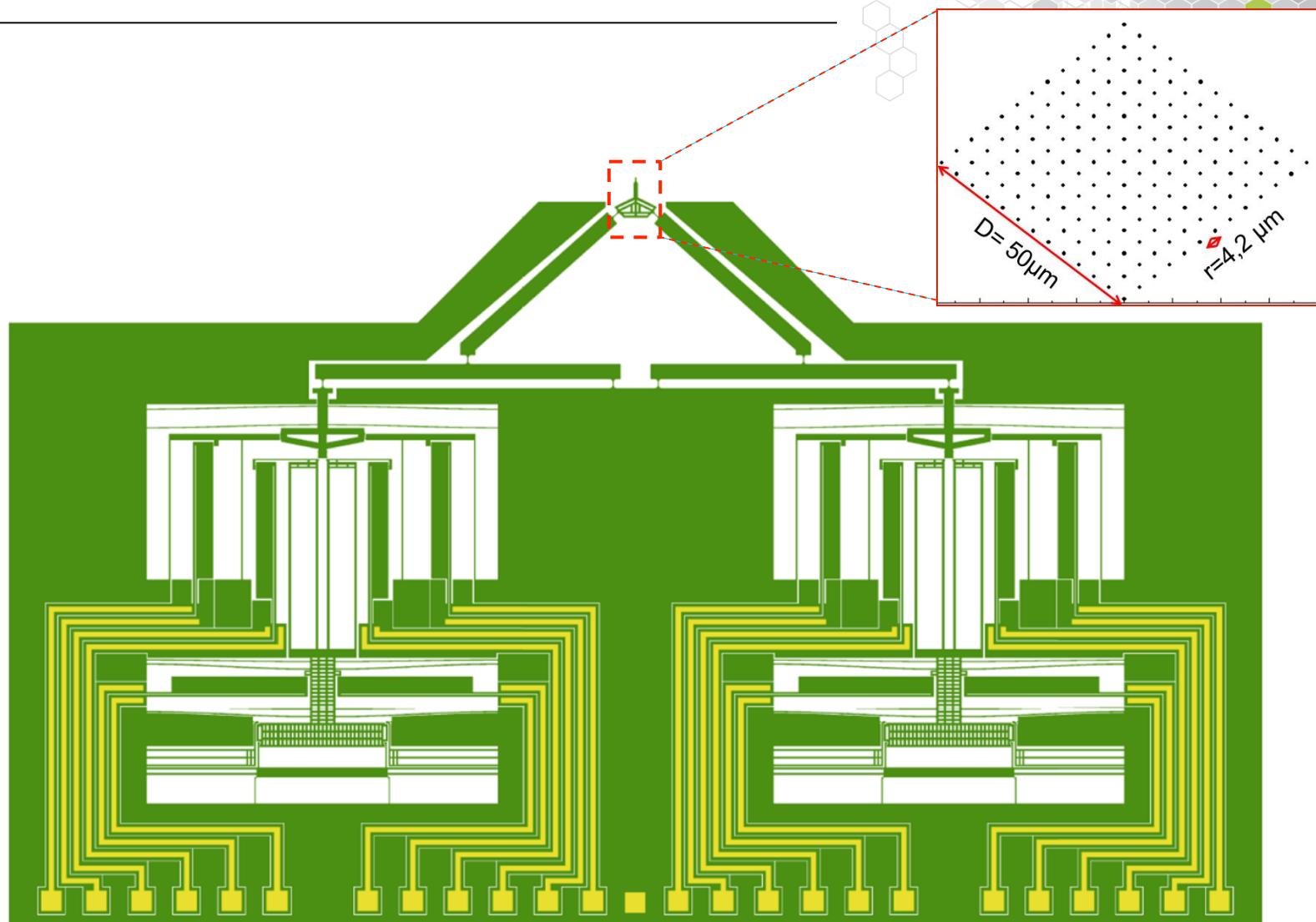
Fabricated multistable



Upward and downward steps principle

