

Supporting Information

**Bi³⁺/Sb³⁺ Co-doped Cs₂HfCl₆ Vacancy-ordered Double Perovskite for
Multifunctional Optoelectronic Applications**

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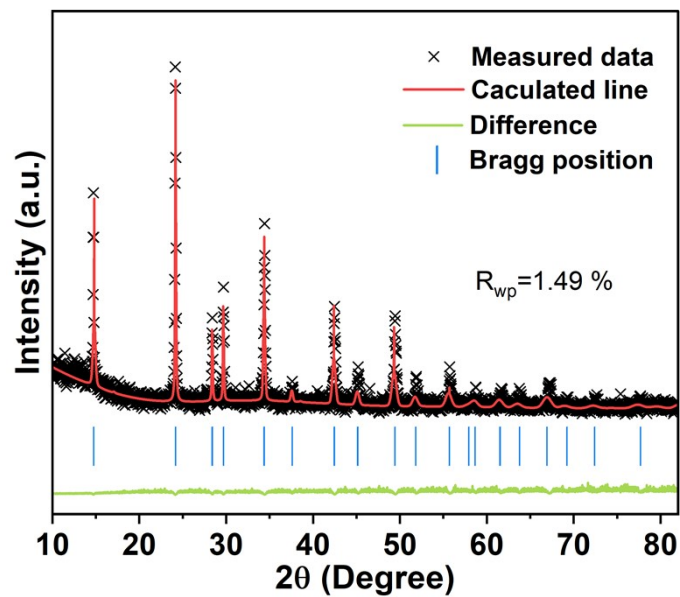


Figure S1. The Rietveld refinement for the XRD pattern of $\text{Cs}_2\text{HfCl}_6:9\%\text{Bi}^{3+}/10\%\text{Sb}^{3+}$.

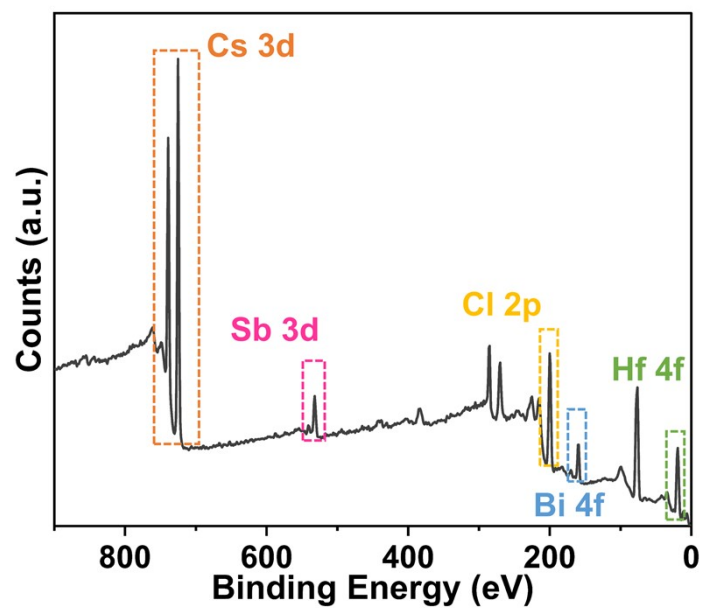


Figure S2. XPS spectrum of $\text{Cs}_2\text{HfCl}_6:9\%\text{Bi}^{3+}/10\%\text{Sb}^{3+}$.

