

Solid-State Synthesis of Lead-Free Perovskite Materials Toward Near-Ultraviolet Flexible Electronics

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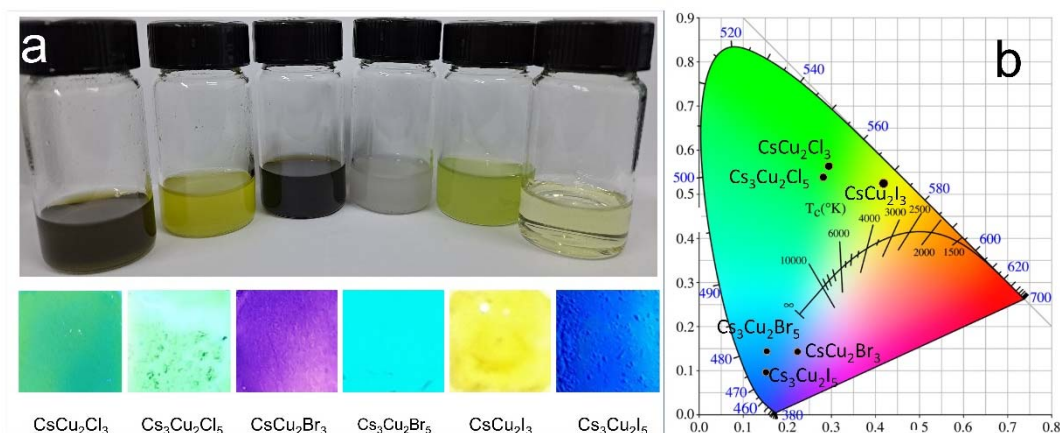


Figure S1. (a) The digital images of CsCu₂Cl₃, Cs₃Cu₂Cl₅, CsCu₂Br₃, Cs₃Cu₂Br₅, CsCu₂I₃ and Cs₃Cu₂I₅ dissolved into DMF. Insets (below the images) demonstrate the corresponding PL emission on paper substrate. (b) CIE 1931 chromaticity plot of the six lead-free halides perovskite.

Table S1. Photophysical properties of Cs₃Cu₂X₅ perovskite, exposed to Air for 60 days

Materials	λ_{ex} (nm)	λ_{em} (nm)	CIE	lifetime (μs)	PLQY(%)
CsCu ₂ Cl ₃	308	530	(0.2938, 0.5643)	111.065	3.69
Cs ₃ Cu ₂ Cl ₅	312	495	(0.2813, 0.5424)	109.815	4.26
CsCu ₂ Br ₃	315	435	(0.1814, 0.1542)	5.433	9.56
Cs ₃ Cu ₂ Br ₅	310	460	(0.155, 0.1415)	20.668	20.22
CsCu ₂ I ₃	334	560	(0.4156, 0.5267)	0.631	22.81
Cs ₃ Cu ₂ I ₅	320	445	(0.1513, 0.0978)	1.002	95.20

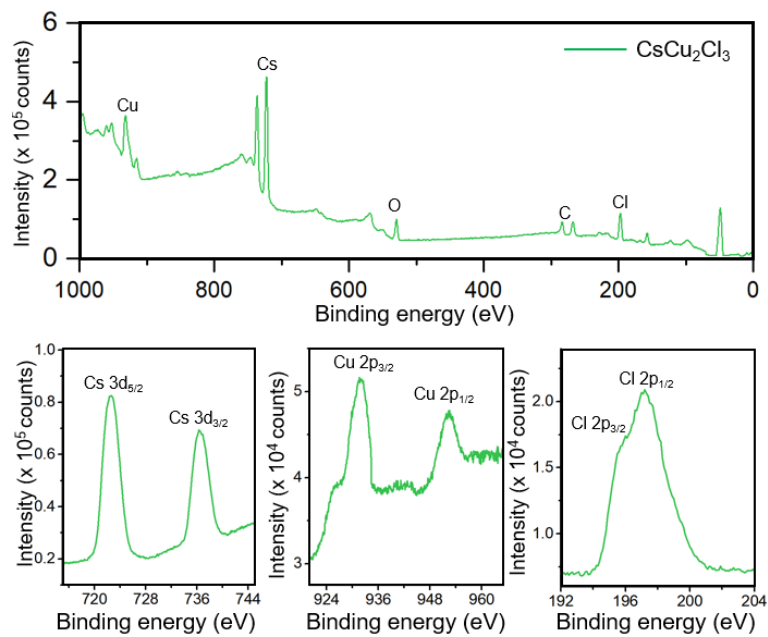


Figure S2. XPS spectra of CsCu_2Cl_3 powders.

