Supplementary Information

Flexible Remote Phosphor Color Converter based on Ultra-Thin Glass and $CsPbBr_3$ Perovskite Nanocrystal Embedded Glass for Wide Color Gamut White LED

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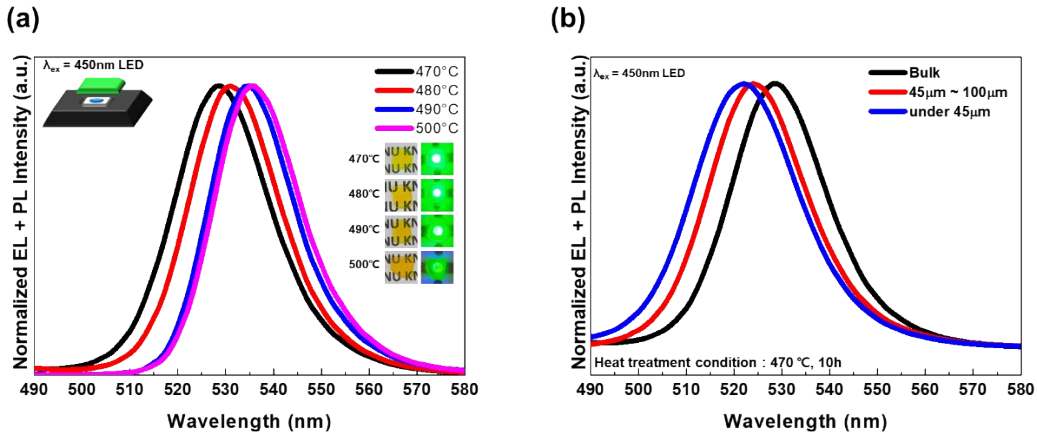
Experimental

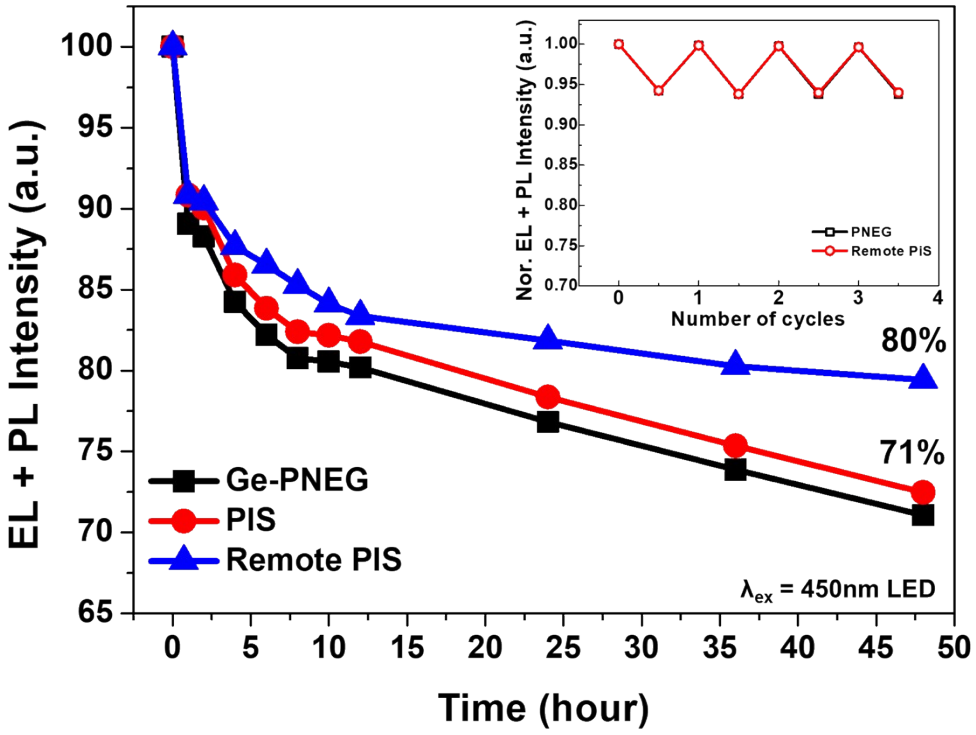
High purity raw materials (>3N) were weighed and mixed by ball milling. The mixture was melted at 1200 ℃ for 30 minutes in an alumina crucible with a cover in an electric furnace, and the melt was then poured onto a brass mold for quenching, followed by annealing at 370 °C for 2 hours to remove thermal stress of the glass.

The glass was then heat-treated varying temperature from 470 to 500 ℃ for 10 hours to form perovskite nanocrystals (PNCs) within the glass matrix. The obtained PNEG was cut into a square shape with 10 × 10 × 1 mm^3 in dimension or pulverized to be mixed with red phosphors and silicone resin to make PiS. The PNEG was mixed with KSF:Mn^{4+} as a red phosphor to fabricate a white LED (wLED) varying mixing ratio. β-SiAlON:Eu^{2+} (Eu^{2+}-doped $Si_{6-z}Al_zO_zN_{8-z}$) was also used as a green phosphor for comparison. The PiS was prepared with the mixing ratio of phosphor to silicone as 2:1 in weight and then pasted on a glass substrate via screen printing to make a remote phosphor with thickness of 120 ~ 380 μm depending on their phosphor content and resultant color coordination. Conventional soda-lime silicate (SLS) glass with 1 mm in thickness and ultra-thin glass (UTG) based on alumino-silicate glass with 50 μm in thickness were used for glass substrate.

