Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

The Role of Gold Oxidation State in the Synthesis of Au-$CsPbX_3$ Heterostructure or Lead-free $Cs_2Au^{I}Au^{III}X_6$ Perovskite Nanoparticles

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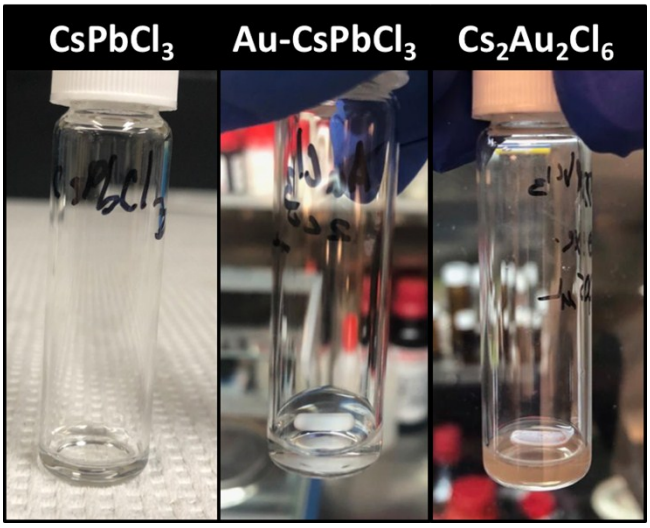

Figure S1. Photograph of suspension $CsPbCl_3$ nanocrystals after gold deposition or cation exchange reactions. $CsPbCl_3$ (left), Au-$CsPbCl_3$ (middle), and $Cs_2Au_2Cl_6$ (right). The photogrpahs were taken after 1 minutes of reaction.

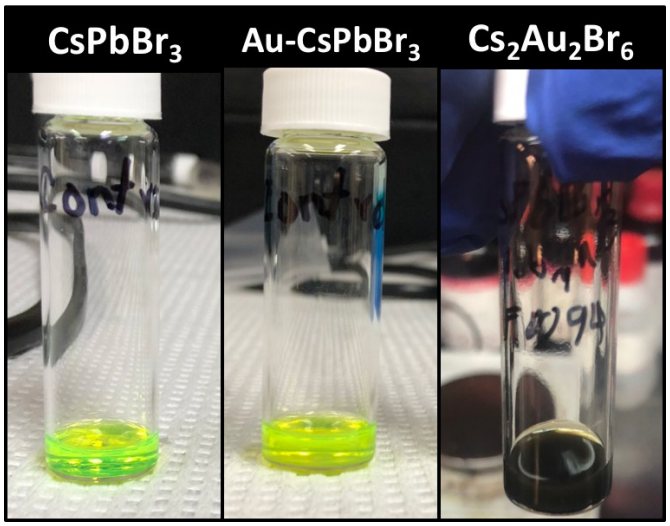

Figure S2. Photograph of suspension of $CsPbBr_3$ nanocrystals after gold deposition or cation exchange reactions. $CsPbBr_3$ (left), Au-$CsPbBr_3$ (middle), and $Cs_2Au_2Br_6$ (right), . The photogrpahs were taken after 5 minutes of reaction.

