

Electronic Supplementary information (ESI)

Photo-annealed Amorphous Titanium Oxide for Perovskite Solar Cells

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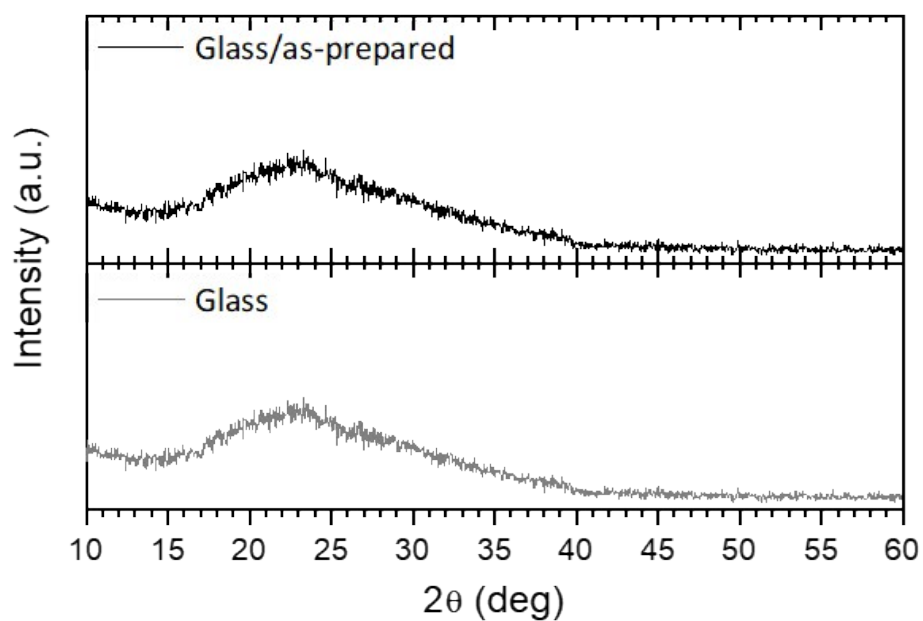


Fig. S1 Grazing incidence X-ray diffraction of Glass substrate and as-prepared sample

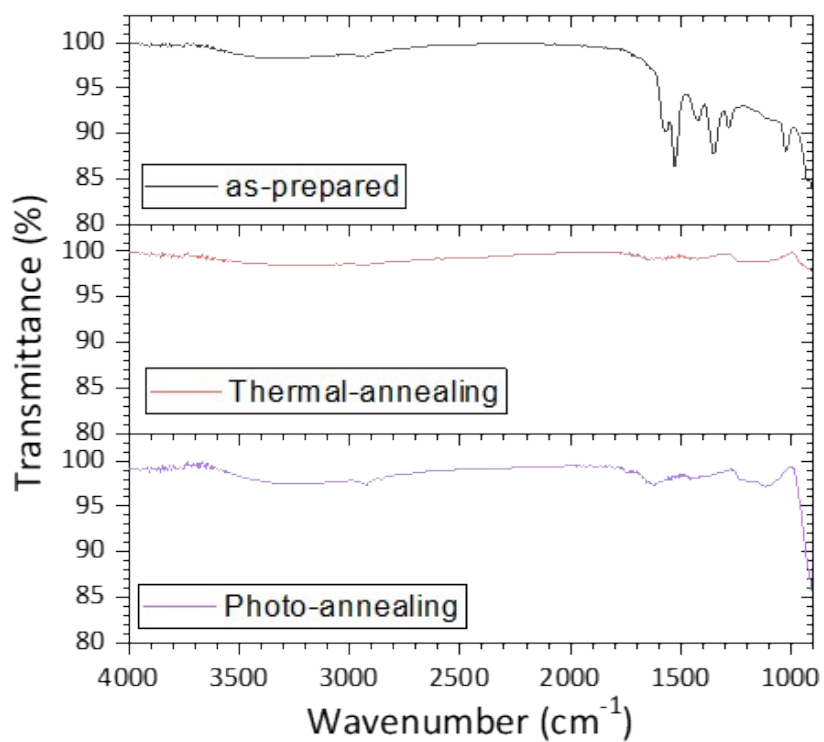


Fig. S2 Full range of FT-IR spectra of as-prepared (soft-baked), thermal-annealed, and photo-annealed TDIP films on Si substrate in Fig. 1b