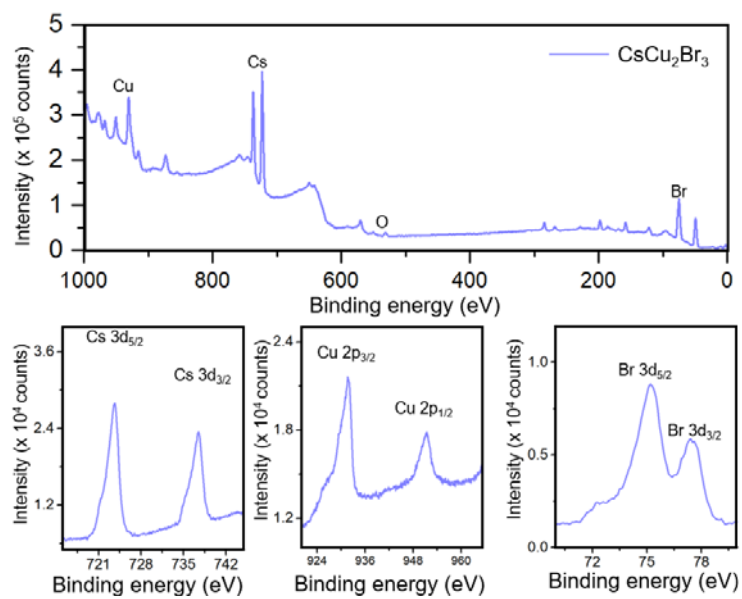


Figure S3. XPS spectra of CsCu_2Br_3 powders.

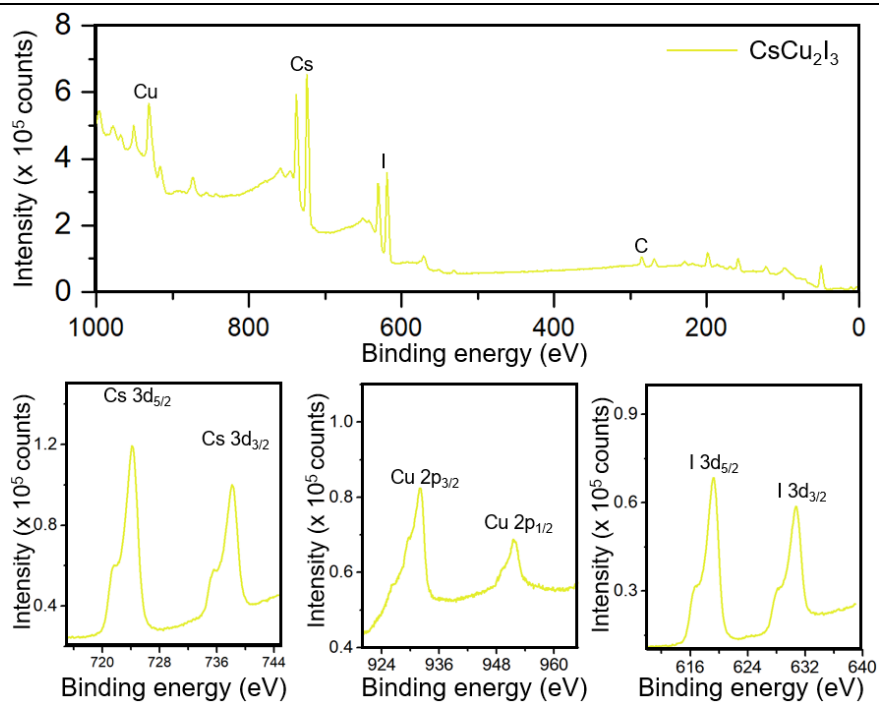


Figure S4. XPS spectra of CsCu_2I_3 powders.