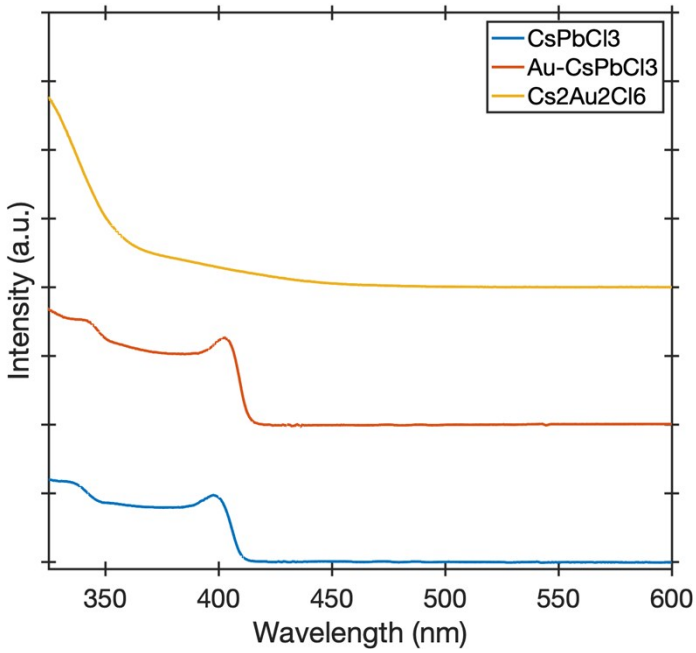

Figure S3. Absorbance of $CsPbCl_3$ nanocrystals before and after Au metal deposition compared to the cation exchange product, $Cs_2Au_2Cl_6$.

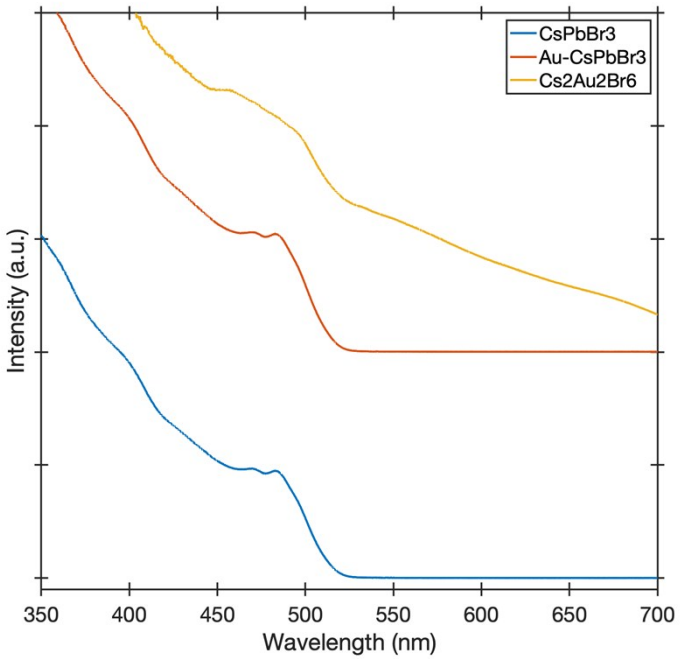

Figure S4. Absorbance of $CsPbBr_3$ nanocrystals before and after Au metal deposition compared to the cation exchange product, Cs_2Au_2B

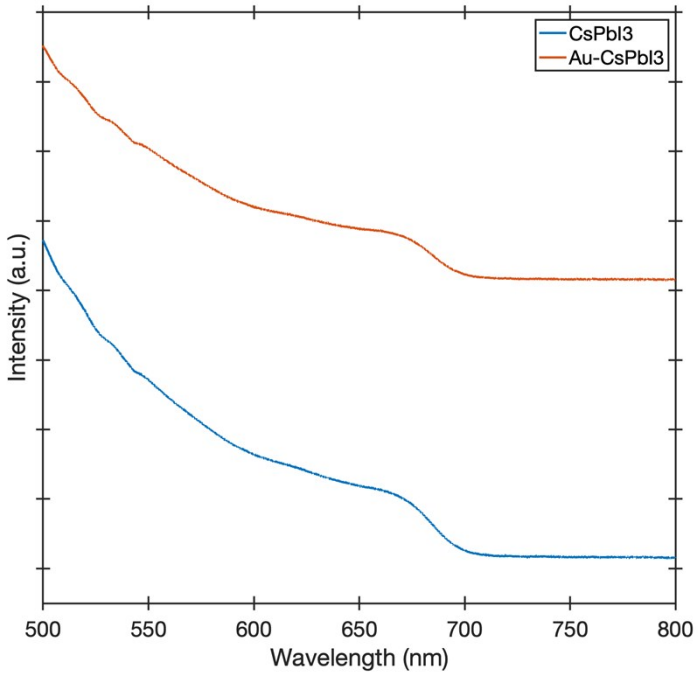

Figure S5. Absorbance of $CsPbI_3$ nanocrystals before and after Au metal deposition.