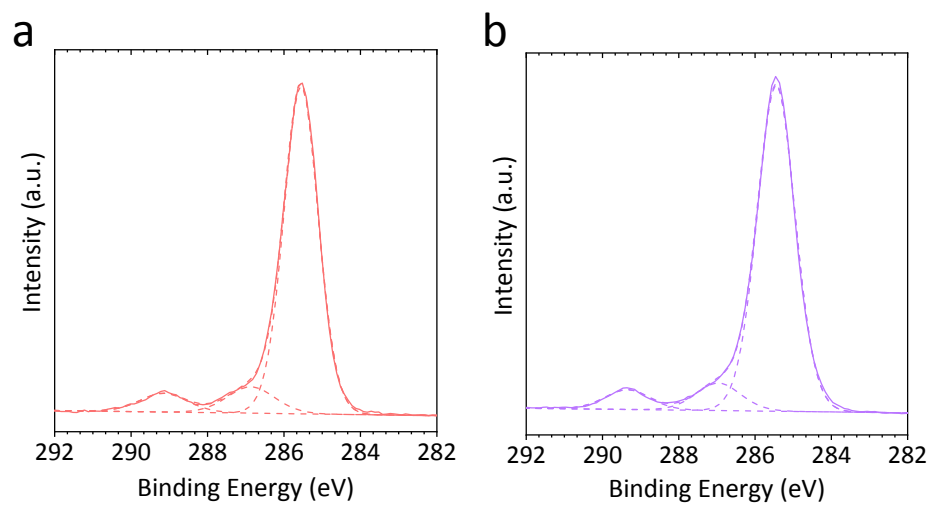


Fig. S3 X-ray photoelectron spectroscopy for C 1s peak of P-, and T-TiO₂

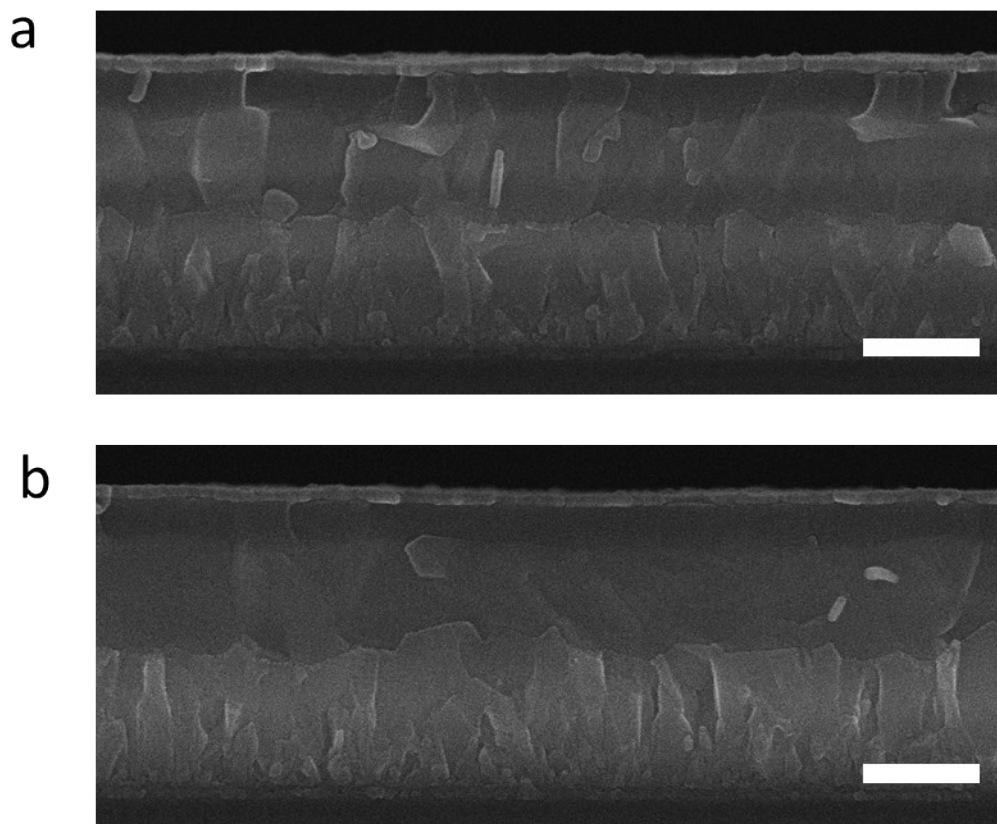


Fig. S4 Cross sectional FESEM images of perovskite solar cell fabricated on (a) T-TiO₂ and (b) P-TiO₂ ESL. Scale bar = 500 nm