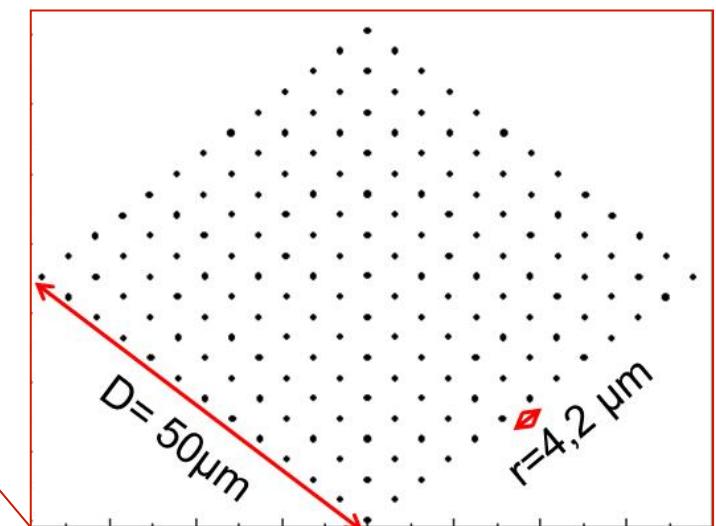
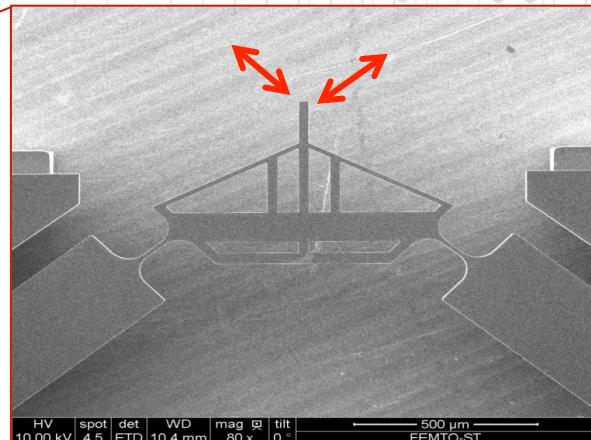
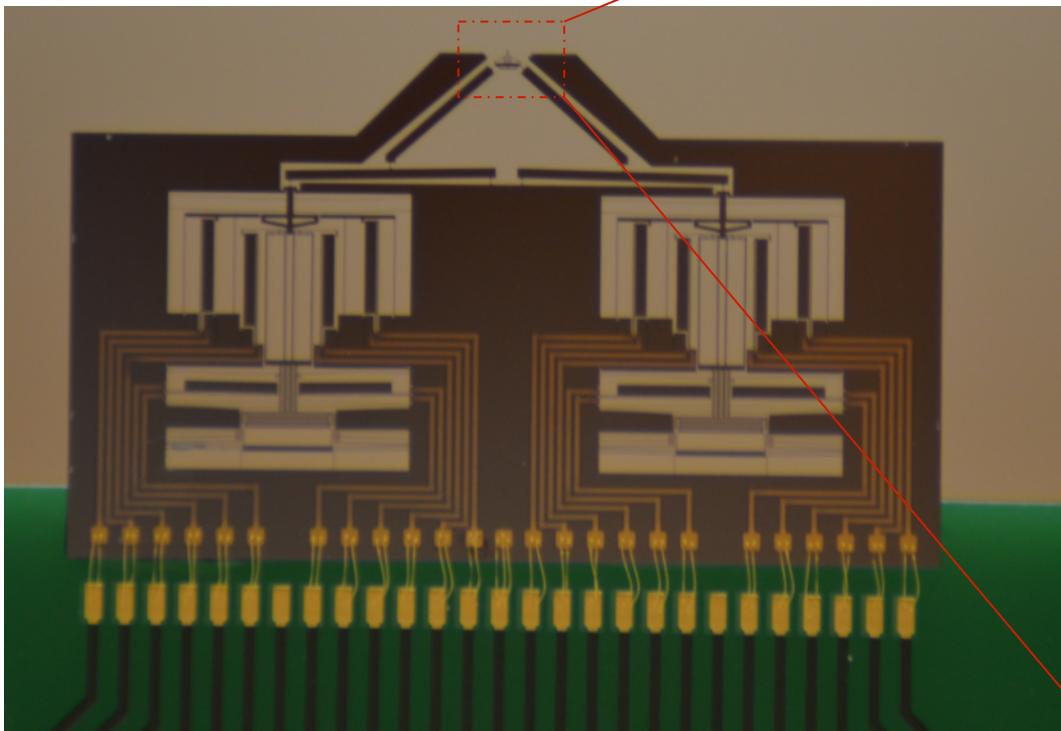