Additional TEM images

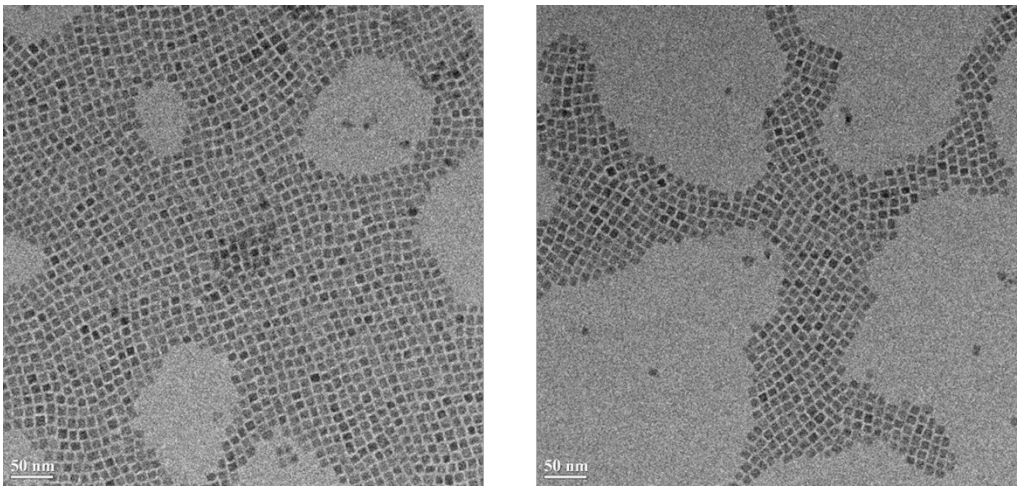

Figure S6. TEM image of $CsPbCl_3$. Average particle edge length is 8.3 ± 1.3 nm

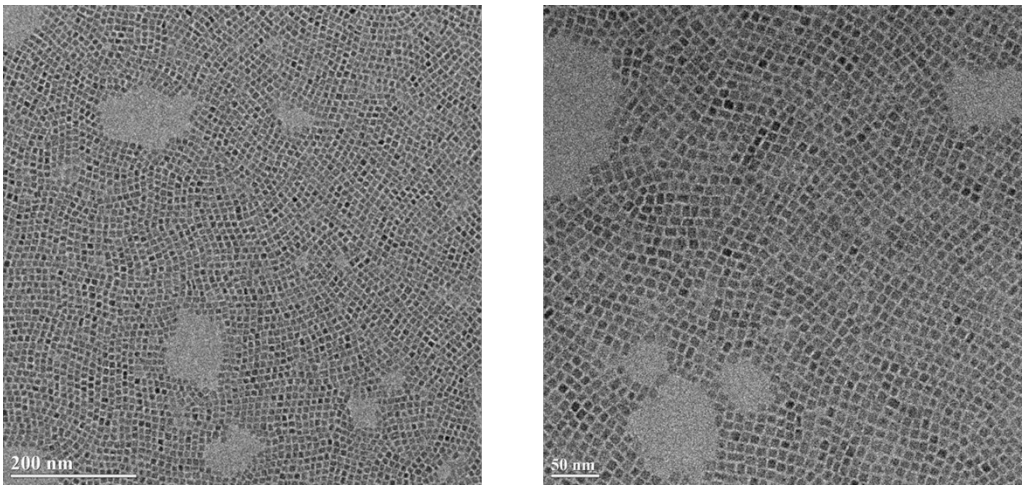

Figure S7. TEM image of $CsPbBr_3$. Average particle edge length is 8.2 ± 1.1 nm

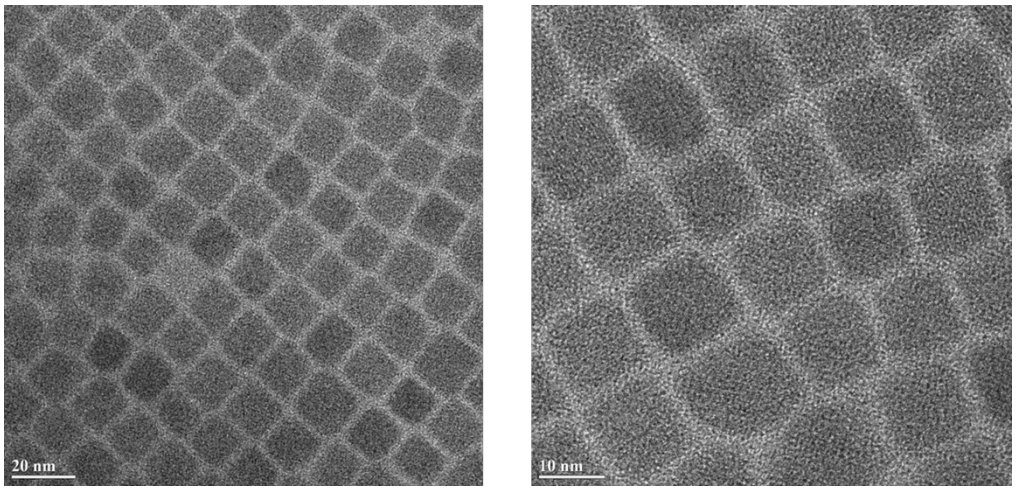