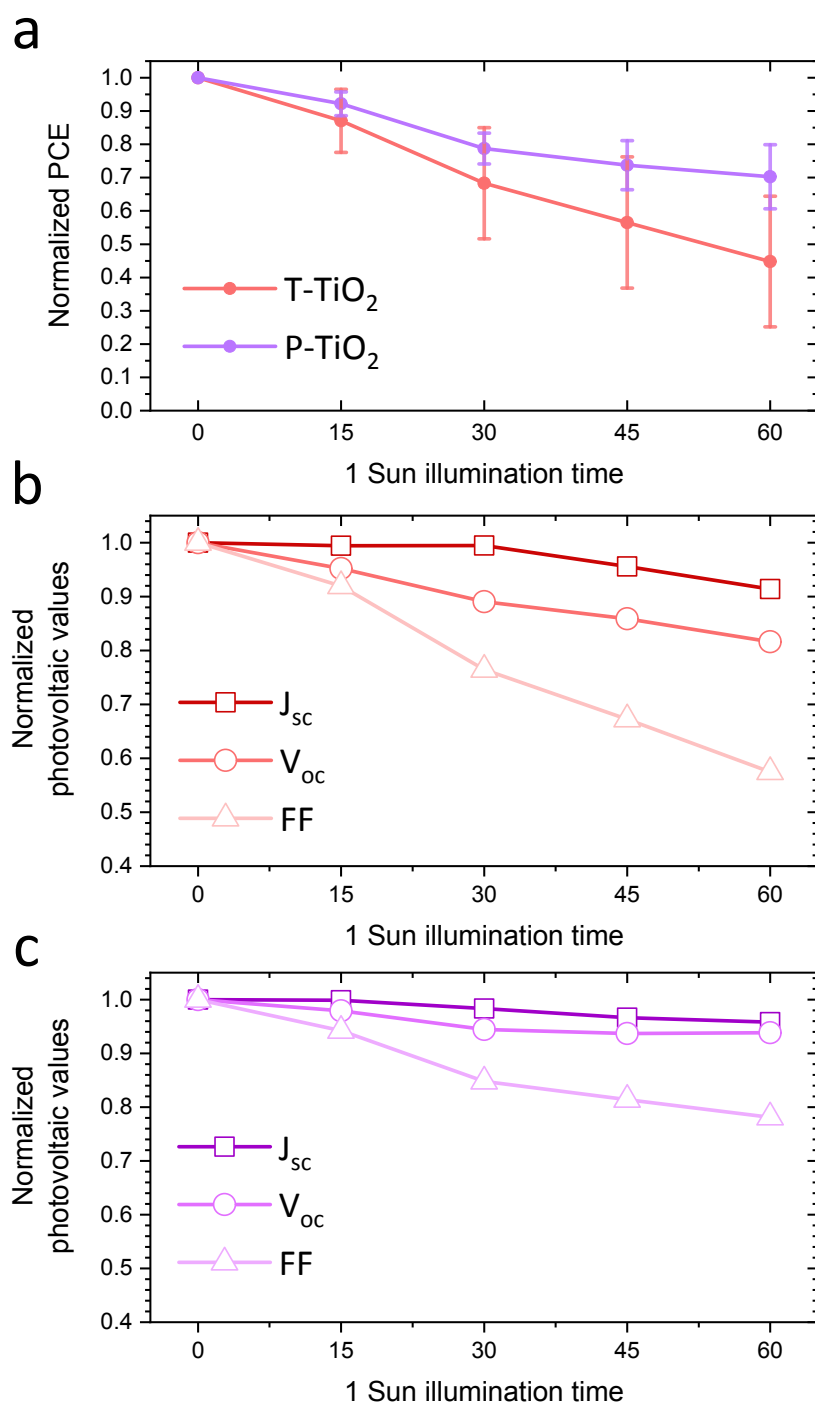


Fig. S5 Stability test of P-, and T-TiO₂ based PSCs under 1 sun illumination. (a) Normalized PCE of P-, and T-TiO₂ based PSCs. Degradation trend of photovoltaic values of (b) P-, and (c) T-TiO₂ based PSCs. Stability data extracted resulted from J-V curve using 4 devices.

