Enhanced photoluminescence quantum yield of Ce^{3+}-doped aluminium-silicate glasses for scintillation application

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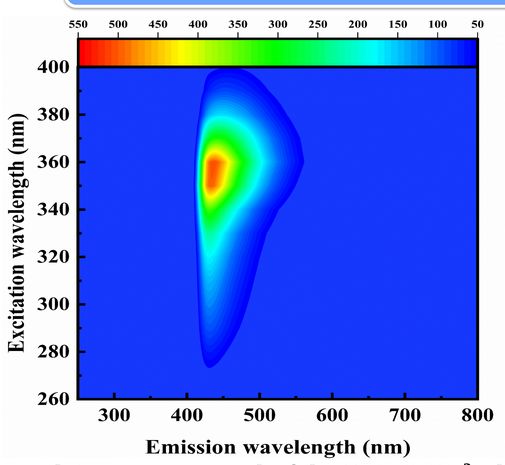
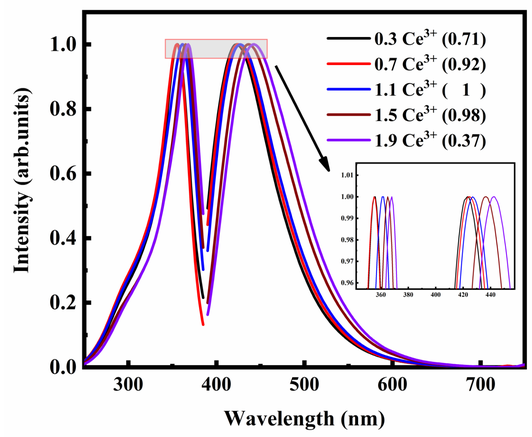
Introduction

The Circular Electron Positron Collider (CEPC) is a large international scientific facility proposed by the Chinese particle physics community. Using the glass scintillator coupled with silicon photomultiplier (SiPM) as the active layer is a new proposal for the next generation hadron calorimeter (HCAL). In this work, Ce^{3+}-doped $20Gd_2O_3$-$20Al_2O_3$-$60SiO_2$ (GAS: xCe^{3+}) glasses (x = 0.3, 0.7, 1.1, 1.5,1.9 mol%) with Si_3N_4 as a reducing agent were prepared. The density of the glasses is around 4.2 g/cm^3. With the increase in the Ce^{3+} concentration, both the photoluminescence (PL) and PL excitation (PLE) peaks of GAS: xCe^{3+} glasses show a red-shift due to the narrowing of the 4f-5d energy levels. Photoluminescence quantum yield (PL QY) and PL decay time of GAS: xCe^{3+}glasses are 28.32-50.59% and 43-64 ns, respectively. The thermal quenching behavior of the glasses under UV and X-ray excitation was investigated. The integrated X-ray excited luminescence (XEL) intensity of the GAS: 1.1Ce^{3+} glass is 23.86% of that of the $Bi_4Ge_3O_{12}$ (BGO) crystal, and the light yield reaches 1200 ph/MeV with an energy resolution of 22.98% at 662keV when exposed to γ-rays. Scintillating decay time of the glasses exhibits two components consisting of nanosecond and microsecond levels. The difference between PL and scintillating decay time is discussed regarding the different luminescent mechanisms.

1. PL-PLE spectra



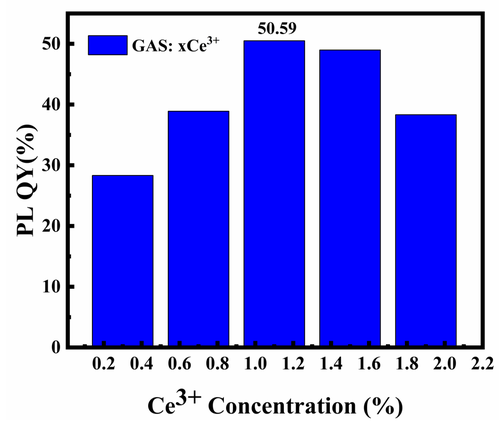
PL and PLE contour graph of the GAS: 0.3Ce^{3+} glass.



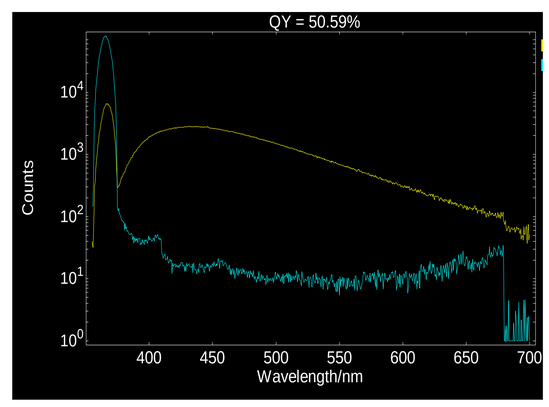
The normalized PLE and PL spectra under their strongest excitation emission wavelengths

- A broad emission band around 400-600 nm is observed under excitation of 360 nm.The With the increase of Ce^{3+} concentration, the PL intensity of the glasses first increases and then decreases and reaches maximum when x=1.1 mol%. All the glasses show similar excitation and emission features.