Figure 8. TEM image of $CsPbI_3$. Average particle edge length is 9.6 ± 1.6 nm

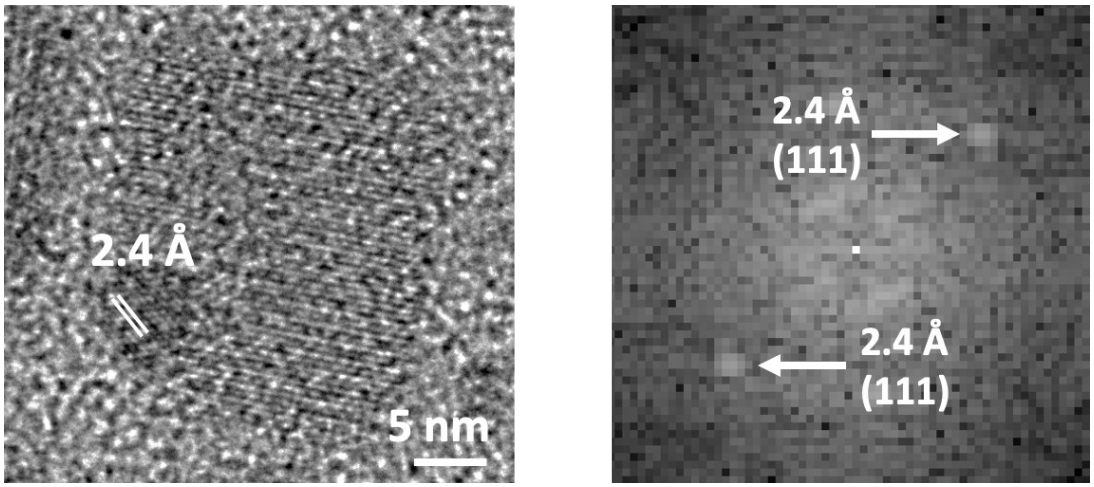

Figure S9. Left) HRTEM image of an Au-$CsPbCl_3$ NCs showing the fringes of the Au nanoparticles (yellow square). (Right) Fast Fourier transform revealing the lattice spacing between (111) planes of cubic gold.