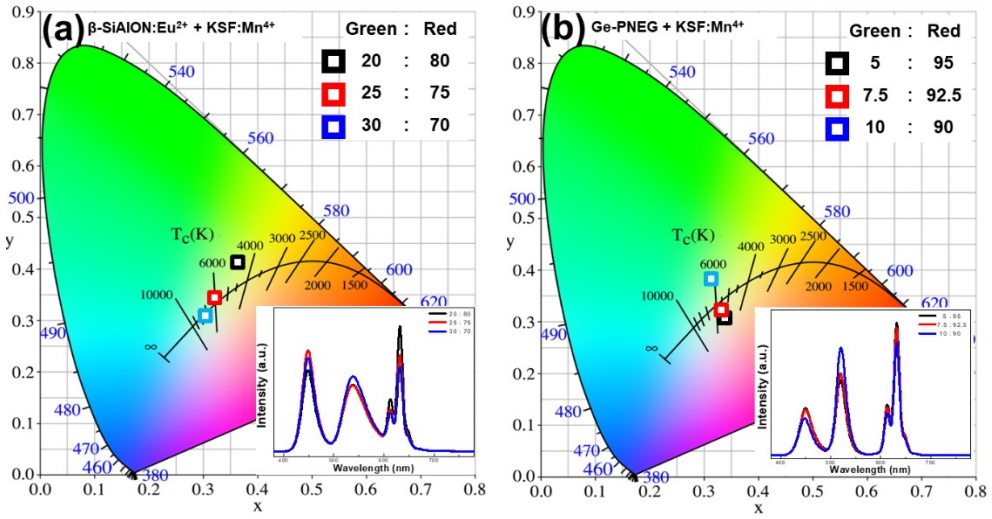
The PNEG and remote PiS were mounted on top of a blue LED chip (5 mm × 5 mm) with a 450 nm wavelength which was operated with 60 mA and 3.4 V for its driving current and voltage, respectively. The electro-luminescence (EL) of the blue LED as well as the photoluminescence (PL) of the phosphors were recorded with a visible spectrometer (DARSA PRO 5200, PSI, Suwon, Korea) equipped with an integrating sphere (C9920-02, Hamamatsu, Hamamatsu, Japan). The packaged LEDs were placed on a heating stage to inspect the change of visible spectra depending on temperature. The color reproduction range was obtained using a multi-channel spectroradiometer system (OL-770, Optronic Laboratories, Orlando, FL) equipped with an integrating sphere. Quantum yield was measured using a calibrated integrating sphere (LED Fluorescence PL System, PSI, Suwon, Korea). CIE color coordinates were calculated based on the visible spectra as described previously [1,2]. A field emission scanning electron microscope (FE-SEM; MIRA LMH2, TESCAN, Brno–Kohoutovice, Czech Republic) was used to observe the morphology of the remote PiS. All experiments were carried out at room temperature except the experiment for thermal effect on PL intensity.



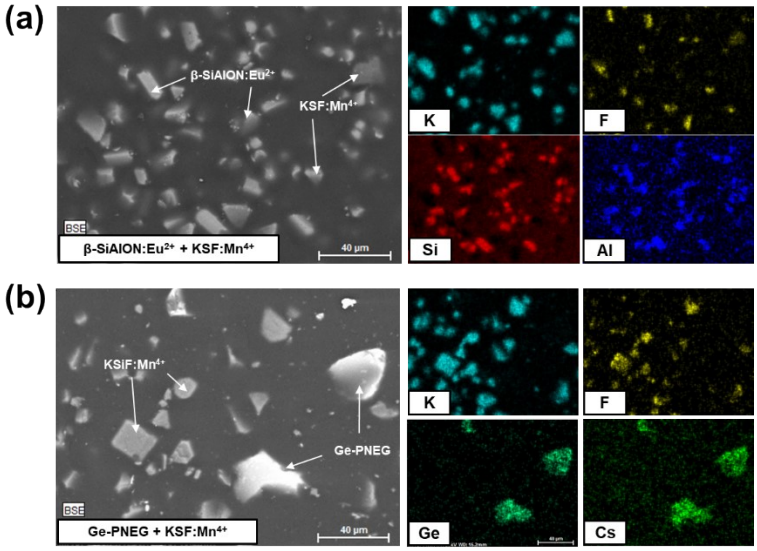
Supplementary Fig. S1. EL+PL spectra of (a)PNEG mounted LEDs depending on the heat treatment temperature and (b)PNEG powder particle size on the 450 nm LED excitation



Supplementary Fig. S2. PL intensity change of bulk PNEG and remote PiS on top of a blue LED depending on continuous LED driving time. The inset figure shows the PL intensity change of those LEDs under on and off cycle test with 1 hr interval.



Supplementary Fig. S3. Color coordinate of the wLEDs mounted with a remote PiS structured color converter varying mixing ratio of green phosphors to red phosphors. (a) β-SiAlON:Eu^{2+}: KSF:Mn^{4+} and (b) $CsPbBr_3$ PNEG: KSF:Mn^{4+}.



Supplementary Fig. S4. Scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS) image of the remote PiS with (a) β-SiAlON:Eu^{2+} + K_2SiF_6:Mn^{4+} and (b) PNEG + K_2SiF_6:Mn^{4+}

Supporting References

[1] T. Smith and J. Guild, *Transactions of the Optical Society*, 1931, **33**, 73
[2] W.M. Yen, S. Shionoya and H. Yamamoto, *Phosphor Handbook* 2nd Ed., CRC Press, 2007, pp. 966-972