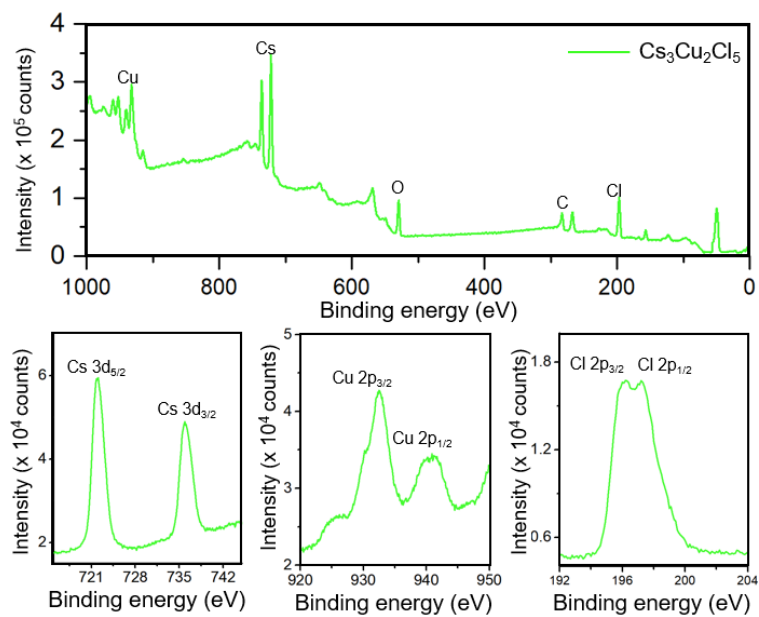


Figure S5. XPS spectra of $\text{Cs}_3\text{Cu}_2\text{Cl}_5$ powders.

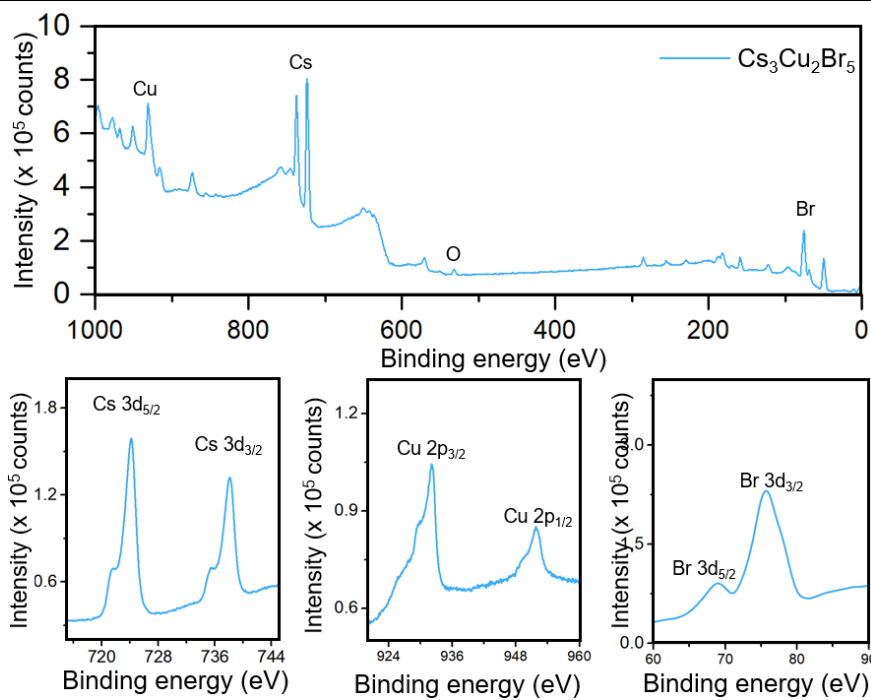


Figure S6. XPS spectra of $\text{Cs}_3\text{Cu}_2\text{Br}_5$ powders.