2. Photoluminescence quantum yield



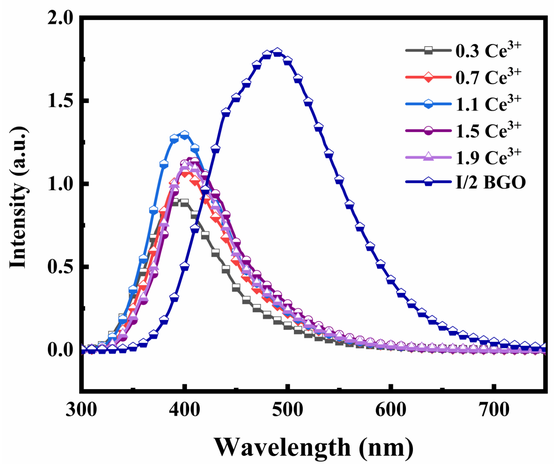
The PL QYs of GAS: xCe^{3+} glasses



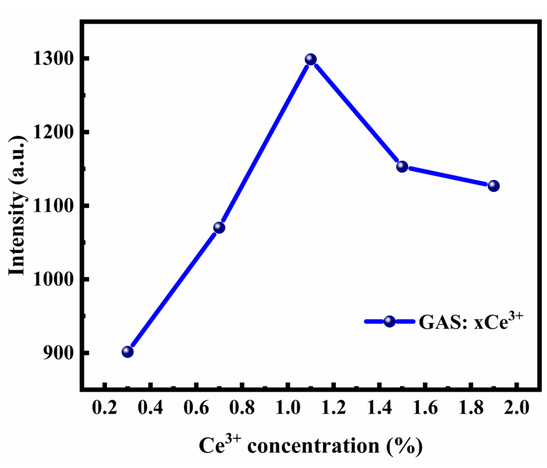
The PL QYs of GAS: 1.1Ce^{3+} glasses

- PL QY is crucial for light yield of scintillating glasses. The PL QYs of GAS: xCe^{3+} glasses first increase and then decrease with the increase of Ce^{3+} concentration, and reach the maximum when x=1.1 mol%.

3. X-ray excited luminescence



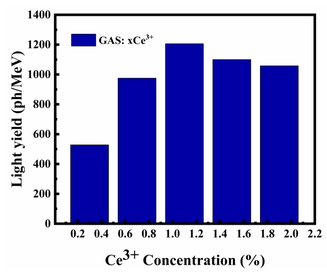
The X-ray excited luminescence (XEL) of GAS: xCe^{3+} glasses



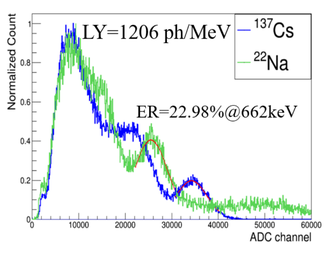
The XEL intensity change of GAS: xCe^{3+} glasses

- It is the same trend as that of PL QY of the glasses. And the GAS:1.1Ce^{3+} glass shows the highest intensity which is approximately 23.86% that of BGO crystal.

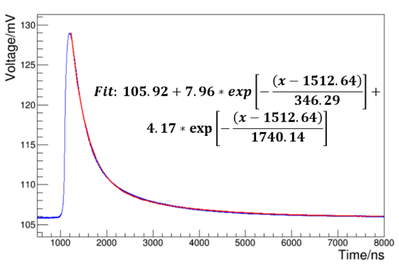
4. Light yield、energy resolution and Scintillating decay time



The Light yield of GAS: xCe^{3+} glass



The energy spectra of GAS: 1.1Ce^{3+} glass irradiated by γ-ray



The scintillating decay time of the GAS: 1.1Ce^{3+} glasses.

- The light yield of the GAS: 1.1Ce^{3+} glass is calculated to be about 1206 ph/MeV. The measured energy resolution ($\Delta E/E$) of glass scintillator is obtained by fitting the full-energy peak. The measured energy resolution of the glass is 22.98% @662 keV.
- The fast component originates from the direct capture of electrons by Ce^{3+} ions and the slow component originates from the repeated capture of electrons by defect levels, which are subsequently transferred to the emitting Ce^{3+} ions.

5. Conclusions

- **The optimal doping concentration of Ce^{3+} ions is 1.1 mol% with a maximum PL QY of 50.59%.**
- **From the energy spectra measured under ^{22}Na and ^{137}Cs γ-ray and comparison with BGO crystal, the light yield of GAS:1.1Ce^{3+} glasses are approximately 1200 ph/MeV with an energy resolution of 22.98% at 662 keV.**
- **The scintillating decay time of the glasses ranged from 395-285 ns (fast components) and 2332-1382 ns (slow components) due to the re-trapping processes during the transport stage. The results obtained on the GAS glass scintillator have shown the potential application in hadron calorimeter of CEPC.**

Acknowledgement

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