Supporting Information

Te^{4+} doped zero-dimensional perovskite for dual-mode thermometry in electronic devices

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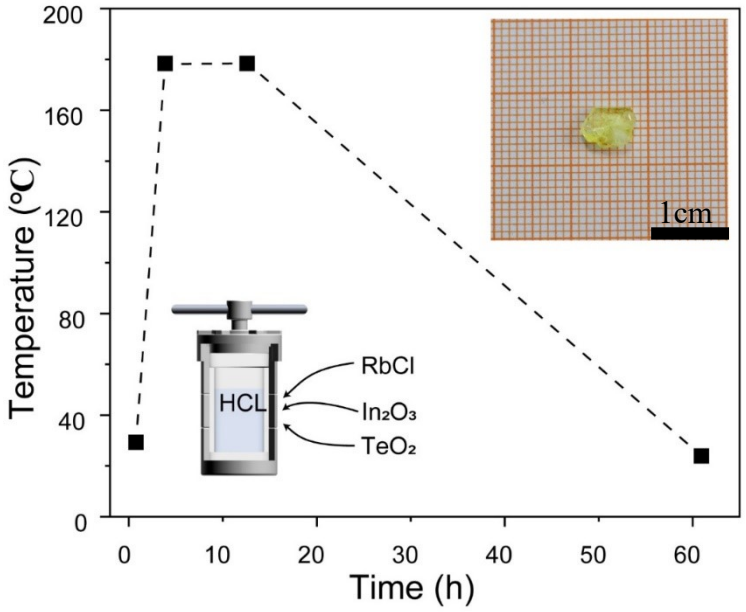

Figure S1. Showing the preparation procedure of $Rb_2InCl_5 \cdot H_2O:Te^{4+}$ single crystal.