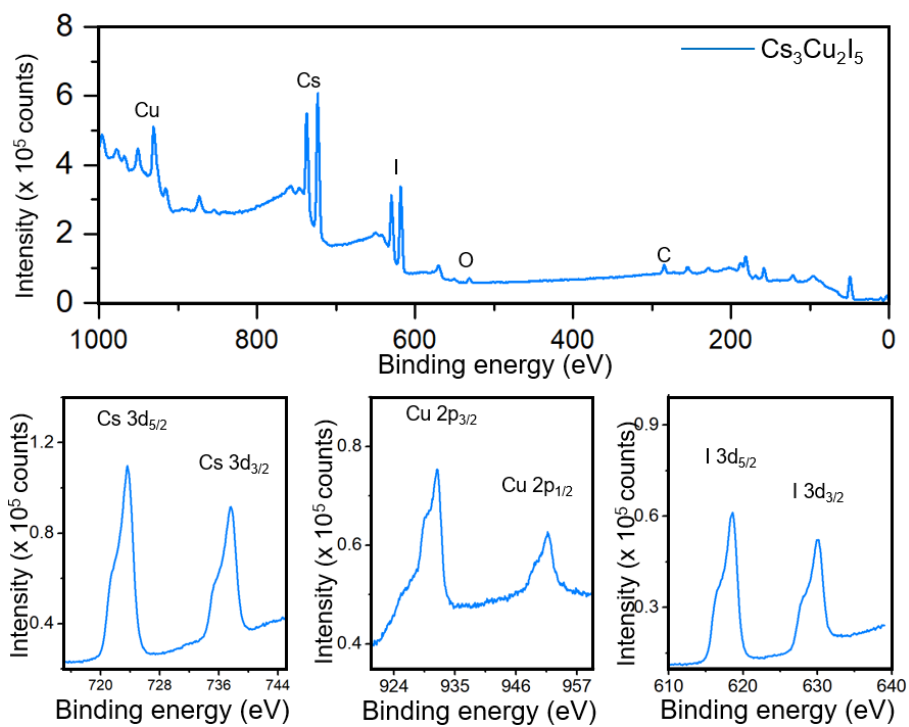
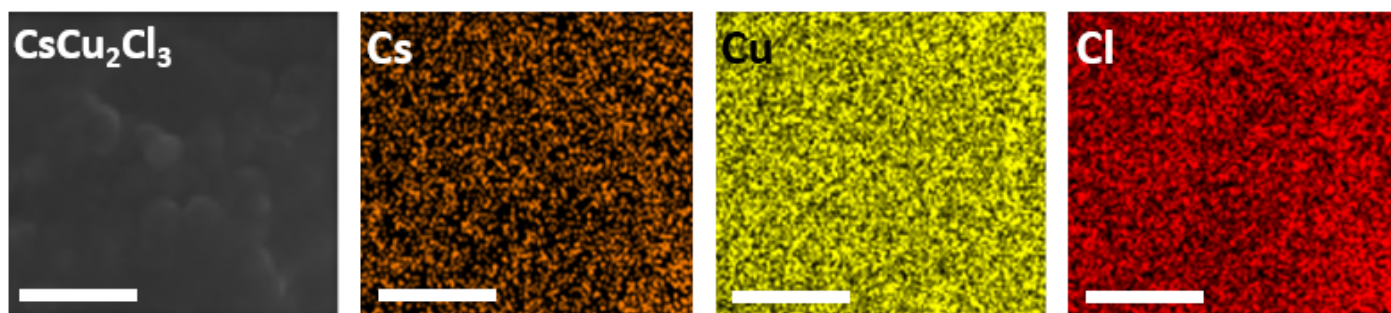
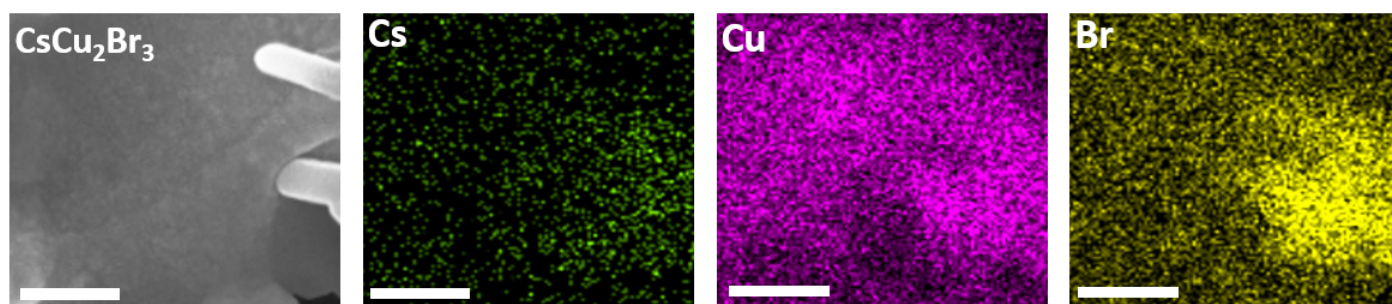


Figure S7. XPS spectra of $\text{Cs}_3\text{Cu}_2\text{I}_5$ powders.