Multistable architecture (elementary component)



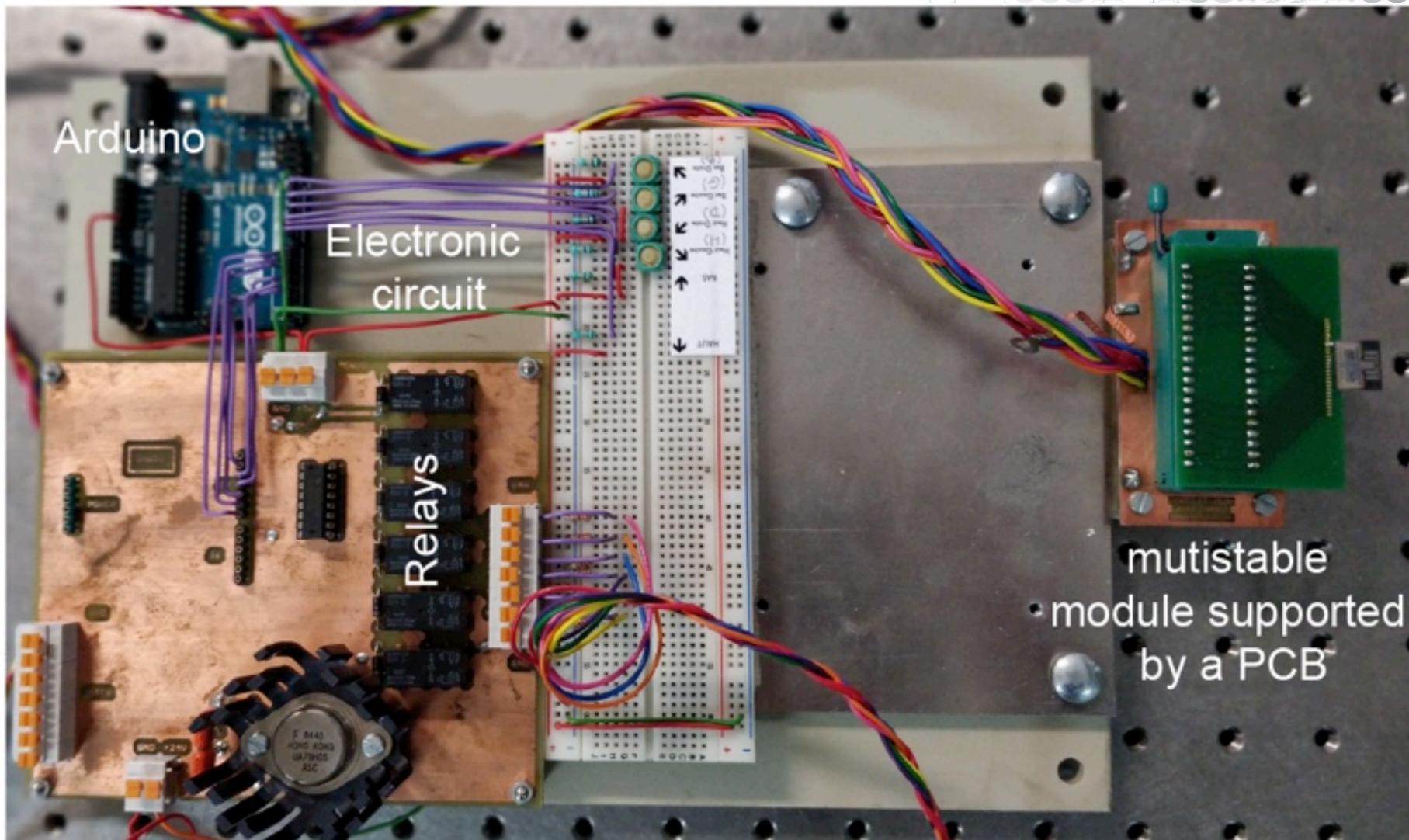
New generation of digital microrobots

Next generation of digital microrobots



169 positions (13X13)

