Highly Improved Upconversion Luminescence in $NaGd(WO_4)_2:Yb^{3+}/Tm^{3+}$ Inverse Opal Photonic Crystals

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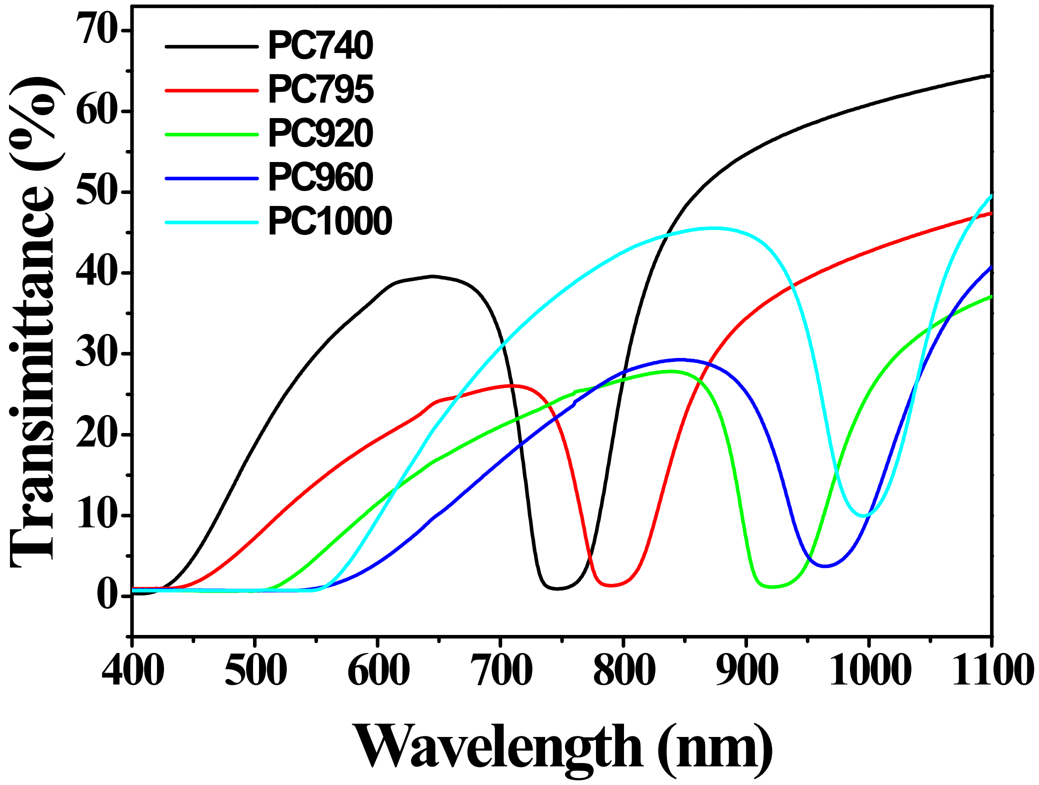

Figure s1: Transmittance spectra of the PMMA templates measured at $\theta = 0^o$.