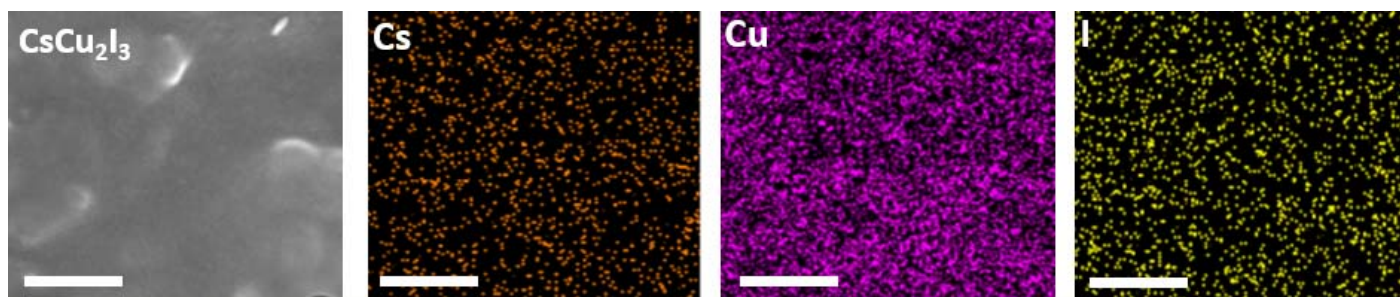
Element	Line Type	Apparent Concentration	k Ratio	Wt%	Wt% Sigma	Atomic %
Cl	L series	15.97	0.12875	31.56	0.34	48.42
Cu	L series	14.73	0.14967	33.86	0.52	35.85
Cs	L series	12.18	0.12177	34.58	0.68	15.73
Total:				100.00		100.00

Figure S8. SEM images (top) of CsCu_2Cl_3 thin film on paper, the scale bar is 500 nm. The colors reflect different material content in pvs. The element EDS results summarized also in the Table below obtained for the corresponding perovskite films on paper.



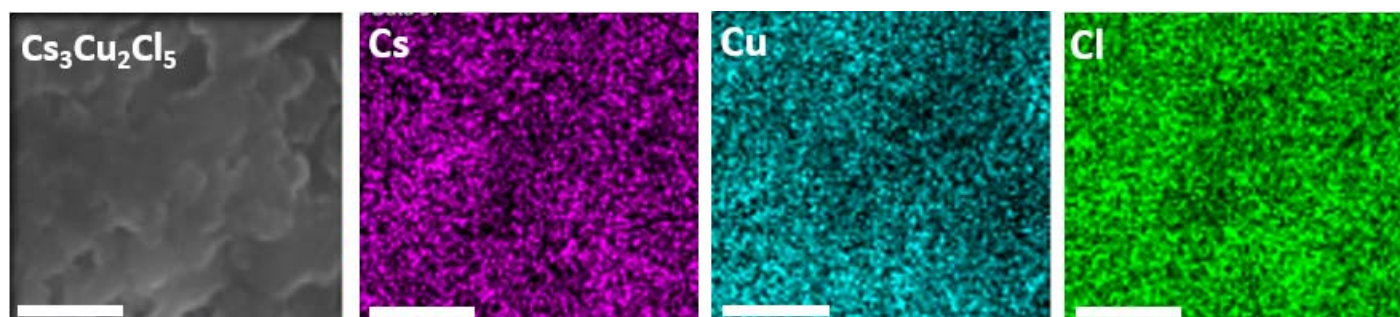
Element	Line Type	Apparent Concentration	k Ratio	Wt%	Wt% Sigma	Atomic %
Br	L series	38.51	0.38514	43.37	0.58	53.91
Cu	L series	22.42	0.20073	13.52	0.49	30.05
Cs	L series	26.58	0.05010	43.11	0.75	16.04
Total:				100.00		100.00

Figure S9. SEM image (top on the left) of CsCu_2Br_3 thin film on paper, the scale bar is 500 nm. The element EDS results of the corresponding perovskite films on paper.