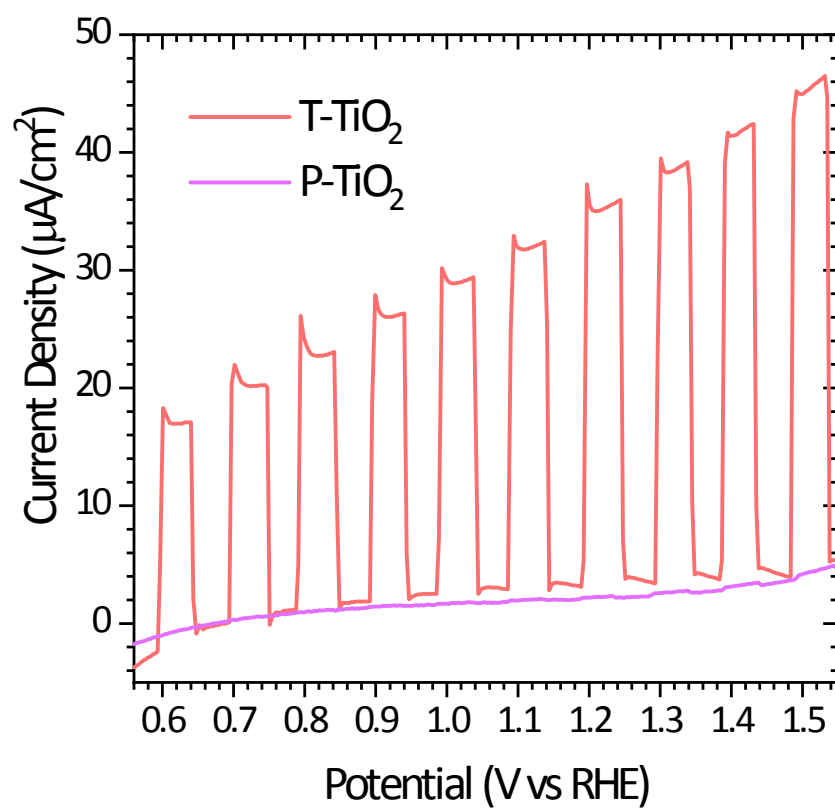


Fig. S6. J-V curves collected from a photoelectrochemical system, where the P- and T-TiO₂ films were used as working electrodes. The J-V curves were measured in three electrode system with the Ag/AgCl reference electrode (3 M NaCl solution), under chopped simulated solar light illumination with a Pt counter electrode.