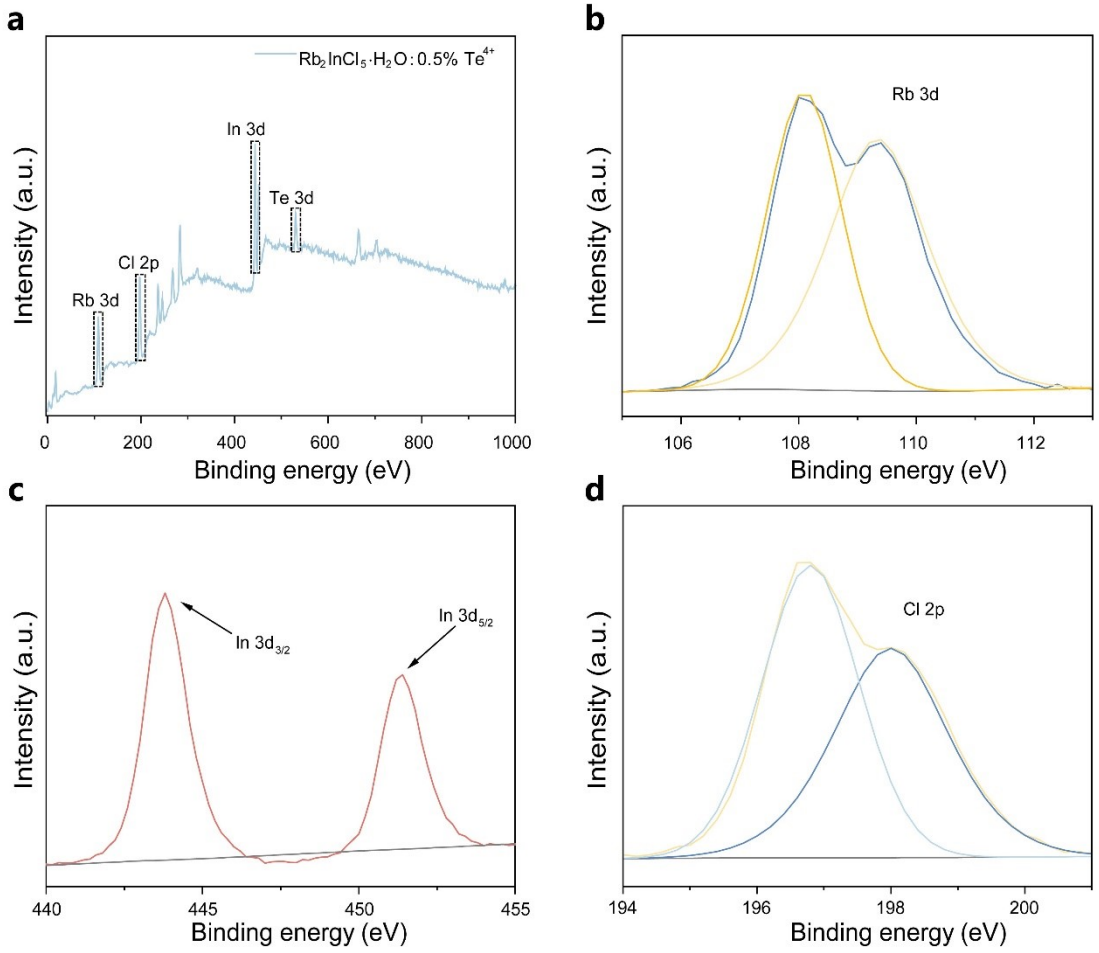

Figure S2. XPS survey spectrum of $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+} a) The High-resolution XPS spectra of $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+} corresponding to b) Rb 3d, c) In 3d and d) Cl 2P respectively.

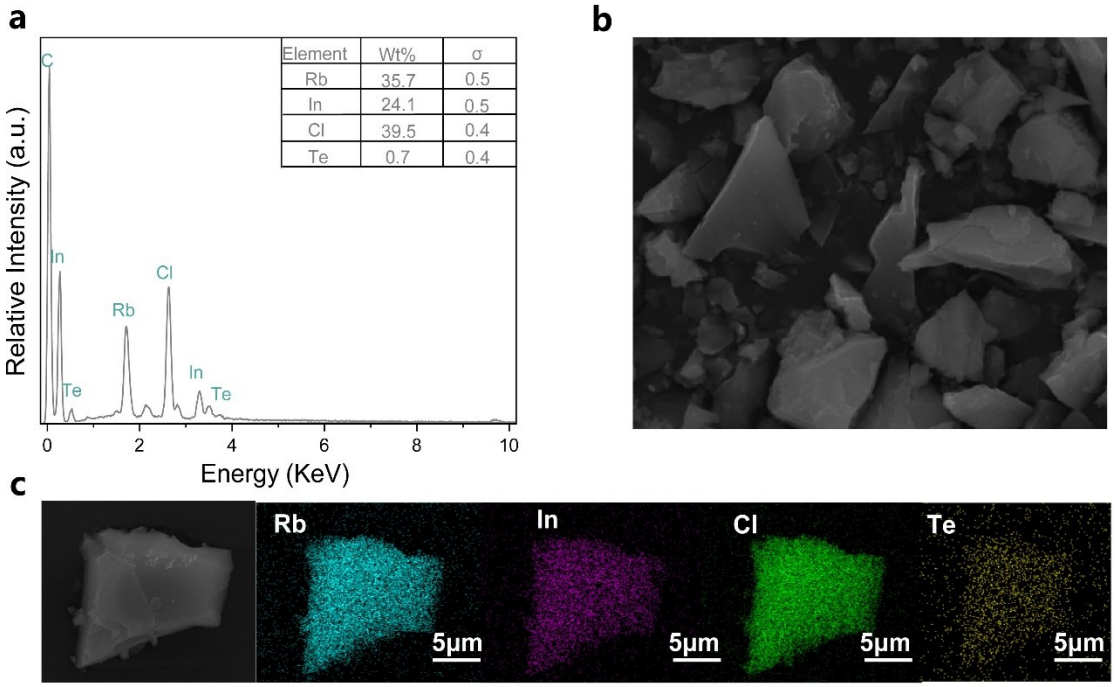

Figure S3.a) Energy disperse spectrum of $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+}. b) and c) SEM and EDS-mapping of selected area for $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+}.

