Tunable trap depth in $Zn(Ga_{1-x}Al_x)_2O_4$:Cr,Bi red persistent phosphors: considerations of high-temperature persistent luminescence and photostimulated persistent luminescence

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Fig. S1 X-ray powder diffraction patterns of $Zn(Ga_{1-x}Al_x)_2O_4$:Cr,Bi (x=0, 0.02, and 0.04) phosphors. Standard silicon powders (Siltronic AG, SRM 640d) were used as standard reference materials for calibration of diffraction peak positions. Marks * and ● correspond to (111) and (220) diffraction peaks of the silicon. Lattice constant *a* (cubic) for each sample was calculated and noted in the top of pattern. The unit cell shrinks by Al codoping.

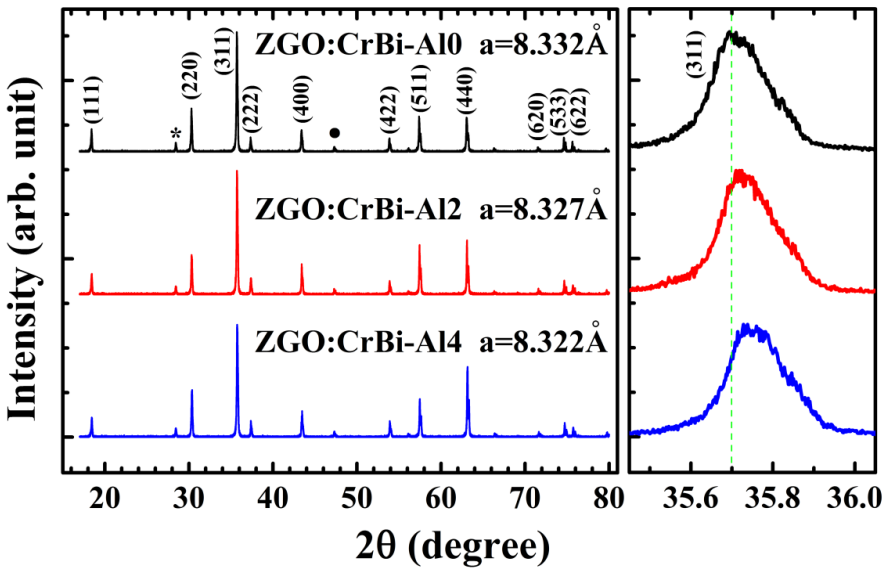

Fig. S2 Measurement system of NIR photostimulated persistent luminescence. The sample (green) was pre-excited by an UV lamp (250 to 380 nm). After the UV excitation was shut-off, persistent luminescence decay curves were continuously recorded by a photomultiplier tube (PMT) or silicon photodiode. The luminescence intensity can be converted to an absolute intensity by using a luminance meter (a precisely calibrated CCD spectrometer). The NIR light source was a 977 nm fiber laser diode (LD). The output mode of the NIR laser could be controlled by a synthesized function generator.

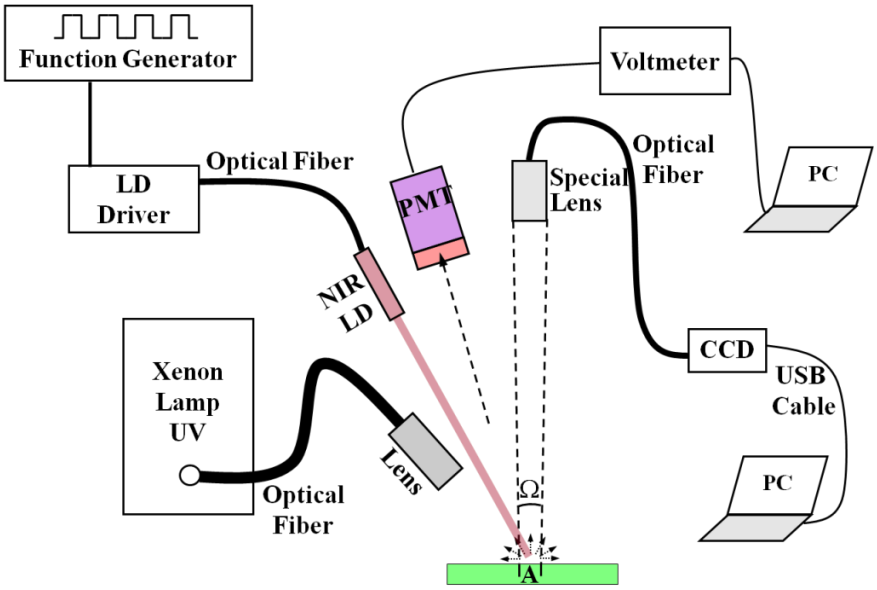

Fig. S3 PL spectra of $Zn(Ga_{1-x}Al_x)_2O_4$:Cr,Bi (x=0, 0.02, and 0.04) phosphors. The excitation wavelength was 320 nm. Spectral shapes were almost identical.