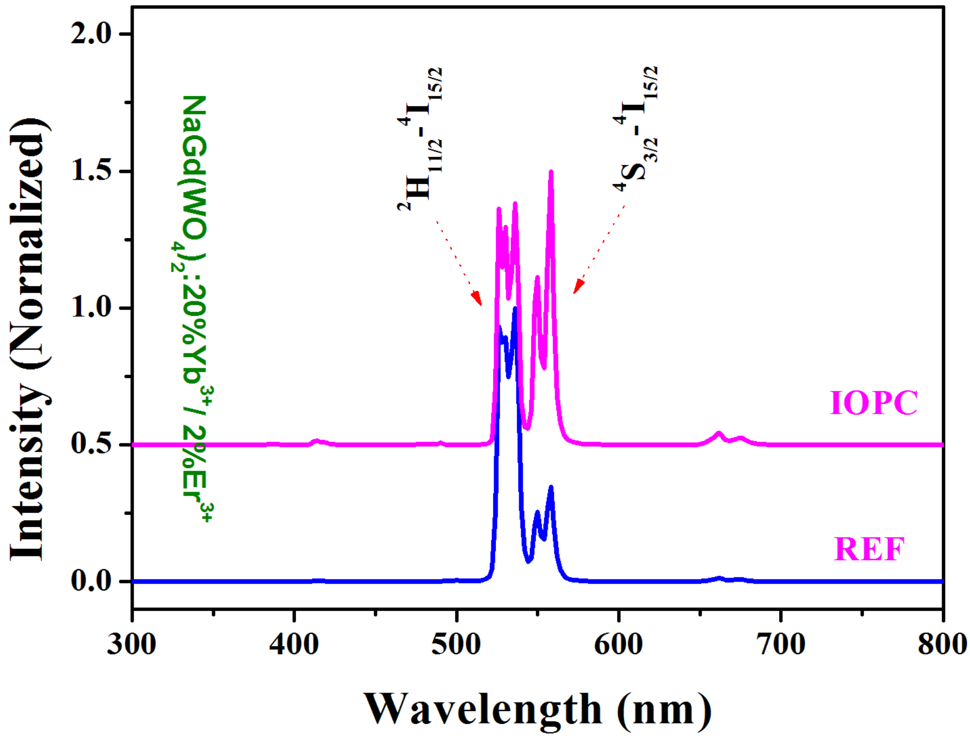

Figure S2: The typical UCL spectra of the IOPC and REF samples under the 980 nm NIR excitation power density (75mW/mm^2) with the doping concentration of 20% Yb^{3+}/ 2% Er^{3+}.