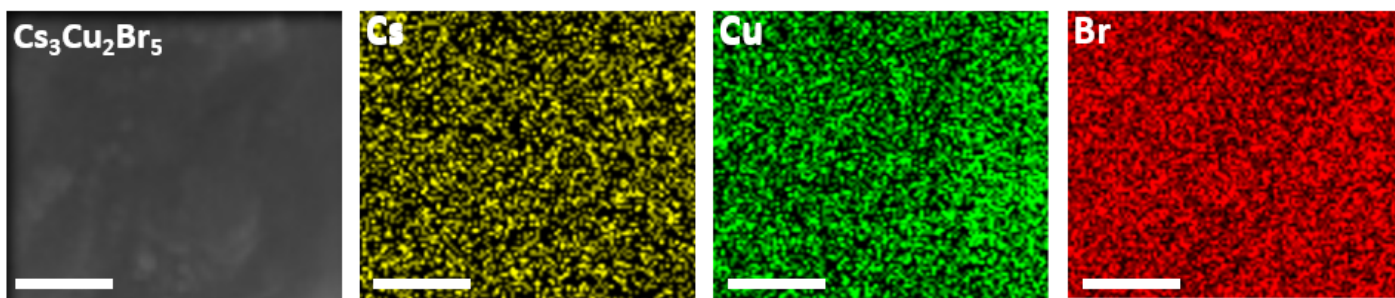
Element	Line Type	Apparent Concentration	k Ratio	Wt%	Wt% Sigma	Atomic %
I	L series	12.63	0.08075	59.58	1.42	35.66
Cu	L series	4.07	0.16631	19.91	1.82	50.78
Cs	L series	4.97	0.02969	20.51	1.94	13.56
Total:				100.00		100.00

Figure S10. SEM image (top on the left) of CsCu_2I_3 thin film on paper, the scale bar is 500 nm. The element EDS results summarized also in the Table below obtained for the corresponding perovskite films on paper.



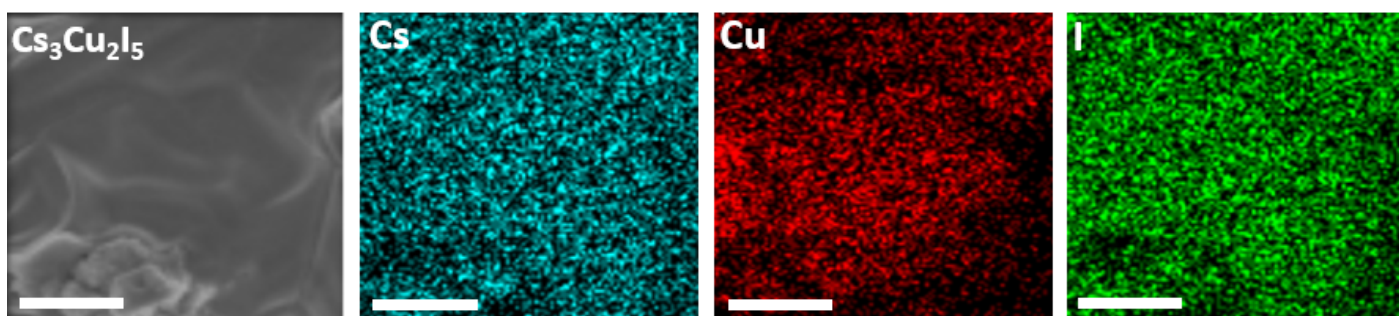
Element	Line Type	Apparent Concentration	k Ratio	Wt%	Wt% Sigma	Atomic %
Cl	K series	40.81	0.35665	23.87	0.26	46.91
Cu	L series	19.27	0.19271	23.00	0.31	25.23
Cs	L series	63.39	0.63392	53.13	0.43	27.86
Total:				100.00		100.00

Figure S11. SEM image (top on the left) of $\text{Cs}_3\text{Cu}_2\text{Cl}_5$ thin film on paper, the scale bar is 500 nm. The element EDS results summarized also in the Table below obtained for the corresponding perovskite films on paper.



Element	Line Type	Apparent Concentration	k Ratio	Wt%	Wt% Sigma	Atomic %
Br	L series	58.98	0.52817	42.67	0.51	49.38
Cu	L series	15.29	0.15294	14.12	0.32	20.56
Cs	L series	63.50	0.63501	43.20	0.59	30.06
Total:				100.00		100.00

Figure S12. SEM image (top on the left) of $\text{Cs}_3\text{Cu}_2\text{Br}_5$ thin film on paper, the scale bar is 500 nm. The element EDS results summarized also in the Table below obtained for the corresponding perovskite films on paper.



Element	Line Type	Apparent Concentration	k Ratio	Wt%	Wt% Sigma	Atomic %
I	L series	94.23	0.94229	54.20	0.60	48.97
Cu	L series	10.94	0.10938	12.24	0.31	22.09
Cs	L series	57.83	0.57827	33.55	0.63	28.94
Total:				100.00		100.00

Figure S13. SEM image (top on the left) of $\text{Cs}_3\text{Cu}_2\text{I}_5$ thin film on paper, the scale bar is 500 nm. The element EDS results summarized also in the Table below obtained for the corresponding perovskite films on paper.