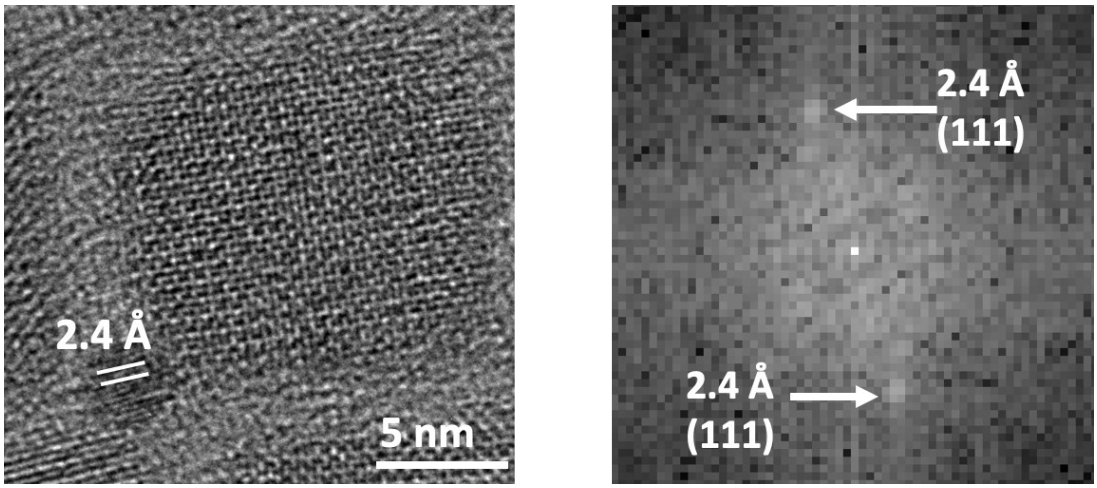

Figure S10. Left) HRTEM image of an Au-$CsPbBr_3$ NCs showing the fringes of the Au nanoparticles (yellow square). (Right) Fast Fourier transform revealing the lattice spacing between (111) planes of cubic gold.

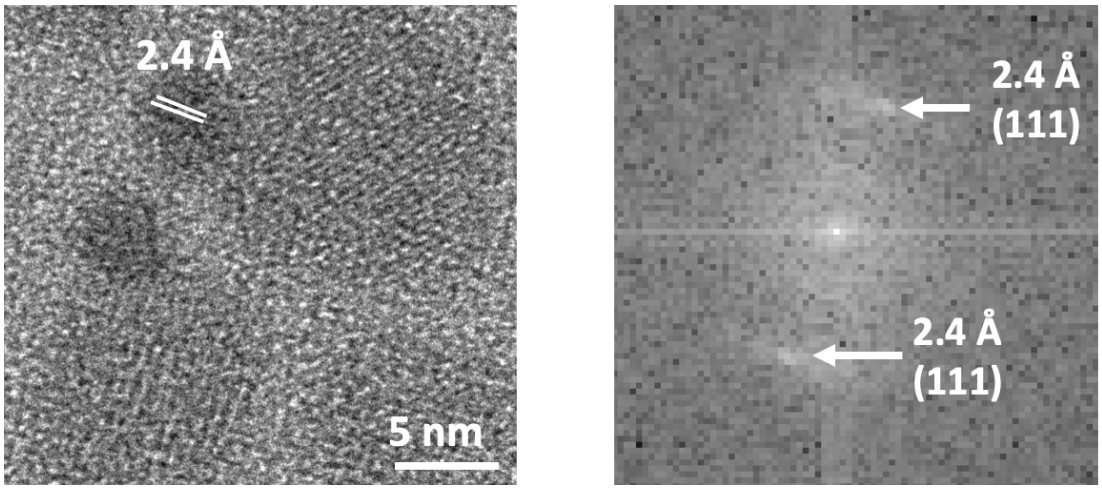

Figure S11. Left) HRTEM image of an Au-$CsPbI_3$ NCs showing the fringes of the Au nanoparticles (yellow square). (Right) Fast Fourier transform revealing the lattice spacing between (111) planes of cubic gold.

Sample	Fluorescence Quantum Yield (FQY)
$CsPbBr_3$	63.28 %
Au-$CsPbBr_3$	52.07 %
$CsPbCl_3$	6.27 %
Au-$CsPbCl_3$	2.97 %
$CsPbI_3$	35.62 %
Au-$CsPbI_3$	23.05 %

Table S1. PLQY of $CsPbX_3$ perovskite nanocrystal before and after Au deposition.