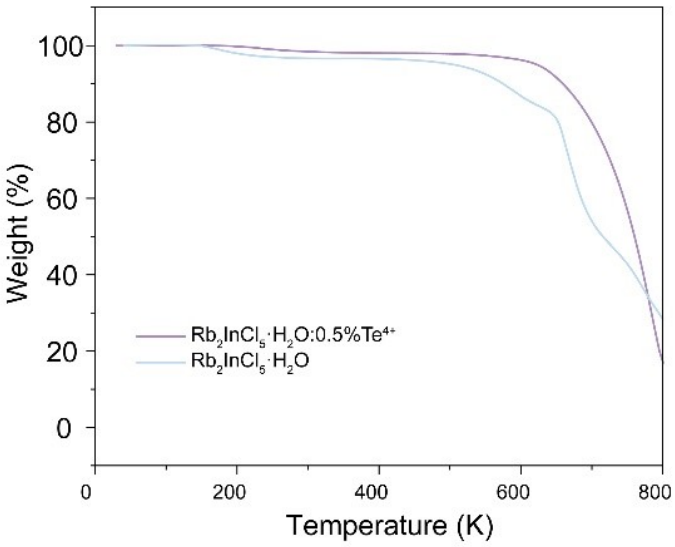

Figure S4. Thermogravimetric curves of $Rb_2InCl_5 \cdot H_2O$ and $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+}.

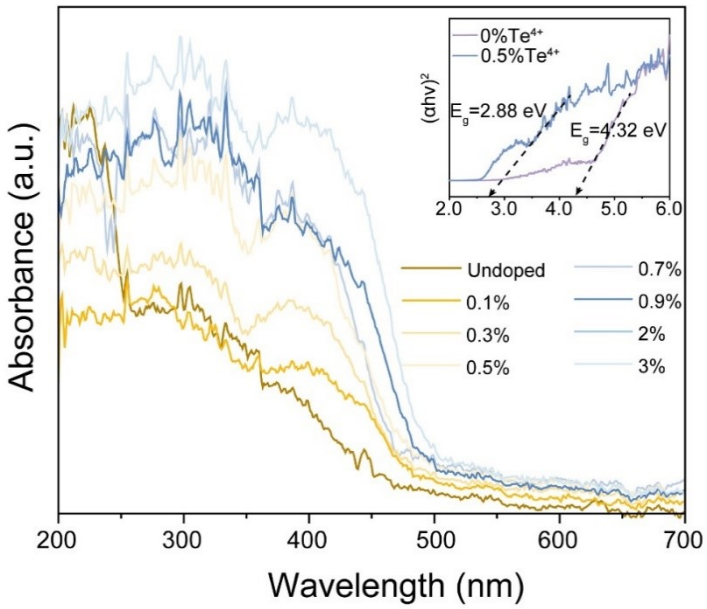

Figure S5. The spectra of $Rb_2InCl_5 \cdot H_2O$:xTe^{4+}(x=0.1-3%) and Tauc plots of $Rb_2InCl_5 \cdot H_2O$ and $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+}

The optical band gap can be calculated by the following formula:

$$\left[F(R_\infty)hv\right]^n = A(hv - E_g)$$

where hv is the photon energy, A is the proportional constant and E_g is the optical bandgap value.

Considering the direct bandgap of $Rb_2InCl_5 \cdot H_2O$:Te^{4+}, n = 2 is used to reckoning. is the F(R∞) Kubelka−Munk function defined as:

$$F(R_\infty) = (1 - R)^2 \,/\, 2R = K/S$$

Where R, K, and S are the reflection, absorption, and scattering coefficient, respectively. From the linear extrapolation of = 0 in Figure S5, the bandgap of $Rb_2InCl_5 \cdot H_2O$ and $Rb_2InCl_5 \cdot H_2O$:Te^{4+} $[F(R_\infty)hv]_2$ Te^{4+} is calculated to be 2.88eV and 4.32 eV respectively.