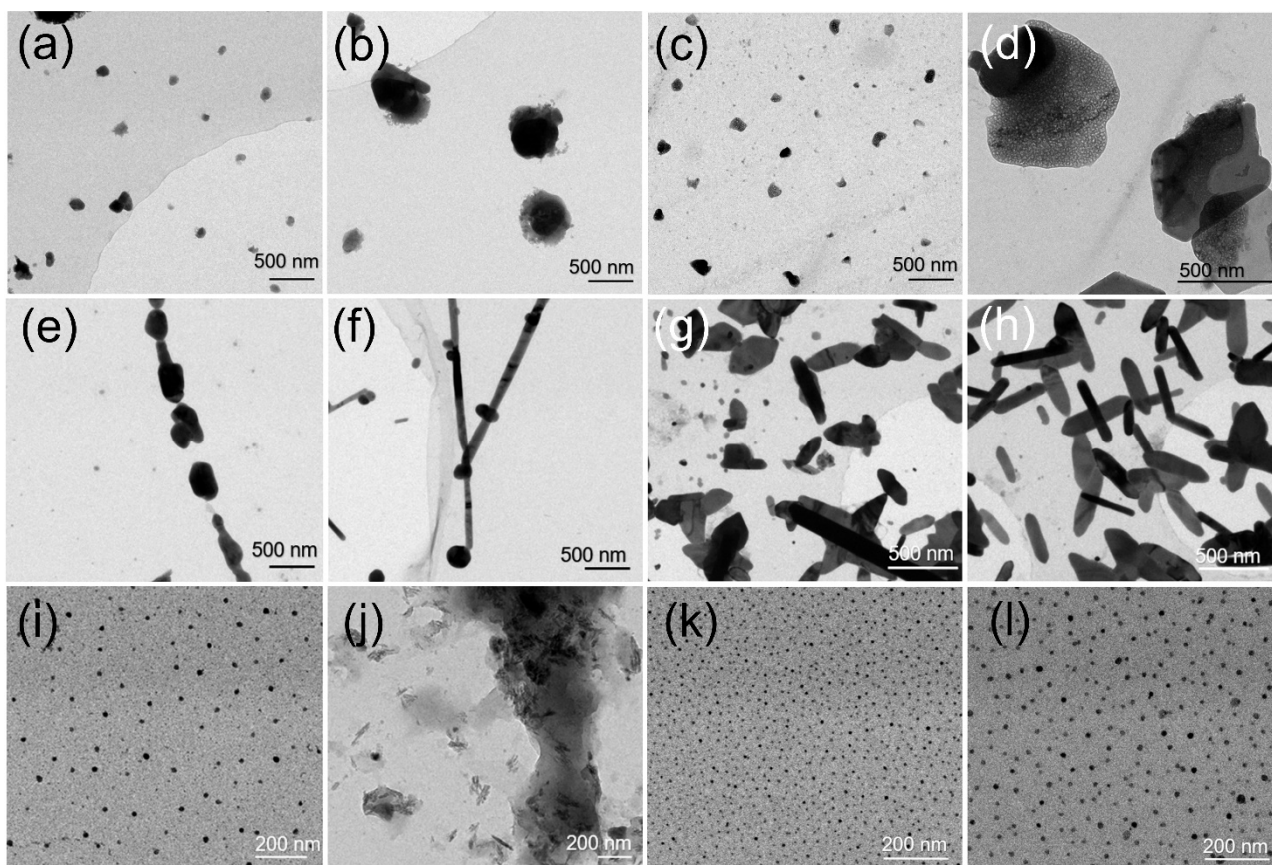


Figure S14. Morphology and shape evolution of the as-prepared CsCu_2X_3 and $\text{Cs}_3\text{Cu}_2\text{X}_5$ NCs synthesized with different reaction time. 2h and 4h; (a) and (b) for CsCu_2Cl_3 , (c) and (d) for $\text{Cs}_3\text{Cu}_2\text{Cl}_5$, (e) and (f) for CsCu_2Br_3 , (g) and (h) for $\text{Cs}_3\text{Cu}_2\text{Br}_5$, (i) and (j) for CsCu_2I_3 , (k) and (l) for $\text{Cs}_3\text{Cu}_2\text{I}_5$, respectively