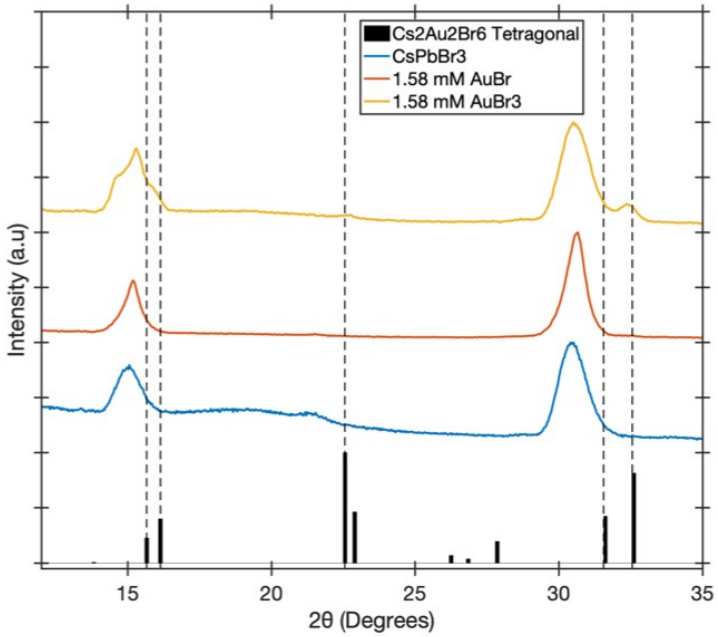

Figure S12. Normalized XRD diffractograms showing the presence and absence of $CsPbBr_3$ and $Cs_2Au_2Br_6$ peaks as 300 µL of 1.58 mM $AuBr_3$ or AuBr are added to identical amounts of $CsPbBr_3$. The peak located at a 2θ value of 32.56 degrees (yellow trace) correspond to the (220) reflection of tetragonal phase $Cs_2Au_2Br_6$. The black ticks on the bottom horizontal axis denote reflections of tetragonal $Cs_2Au_2Br_6$.

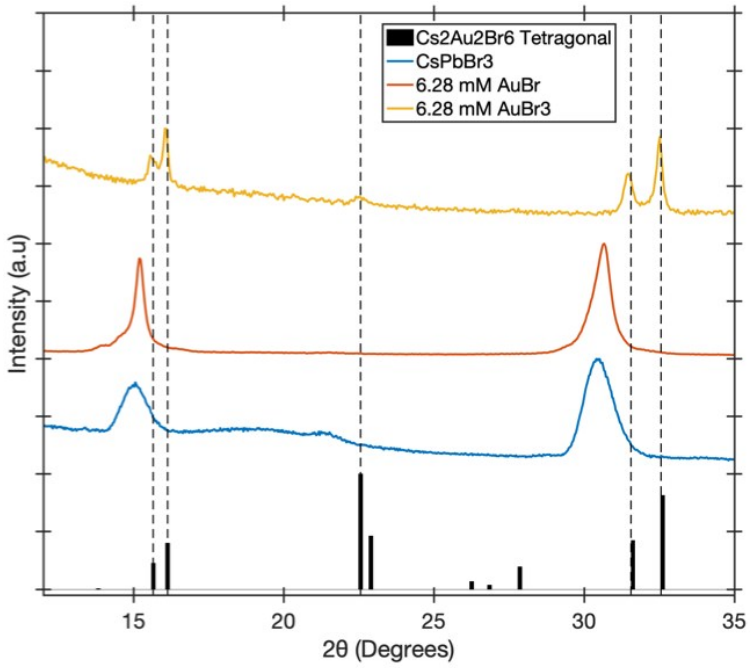

Figure S13. Normalized XRD diffractograms showing the presence and absence of $CsPbBr_3$ and $Cs_2Au_2Br_6$ peaks as 300 µL of 6.28 mM $AuBr_3$ or AuBr are added to identical amounts of $CsPbBr_3$. The black ticks on the bottom horizontal axis denote reflections of tetragonal $Cs_2Au_2Br_6$.