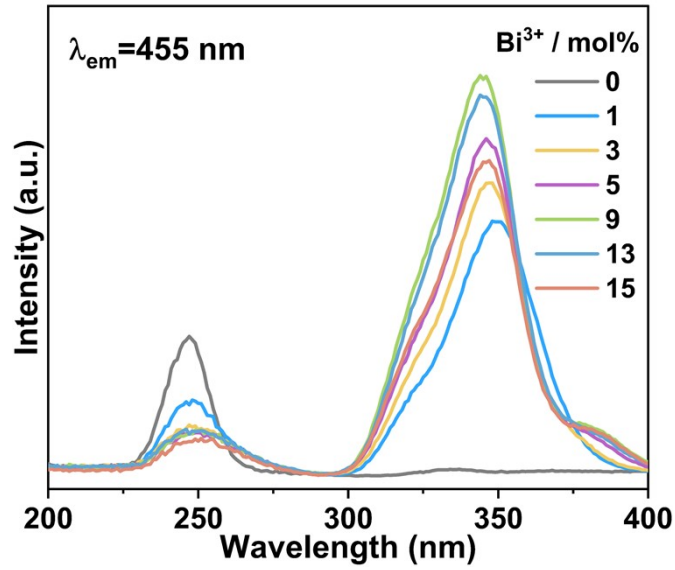


Figure S3. PL excitation (PLE) spectra of $\text{Cs}_2\text{HfCl}_6:x\%\text{Bi}^{3+}$ ($\lambda_{\text{em}}=455$ nm).

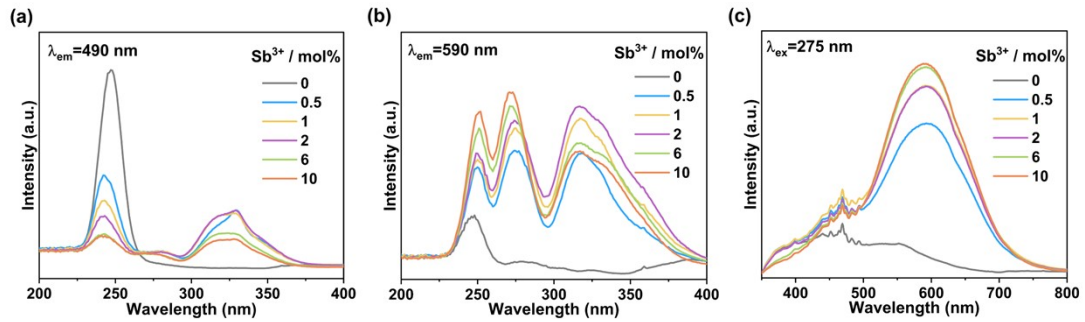


Figure S4. PL excitation spectra monitored at (a) $\lambda_{\text{em}}=490$ nm and (b) $\lambda_{\text{em}}=590$ nm and (c) PL emission spectra excited with $\lambda_{\text{ex}}=275$ nm of $\text{Cs}_2\text{HfCl}_6:y\%\text{Sb}^{3+}$ MCs with different Sb^{3+} concentrations.

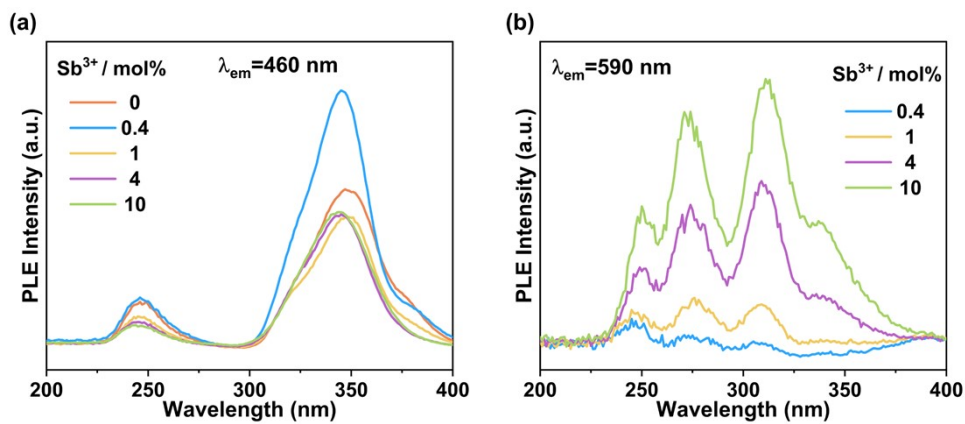


Figure S5. PL excitation spectra (a) $\lambda_{\text{em}}=460$ nm and (b) $\lambda_{\text{em}}=590$ nm of $\text{Cs}_2\text{HfCl}_6:9\%\text{Bi}^{3+}/y\%\text{Sb}^{3+}$ MCs with different Sb^{3+} concentrations.