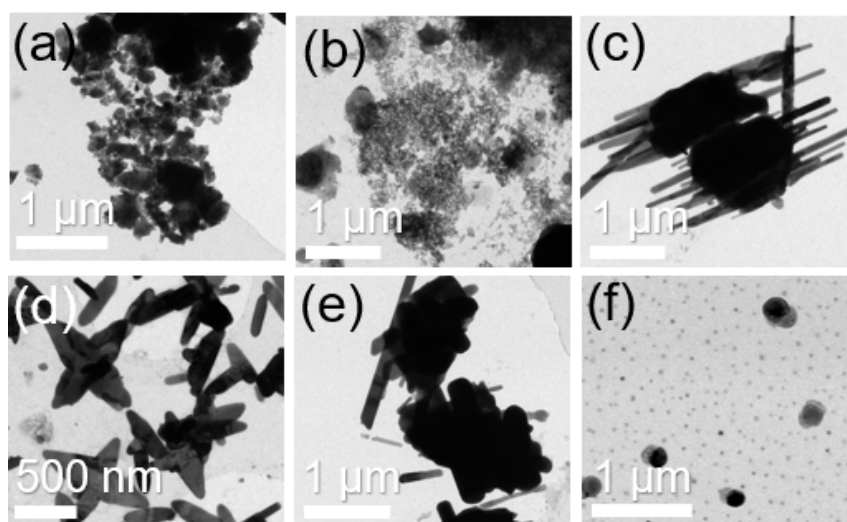


Figure S15. TEM images of (a) CsCu_2Cl_3 (b) $\text{Cs}_3\text{Cu}_2\text{Cl}_5$ (c) CsCu_2Br_3 (d) $\text{Cs}_3\text{Cu}_2\text{Br}_5$ (e) CsCu_2I_3 (f) $\text{Cs}_3\text{Cu}_2\text{I}_5$ obtained for the case of 6h reaction time.

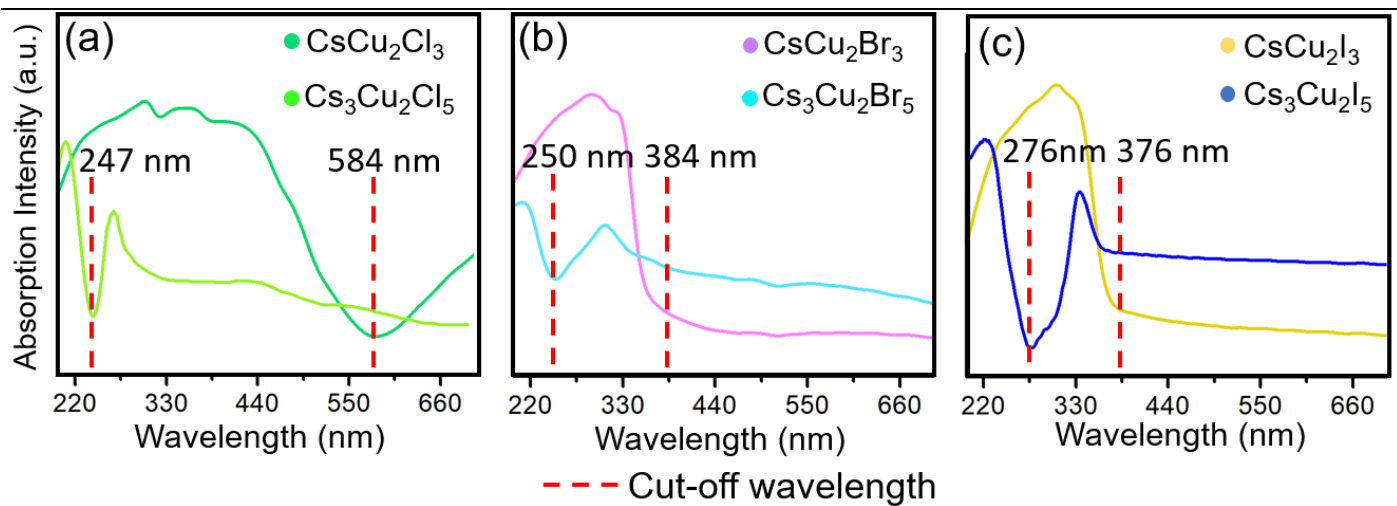


Figure S16. UV/Vis absorption spectra of (a) CsCu_2Cl_3 and $\text{Cs}_3\text{Cu}_2\text{Cl}_5$, (b) CsCu_2Br_3 and $\text{Cs}_3\text{Cu}_2\text{Br}_5$, (c) CsCu_2I_3 and $\text{Cs}_3\text{Cu}_2\text{I}_5$ crystals.