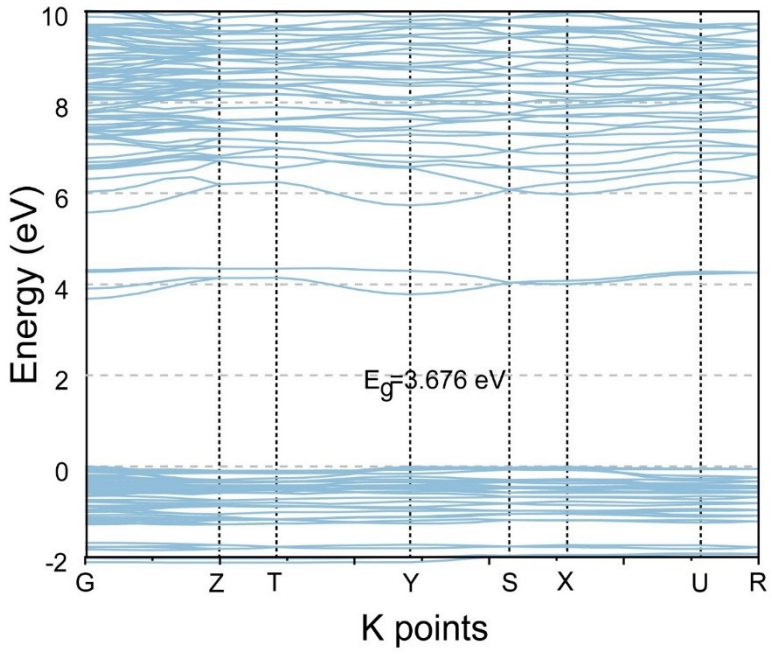

Figure S6. Calculated band structures for a $Rb_2InCl_5 \cdot H_2O$.

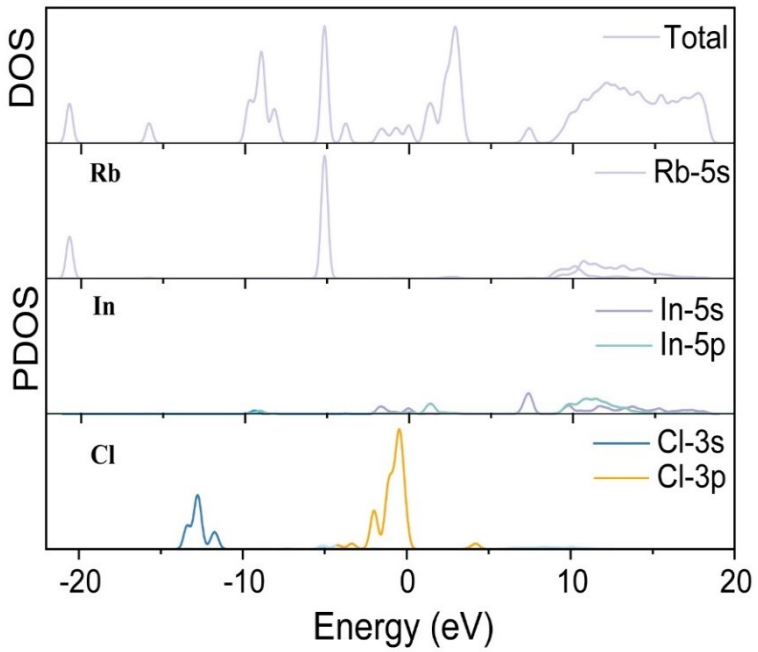

Figure S7. Calculated partial density of states for $Rb_2InCl_5 \cdot H_2O$.

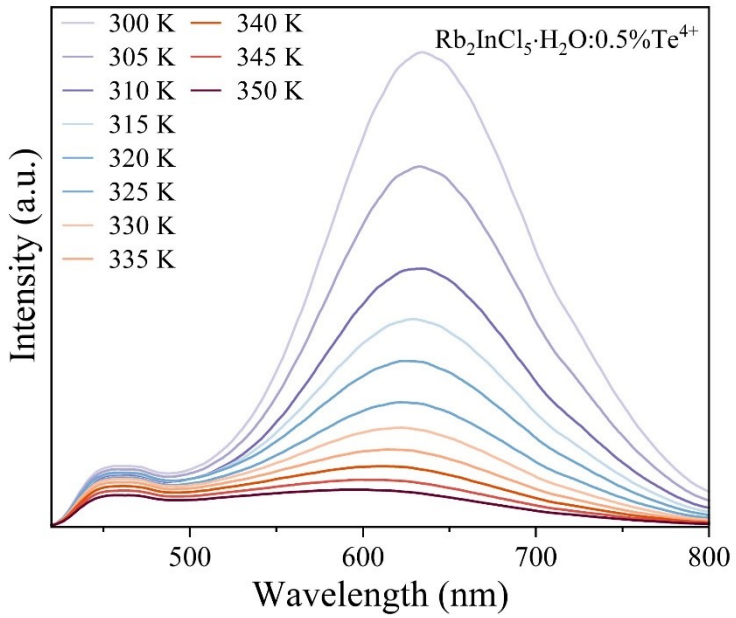

Figure S8. Temperature-dependent PL spectra of $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+}.