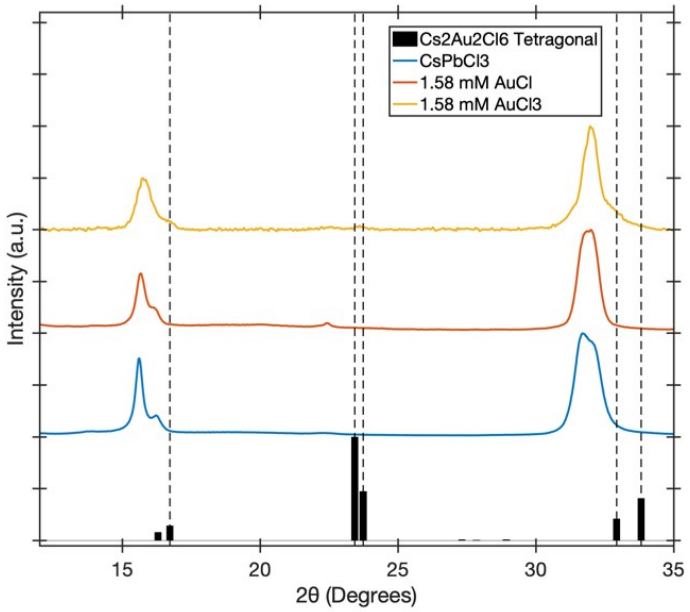

Figure S14. Normalized XRD diffractograms showing the presence and absence of $CsPbBCl_3$ and $Cs_2Au_2Cl_6$ peaks as 300 µL of 1.58 mM $AuCl_3$ or AuCl are added to identical amounts of $CsPbCl_3$. Shoulder peaks at a 2θ values of 16.73 and 32.93 degrees (yellow trace) can be attributed to the (110) and (004) reflections of tetragonal phase $Cs_2Au_2Cl_6$. The black ticks on the bottom horizontal axis denote reflections of tetragonal $Cs_2Au_2Cl_6$.

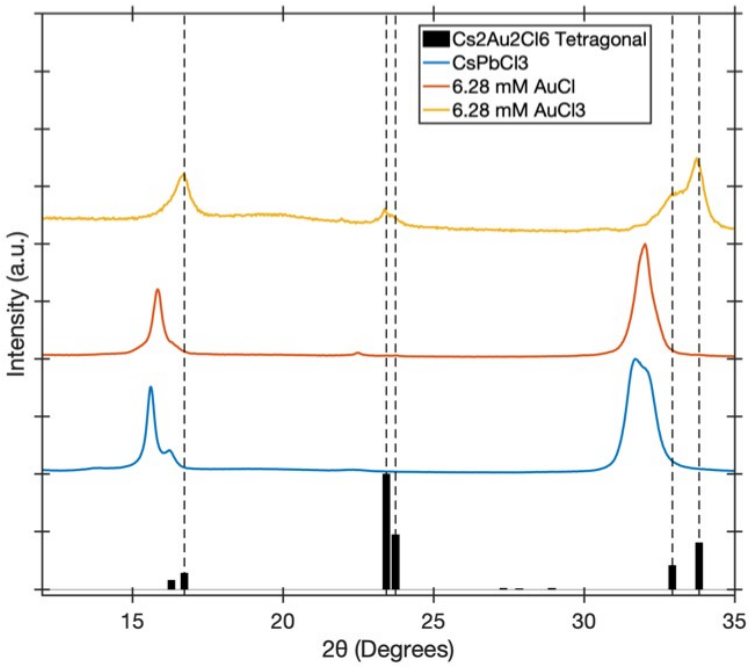

Figure S15. Normalized XRD diffractograms showing the presence and absence of $CsPbCl_3$ and $Cs_2Au_2Cl_6$ peaks as 300 µL of 6.28 mM $AuCl_3$ or 6.28 mM AuCl are added to dentical amounts of $CsPbCl_3$. The black ticks on the bottom horizontal axis denote reflections of tetragonal $Cs_2Au_2Cl_6$.