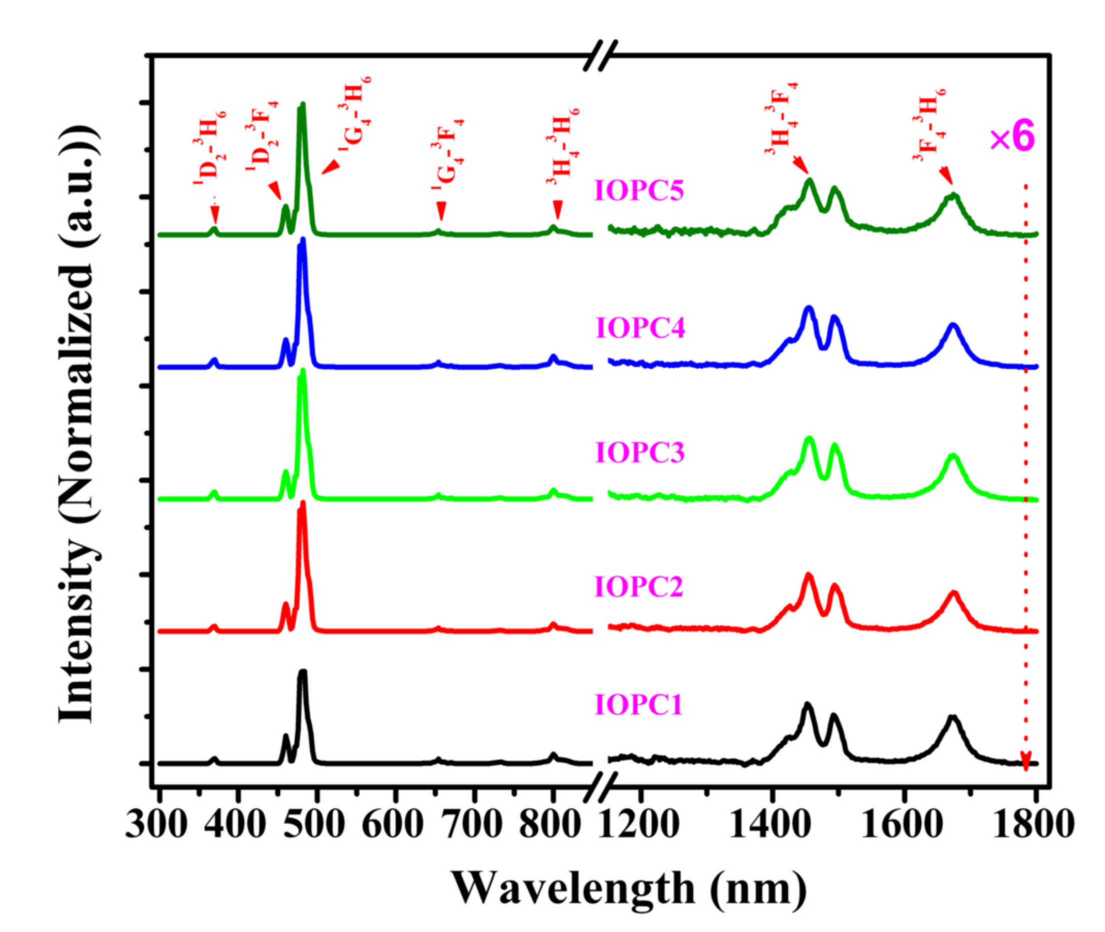

Figure S3: The UCL and NIR emission lines of the $NaGd(WO_4)_2$: 20%Yb^{3+}/ 0.5Tm^{3+} IOPCs with the different PSBs under the same 980 nm NIR excitation power density (75mW/mm^2).

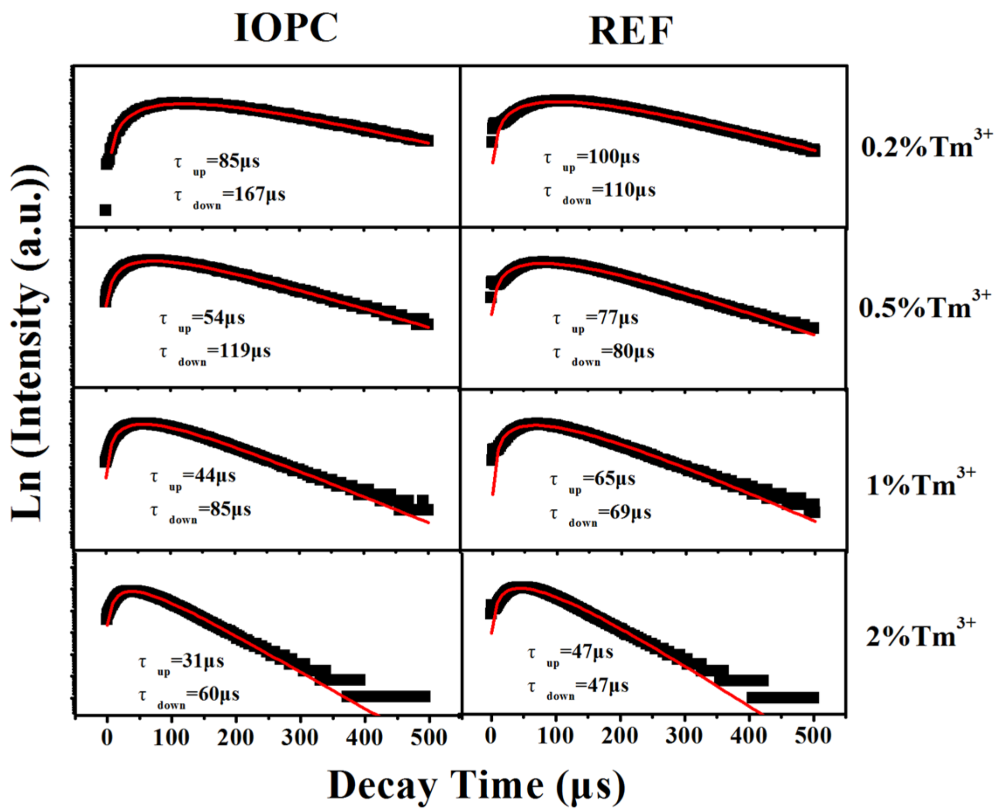

Figure S4: The UCL decay dynamics of the transitions at 480nm of Tm^{3+} ions in $NaGd(WO_4)_2$:20%Yb^{3+}/xTm^{3+} IOPC and REF samples with the different doping concentrations of Tm^{3+} ions (0.2%, 0.5%, 1% and 2%) by monitoring the UC emissions under the excitation of 980 nm laser.