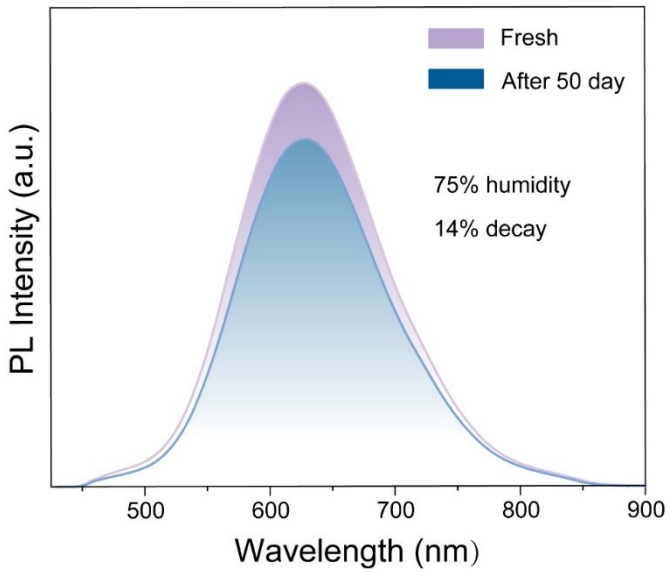

Figure S9. PL spectra of the $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+} single crystal before and after storage for 50 days in air ambient (75% humidity).

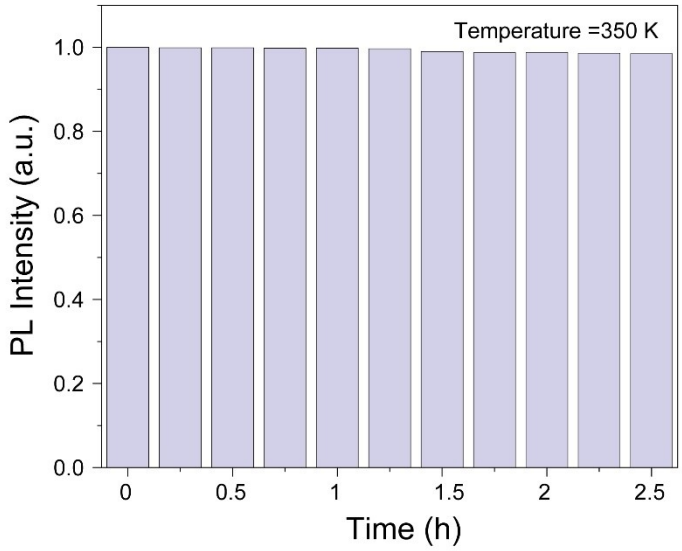

Figure S10. Fluorescent thermal stability at 350k.

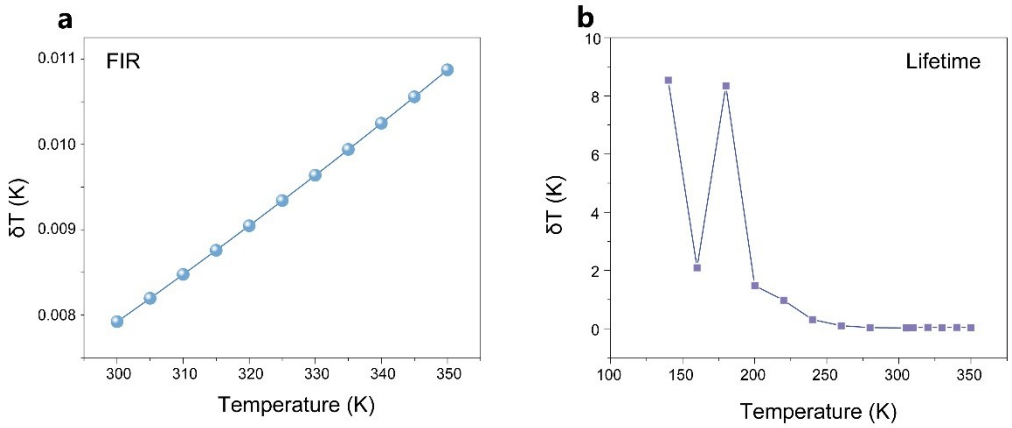

Figure S11. a) Temperature resolution of FIR mode in the temperature range from 300 K to 350 K. **b)** Temperature resolution of lifetime mode in the temperature range from 120 K to 350 K.

Table S1. Crystal data information.