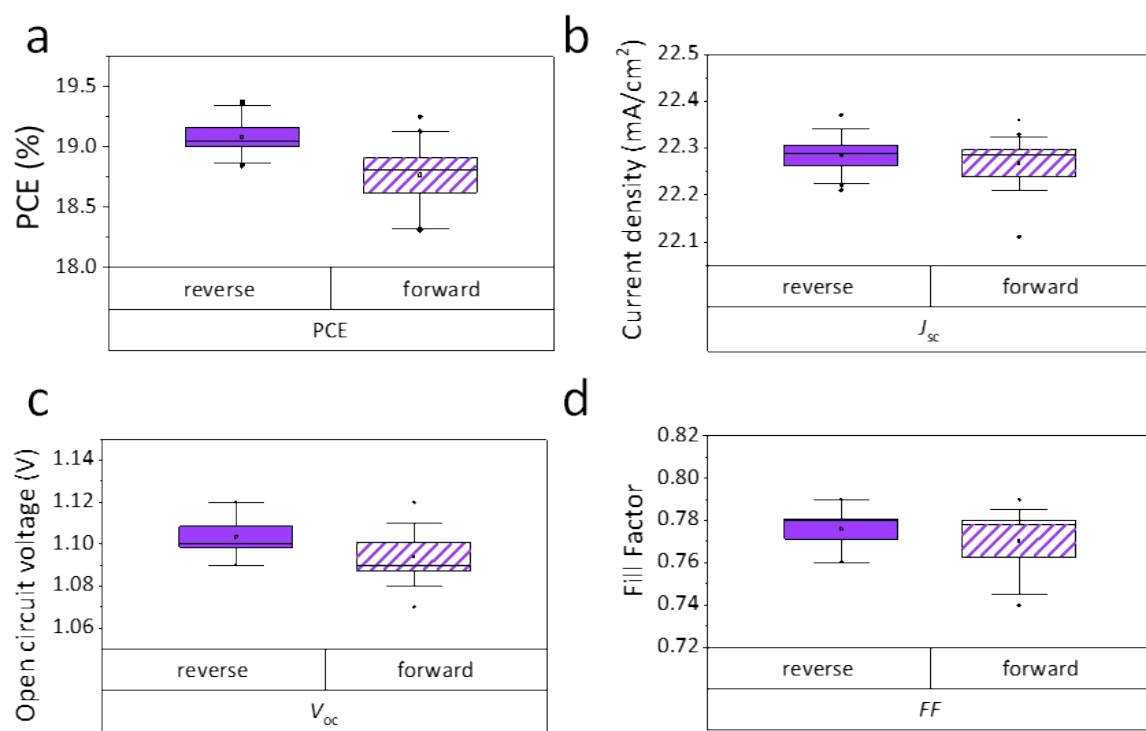


Fig. S7 Box chart of (a) PCE, (b) J_{sc} , (c) V_{oc} and (d) FF extracted from the optimized P-TiO₂ based PSCs. The boxes show the standard deviations; the whiskers represent the 10/90 percentiles; the small squares denote the mean, the two horizontal bars denote the 99% and 1% values, and the two diagonal crosses denote the highest and lowest values.

ESI Table S1 Atomic concentration analysis of T-, and P-TiO₂ by XPS peak analysis.

Sample	C	Ti	O	O/Ti
T-TiO ₂	0.39	30.67	68.94	2.25
P-TiO ₂	0.26	29.33	70.41	2.40

ESI Table S2 Photovoltaic parameters of the PSCs fabricated on T-TiO₂ in Fig. 3d. Active area: 0.14 cm²

No.	Reverse scan				Forward scan				PCE of For. / PCE of Rev.
	J_{sc} (mA/c m ²)	V_{oc} (V)	FF	PCE (%)	J_{sc} (mA/c m ²)	V_{oc} (V)	FF	PCE (%)	
1	21.16	1.08	0.76	17.37	21.16	1.04	0.73	16.06	0.99
2	21.34	1.08	0.77	17.75	21.32	1.04	0.74	16.41	0.99
3	21.24	1.08	0.77	17.66	21.22	1.03	0.73	15.96	0.99
4	21.41	1.08	0.75	17.34	21.36	1.03	0.72	15.84	0.98
5	21.18	1.08	0.76	17.38	21.09	1.03	0.72	15.64	0.98
6	21.14	1.07	0.77	17.42	21.08	1.02	0.75	16.13	0.99
7	21.24	1.07	0.77	17.5	21.21	1.01	0.74	15.85	0.99
8	21.79	1.09	0.75	17.81	21.66	1.07	0.75	17.38	0.99
9	21.81	1.1	0.77	18.47	21.77	1.06	0.74	17.08	0.99
10	21.82	1.1	0.77	18.48	21.78	1.06	0.71	16.39	0.98
11	21.84	1.1	0.77	18.5	21.54	1.05	0.71	16.06	0.98
12	21.6	1.09	0.74	17.42	21.56	1.03	0.68	15.1	1
13	21.61	1.1	0.77	18.3	21.59	1.03	0.69	15.34	0.96
14	21.82	1.08	0.74	17.44	21.74	1.07	0.73	16.98	0.97
15	21.88	1.09	0.74	17.65	21.86	1.06	0.7	16.22	0.98
16	21.61	1.09	0.77	18.14	21.26	1.04	0.72	15.92	0.97
17	21.51	1.09	0.77	18.05	21.19	1.06	0.7	15.72	0.97
18	21.49	1.09	0.75	17.57	21.11	1.03	0.72	15.66	0.99
19	21.52	1.08	0.76	17.66	21.07	1.01	0.71	15.11	0.98
20	22.26	1.07	0.73	17.39	21.18	1.01	0.73	15.62	1
Average	21.56	1.09	0.76	17.77	21.39	1.04	0.72	16.02	0.98

ESI Table S3. Photovoltaic parameters of the PSCs fabricated on P-TiO₂ in Fig. 3d. Active area: 0.14 cm²