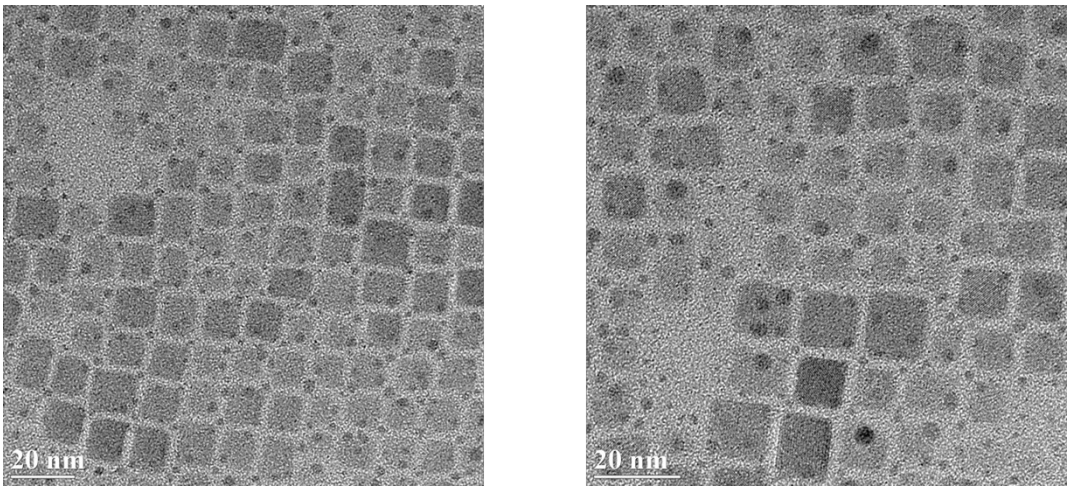

Figure S16. TEM images of Au-$CsPbBr_3$ after Au deposition with 0.3 mL of a 6.28 mM AuBr solution.

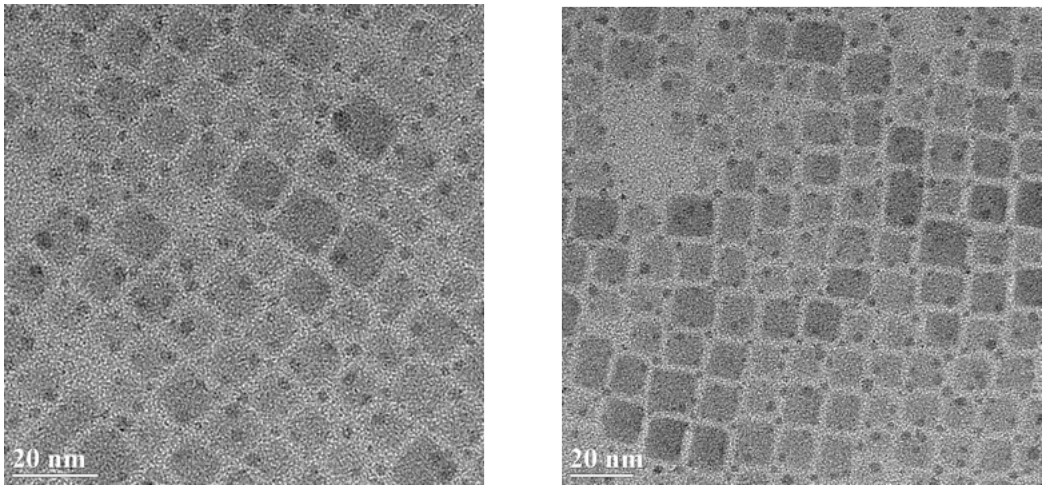

Figure S17. TEM images of Au-$CsPbCl_3$ after Au deposition with 0.3 mL of a 6.28 mM AuCl solution.