Compound	$Rb_2InCl_5 \cdot H_2O$
Empirical formula	$Rb_2InCl_5 \cdot H_2O$
Formula weight	480.99
Crystal system	orthorhombic
Space group	Pnma
a/Å	14.045(1)
b/Å	10.1158(7)
c/Å	7.3551(3)
α/°	90
β/°	90
γ/°	90
Volume/$Å^3$	1027.82(12)

Table S2. The detailed CIE coordinate of the $Rb_2InCl_5 \cdot H_2O$: 0.5%Te^{4+} perovskites.

$Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+}	CIE x	CIE y
300K	0.551	0.409
305K	0.532	0.403
310K	0.491	0.396
315K	0.455	0.381
320K	0.436	0.374
325K	0.415	0.361
330K	0.397	0.357
335K	0.377	0.346
340K	0.359	0.338
345K	0.340	0.327
350K	0.325	0.322

Table S3. Fluorescence lifetime and proportion of $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+} at different temperatures.

Temperature (K)	Average lifetime (ns)
300	608.23
305	484.52
310	393.53
315	326.53
320	266.81
325	206.28
330	166.28
335	130.7
340	107.87
350	73.72

Table S4. The lattice constants of $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+} at different temperatures.

Temperature (K)	*a* (Å)	*b* (Å)	*c* (Å)
310	14.048	10.119	7.240
320	14.054	10.123	7.243
330	14.058	10.127	7.245
340	14.064	10.132	7.247
350	14.066	10.137	7.251

Table S5. Bond length and cell volume of $Rb_2InCl_5 \cdot H_2O$:0.5%Te^{4+} at different temperatures.

Temperature (K)	(Sc/Te) Cl1 (Å)	(Sc/Te) Cl2 (Å)	(Sc/Te) Cl3 (Å)	(Sc/Te) Cl4 (Å)	(Sc/Te) Cl5 (Å)	(Sc/Te) −O (Å)	Cell Volume (Å^3)
310	2.273	2.349	2.349	2.327	2.326	2.242	1029.21
320	2.282	2.351	2.351	2.393	2.340	2.257	1030.47
330	2.287	2.351	2.351	2.401	2.361	2.270	1031.51
340	2.305	2.352	2.352	2.415	2.367	2.271	1032.67
350	2.313	2.352	2.352	2.430	2.436	2.282	1033.92

Table S6. Sensing sensitivity of the reported halide perovskite-based optical thermometers.

Perovskite	Readout	Sr %K $^{-1}$	Max. Sr (K)	Ref.
$[C(NH_2)_3]_2SnBr_4$	Lifetime	6.00	300	[1]
$Rb_7Sb_3Cl_{16}$	Lifetime	6.00	300	[2]
TPP_2SbBr_5	Lifetime	4.50	300	[3]
$Cs_2Ag_{0.6}Na_{0.4}In_{0.9}Bi_{0.1}Cl_6$	FIR	1.37	345	[4]
$:Er^{3+}$, Yb^{3+}	Lifetime	8.70	300	
$Cs_2InCl_5 \cdot H_2O:Te^{4+}$	Lifetime	6.2	320	[5]
$Cs_2NaBiCl_6:Yb^{3+}$, Er^{3+}	FIR	1.57	315-573	[6]
$Rb_2SnCl_6:Te^{4+}$	Lifetime	3.53	310	[7]
$CsPbCl_3:Mn^{2+}$	FIR	7.38	298	[8]
$Rb_2ScCl_5 \cdot H_2O:Te^{4+}$	Lifetime	3.53	310	[9]
$Cs_2ScCl_5 \cdot H_2O:Te^{4+}$	Lifetime	27.36	325	[10]
$Cs_2NaAgInBiCl_6$	Lifetime	1.40	280	[11]
$:Ho^{3+}$, Yb^{3+}				
$Rb_2ZrCl_6:Te^{4+}$	Lifetime	0.89	220	[12]
$Cs_2NaYCl_6:Sb^{3+}$, Ln^{3+}	FIR	4.4	355-370	[13]
$(C_8H_{12}NO_2)_2PbBr_4:Mn^{2+}$	Lifetime	8.09	310	[14]
$Cs_2NaInCl_6:Sb^{3+}$, Er^{3+}	FIR	1.59	260	[15]
$Rb_2InCl_5 \cdot H_2O:Te^{4+}$	FIR	3.67	350	This
	Lifetime	14.65	300-350	

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