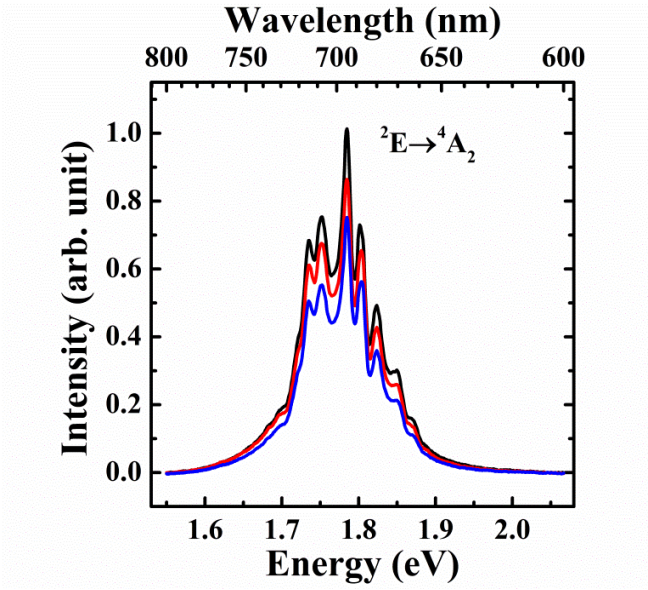

Fig. S4 TL glow curves of $Zn(Ga_{1-x}Al_x)_2O_4$:Cr,Bi (x = 0, 0.02, 0.04, and 0.33) phosphors. The main peak shifts toward higher temperature when Al concentration increases.

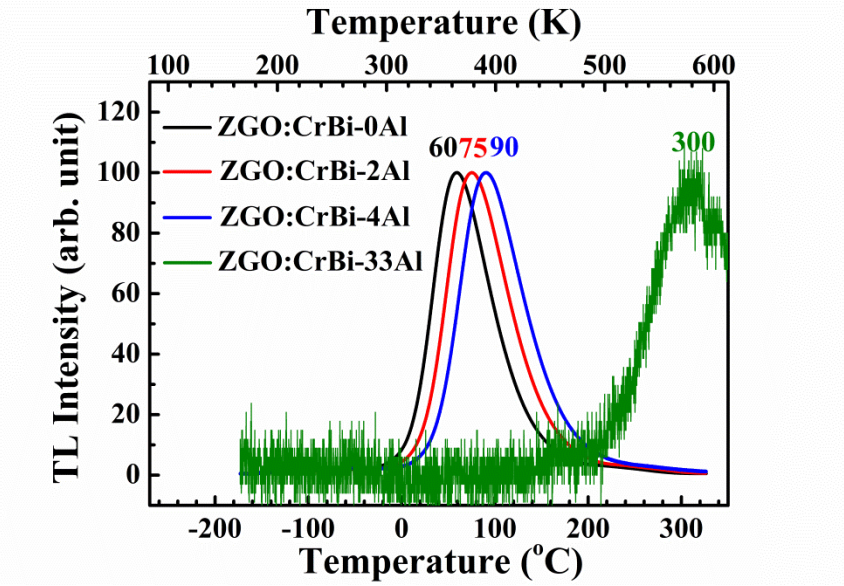

Fig. S5 Initial rise approach to estimate the depths of electron traps by plotting of ln(*I*) verse 1000/*T*. Trap depth (thermal activation energy, ε) was estimated by the slope of fitting straight line.

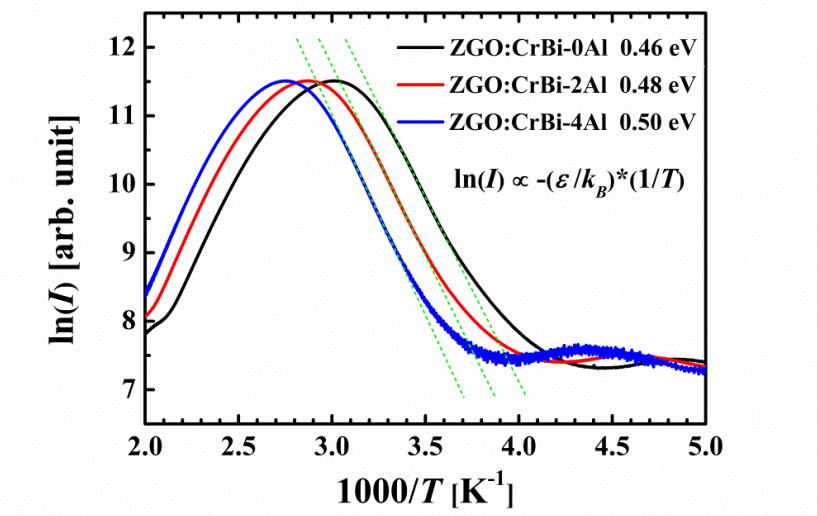

Fig. S6 TL glow curves of $Zn(Ga_{0.96}Al_{0.04})_2O_4$:Cr,Bi phosphor with and without NIR photostimulation. In both cases, the sample was pre-excited by UV (250-380 nm) light for 5 minutes at RT. With waiting time (delay) for 10 minutes, the sample was heated to 600 K and the green curve was recorded. With waiting time for 5 minutes and NIR photostimulation for 5 minutes, the pink curve was obtained.