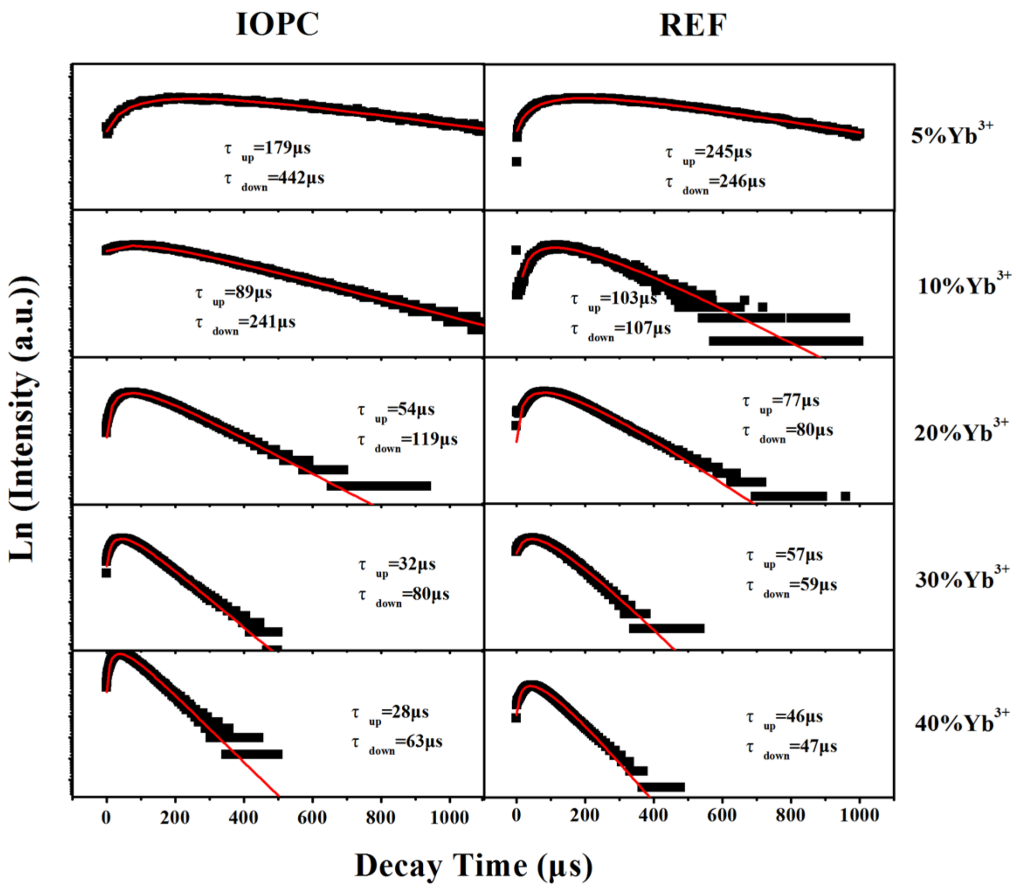

Figure S5: The UCL decay dynamics of the transitions at 480nm of Tm^{3+} ions in $NaGd(WO_4)_2$:xYb^{3+}/0.5%Tm^{3+} IOPC and REF samples with the different doping concentrations of Yb^{3+} ions (5%, 10%, 20%, 30% and 40%) by monitoring the UC emissions under the excitation of 980 nm laser.

Based on the principle of energy conservation law,

$$\eta_{UC}(IOPC) + \eta_{DC}(IOPC) + \eta_{T}(IOPC) = 1$$
$$\eta_{UC}(REF) + \eta_{DC}(REF) + \eta_{T}(REF) = 1$$

Where η_{UC} is the UCL efficiency, η_{DC} is the DCL efficiency, η_{T} is the thermal radiative efficiency. According to the experimental result of Figure 11 $\eta_{T}(IOPC) > \eta_{T}(REF)$,

$$\eta_{UC}(IOPC) + \eta_{DC}(IOPC) > \eta_{UC}(REF) + \eta_{DC}(REF)$$

$$\frac{\eta_{UC}(IOPC)}{\alpha} > \frac{\eta_{UC}(REF)}{\beta}$$

$$\alpha = \frac{\eta_{UC}(IOPC)}{\eta_{UC}(IOPC) + \eta_{DC}(IOPC)} \qquad \beta = \frac{\eta_{UC}(REF)}{\eta_{UC}(REF) + \eta_{DC}(REF)}$$

Where α and β represent the ratio of UCL to UCL+DCL. According to the Equation above, the decrease of DCL in the IOPC would inevitably induce the increase of UCL.