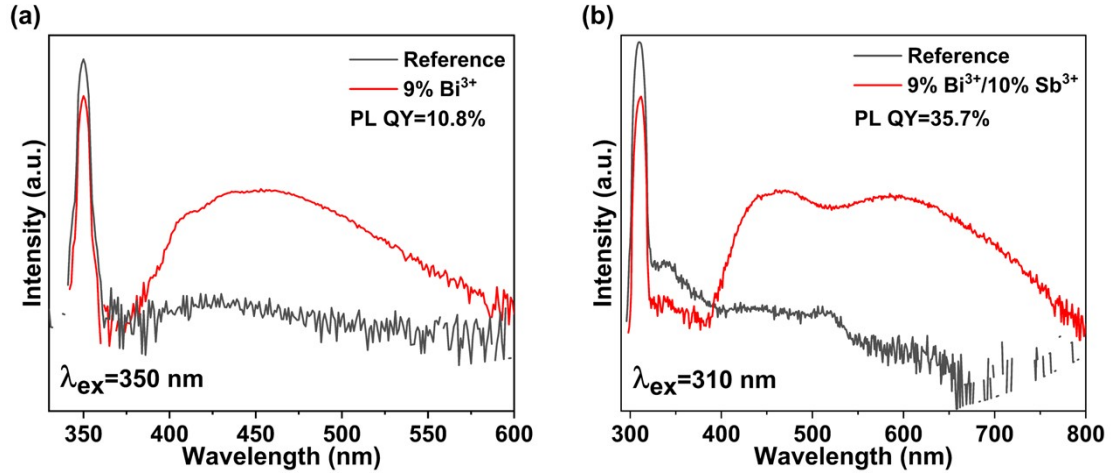


Figure S6. PL QYs of (a) $\text{Cs}_2\text{HfCl}_6:9\%\text{Bi}^{3+}$, (b) $\text{Cs}_2\text{HfCl}_6:9\%\text{Bi}^{3+}/10\%\text{Sb}^{3+}$.

Table S1 The ICP results of $\text{Cs}_2\text{HfCl}_6:9\%\text{Bi}^{3+}/10\%\text{Sb}^{3+}$ sample

Bi (mmol/mL)	Sb (mmol/mL)	Hf (mmol/mL)	Bi^{3+} content (%)	Sb^{3+} content (%)
3.11	2.82	75.8	4.1	3.7

Table S2 PL decay curve of $\text{Cs}_2\text{HfCl}_6:x\%\text{Bi}^{3+}$ ($\lambda_{\text{ex}}=365$ nm, $\lambda_{\text{em}}=455$ nm)

x mol% Bi^{3+}	0	1	3	5	9	13	15
τ (ns)	753.66	723.52	667.45	680.00	684.04	663.37	680.83

Table S3 PL decay curves of $\text{Cs}_2\text{HfCl}_6:y\%\text{Sb}^{3+}$ ($\lambda_{\text{ex}}=365$ nm, $\lambda_{\text{em}}=490$ nm)

y mol% Sb^{3+}	τ_1	Rel.%	τ_2	Rel.%	τ_{ave} (ns)
0.5	83.59	14.52	1811.03	85.48	1560.27
1	85.07	21.88	1882.39	78.12	1489.15
2	89.48	27.69	2062.52	72.31	1516.25
6	89.85	30.47	2186.32	69.53	1547.63
10	87.41	30.14	2291.40	69.86	1627.19

Table S4 PL decay curve of Cs₂HfCl₆:y%Sb³⁺ (λ_{ex} =365 nm, λ_{em} =590 nm)

y mol% Sb ³⁺	0.5	1	2	6	10
τ (ns)	5683.09	5770.40	5670.02	5638.20	5631.59