No.	Reverse scan				Forward scan				PCE of For. / PCE of Rev.
	J_{sc} (mA/c m ²)	V_{oc} (V)	FF	PCE (%)	J_{sc} (mA/c m ²)	V_{oc} (V)	FF	PCE (%)	
1	21.34	1.08	0.77	17.75	21.44	1.01	0.74	16.02	0.99
2	21.5	1.11	0.76	18.14	21.46	1.06	0.7	15.92	0.99
3	21.49	1.1	0.77	18.2	21.41	1.04	0.71	15.81	0.99
4	21.14	1.1	0.76	17.67	21.12	1.06	0.75	16.79	0.98
5	21.24	1.11	0.77	18.15	21.15	1.04	0.73	16.06	0.98
6	21.36	1.11	0.77	18.26	21.26	1.05	0.72	16.07	0.99
7	21.24	1.11	0.77	18.15	21.23	1.05	0.72	16.05	0.99
8	21.29	1.09	0.77	17.87	21.26	1.05	0.74	16.52	0.99
9	21.15	1.1	0.79	18.38	21.11	1.05	0.75	16.62	0.99
10	21.29	1.11	0.76	17.96	21.27	1.05	0.72	16.08	0.98
11	20.96	1.1	0.78	17.98	20.86	1.05	0.75	16.43	0.98
12	21.35	1.09	0.79	18.38	21.24	1.02	0.74	16.03	1
13	21.67	1.12	0.78	18.93	21.59	1.07	0.74	17.09	0.96
14	21.61	1.09	0.77	18.14	21.55	1.06	0.74	16.9	0.97
15	21.46	1.08	0.79	18.31	21.31	1.06	0.75	16.94	0.98
16	21.43	1.11	0.76	18.08	20.84	1.05	0.75	16.41	0.97
17	21.29	1.09	0.77	17.87	21.16	1.04	0.74	16.28	0.97
18	21.33	1.1	0.76	17.83	21.11	1.02	0.73	15.72	0.99
19	21.26	1.09	0.77	17.84	21.03	1.02	0.74	15.87	0.98
20	21.46	1.07	0.78	17.91	21.44	1.05	0.7	15.76	1
Average	21.34	1.1	0.77	18.09	21.24	1.05	0.73	16.27	0.98

ESI Table S4. TRPL amplitudes and lifetimes of the glass/TiO₂/perovskite, and glass/P-TiO₂/perovskite samples. **A_i** and **τ_i** are the amplitude ratio and lifetime of each component, respectively. The intensity weighted average lifetime was calculated by $\tau_{avg} = \sum A_i \tau_i^2 / \sum A_i \tau_i$

Samples	A ₁ (%)	τ ₁ (ns)	A ₂ (%)	τ ₂ (ns)	τ _{ave} (ns)
glass/T-TiO ₂ /perovskite	45.49	9.50	54.51	775.42	767.67
glass/P-TiO ₂ /Perovskite	53.70	8.79	46.30	666.39	656.48

ESI Table S5. Photovoltaic parameters of the optimized PSCs on the P-TiO₂ ESL. Active area: 0.14 cm²

No.	Reverse scan				Forward scan				PCE of For. / PCE of Rev.
	J_{sc} (mA/c m ²)	V_{oc} (V)	FF	PCE (%)	J_{sc} (mA/c m ²)	V_{oc} (V)	FF	PCE (%)	
1	22.37	1.11	0.78	19.37	22.3	1.1	0.78	19.13	0.99
2	22.28	1.1	0.79	19.36	22.36	1.09	0.79	19.25	0.99
3	22.31	1.11	0.78	19.32	22.28	1.1	0.78	19.12	0.99
4	22.21	1.11	0.78	19.23	22.33	1.11	0.76	18.84	0.98
5	22.3	1.09	0.79	19.2	22.32	1.08	0.78	18.8	0.98
6	22.29	1.09	0.79	19.19	22.29	1.08	0.79	19.02	0.99
7	22.31	1.1	0.78	19.14	22.28	1.09	0.78	18.94	0.99
8	22.3	1.1	0.78	19.13	22.32	1.09	0.78	18.98	0.99
9	22.29	1.1	0.78	19.12	22.31	1.09	0.78	18.97	0.99
10	22.24	1.1	0.78	19.08	22.21	1.08	0.78	18.71	0.98
11	22.34	1.12	0.76	19.02	22.32	1.11	0.75	18.58	0.98
12	22.25	1.11	0.77	19.02	22.22	1.1	0.78	19.06	1
13	22.23	1.11	0.77	19	22.29	1.11	0.74	18.31	0.96
14	22.32	1.09	0.78	18.98	22.23	1.07	0.77	18.32	0.97
15	22.34	1.12	0.76	19.02	22.11	1.12	0.75	18.57	0.98
16	22.27	1.12	0.76	18.96	22.31	1.11	0.74	18.33	0.97
17	22.31	1.1	0.77	18.9	22.21	1.09	0.76	18.4	0.97
18	22.22	1.09	0.78	18.89	22.24	1.08	0.78	18.73	0.99
19	22.26	1.1	0.77	18.85	22.24	1.08	0.77	18.49	0.98
20	22.24	1.1	0.77	18.84	22.21	1.1	0.77	18.81	1
Average	22.28	1.1	0.78	19.08	22.27	1.09	0.77	18.77	0.98