Repeatability and reproducibility analysis



Repeatability analysis



- 10 series of measurements on an individual module
- 12 upward and 12 downward steps

Position Nbr.	series Nbr.	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	0	0	0	0
2	10.19	10.2	10.17	10.06	10.18	10.08	10.01	10.04	10.06	10.17	
3	20.3	19.99	20.17	20.17	19.93	20.02	20.17	19.92	20.01	20.15	
4	30.15	30.19	29.98	30.38	29.99	30.05	30.35	30.01	30	30.31	
5	40.32	40.27	40.13	40.39	40.13	40.18	40.35	40.15	40.19	40.25	
6	50.44	50.34	50.33	50.31	50.32	50.34	50.3	50.2	50.33	50.27	
7	60.3	60.34	60.33	60.33	60.31	60.31	60.35	60.1	60.29	60.31	
8	70.57	70.39	70.47	70.6	70.49	70.47	70.54	70.43	70.41	70.53	
9	80.56	80.46	80.47	80.7	80.53	80.4	80.49	80.44	80.36	80.56	
10	90.6	90.51	90.54	90.56	90.46	90.53	90.69	90.47	90.49	90.54	
11	100.8	100.7	100.46	100.85	100.52	100.67	100.73	100.48	100.57	100.8	
12	110.81	110.85	110.71	110.83	110.56	110.65	110.91	110.62	110.52	110.68	
13	120.75	120.76	120.72	120.69	120.63	120.68	120.82	120.59	120.53	120.69	

- ANOVA analysis:
 - p-value = **0.999** (no significant difference)
 - mean square of error = **0.014** (good repeatability)

Reproducibility analysis

- 4 series of measurements on 4 multistables (same wafer)
- 12 upward and 12 downward steps

Module		Position Nbr.												
		1	2	3	4	5	6	7	8	9	10	11	12	13
module 1	series 1	0	10.06	20.01	30	40.19	50.33	60.29	70.41	80.36	90.49	100.57	110.52	120.53
	series 2	0	10.17	20.15	30.31	40.25	50.27	60.31	70.53	80.56	90.54	100.8	110.68	120.69
	series 3	0	9.98	19.86	30.1	40.21	50.21	60.31	70.58	80.3	90.67	100.65	110.57	120.58
	series 4	0	10.11	20.12	30.33	40.4	50.56	60.38	70.64	80.48	90.4	100.65	110.6	120.66
module 2	series 1	0	10.23	20.28	30.3	40.46	50.58	60.7	70.65	80.8	90.87	101.06	110.95	120.98
	series 2	0	10.19	20.32	30.32	40.44	50.61	60.78	70.72	80.87	90.82	101.06	110.98	121.1
	series 3	0	10.26	20.27	30.23	40.47	50.61	60.76	70.66	80.82	90.8	101.11	110.99	120.98
	series 4	0	10.22	20.34	30.24	40.48	50.65	60.76	70.7	80.86	90.85	101.08	110.96	121.04
module 3	series 1	0	10	19.97	30.41	40.09	50.1	60.63	70.87	80.78	90.87	101.08	110.85	120.94
	series 2	0	10.14	20.07	30.54	40.31	50.27	60.58	70.67	80.63	91.01	101.15	110.79	120.69
	series 3	0	10.21	20.07	30.57	40.35	50.31	60.59	70.67	80.72	91.05	101.15	110.89	120.75
	series 4	0	10.14	20.15	30.57	40.33	50.31	60.67	70.74	80.72	91.03	101.13	110.82	120.74
module 4	series 1	0	10.16	20.27	30.44	40.61	50.89	60.8	71	80.76	91.16	100.91	111	120.5
	series 2	0	10.19	20.3	30.48	40.65	50.87	60.81	71	80.77	90.95	100.82	110.93	120.72
	series 3	0	10.22	20.15	30.55	40.62	50.75	61	70.8	80.83	91.01	100.92	110.95	120.78
	series 4	0	10.2	20.32	30.44	40.79	50.73	60.8	70.7	80.78	91.14	100.99	110.8	120.67

- ANOVA analysis:
 - p-value = 1 (no significant difference)
 - mean square of error = 0.033 (good reproducibility)



Thank you for your attention

