Influence of Energy Transfer on the Luminescence Properties of Cr^{3+}:YGG Ceramics

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Introduction

Cr-doped materials find applications as NIR LEDs, solid-state lasers, luminescent thermometry, etc.. However, the presence of parasitic processes, such as energy transfer, can reduce the performance of such devices. One such process is the energy-transfer “chain” phenomenon, in which the absorbed energy by one ion is transferred among the multiple Cr^{3+} ions before being emitted or transferred to a luminescence quenching center. This phenomenon can also induce changes in the emission spectra.

It was shown earlier that an increase in Cr^{3+} concentration led to a redshift of the emission of Cr^{3+}: YGG nanocrystals, while the crystal field strength remains nearly unchanged [1]. These changes were observed at low temperatures, whereas at room temperature the emission spectra remain similar. This behavior has been attributed to the energy-transfer “chain” phenomena. The presence of Cr^{3+} ions in a weak crystal field among interacting ions promotes emission from these sites, resulting in a redshifted emission.

The proposed energy transfer chain phenomenon was used to explain changes in Cr^{3+} emission in nanopowders [1] and nanoceramics [2]. However, the observed patterns could be attributed to the inhomogeneous microstructure of the investigated nanomaterials. Therefore, it remains unclear whether similar behavior occurs in bulk materials. If the proposed hypothesis is valid, a similar pattern should be observed in bulk materials with the same compositions [1].

Methods

I Sample Preparation

Cr3+:YGG ceramics were made by sintering in air at 1600°C for 24 hours. The nanopowders were synthesized by the Pechini method, Cr^{3+} concentrations were 0, 0.1, 0.5, 1, 3, and 5 at.%. Then the synthesized ceramics were polished. The resulting samples (**Fig. 1**) were 8 mm in diameter and 0.3 mm in thickness.

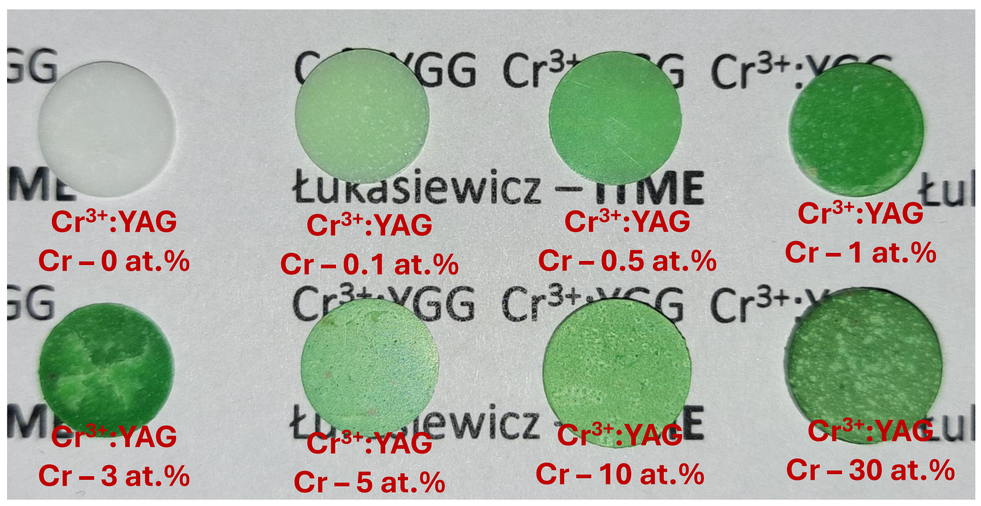

Fig. 1. Photo of the synthesized samples of Cr^{3+}: YGG ceramics Cr0 has 0 at.% Cr^{3+}, Cr0.1 has 0.1 at.% Cr^{3+}, Cr1 has 1 at.% Cr^{3+}, Cr3 has 3 at.% Cr^{3+}, and Cr5 has 5 at.% Cr^{3+}

II Spectroscopic Measurements

Structural and optical characterization of the Cr^{3+}: YGG ceramics was performed using microscopy, absorbance, and photoluminescence spectroscopy. Absorbance spectra were measured using a Varian 5E UV–VIS-NIR spectrophotometer. Excitation and emission spectra, as well as luminescence lifetimes, were measured using a FLS980 fluorescence spectrometer. A 450 W ozone-free xenon lamp and a xenon flash lamp were used as excitation sources.

Conclusions

Investigated Cr: YGG ceramics show a similar grain-sized distribution of the grains, ranging from 1 µm to 6 µm (the grains of the size lower than 1 µm were beyond the optical microscope resolution). No difference in the grain size distribution was detected between the samples. The increase in the Cr^{3+} concentrations caused an increase in the porosity of the samples. However, the microstructure remains dense and homogeneous, consisting of equiaxed grains with clearly defined boundaries.

Based on the diffuse reflectance spectra, concentration dependence of $^4T_{1g}$ and $^4T_{2g}$ bands was not found in the samples. $^4T_{1g}$ and $^4T_{2g}$ position maxima change in the range 440-445 nm and 612-620 nm, respectively. An increase in the concentration of Cr^{3+} ions caused an almost linear increase in ^2E_g absorption maximum from 691.9 nm to 692.6 nm. Such small changes in the band absorption positions indicate small changes in the average crystal field parameter in the samples.

The change in the Cr^{3+} concentration barely affects the excitation band maxima. However, the width of the bands becomes broader with increasing Cr^{3+} concentration. The broader excitation spectra observed for highly doped samples indicate a wider distribution of the local crystal field around Cr^{3+} ions in the ceramics. Consequently, the presence of Cr^{3+} ions experiencing weaker crystal fields leads to changes in the shape of the emission spectra. A similar trend is observed in the emission spectra, which become progressively broader with increasing Cr^{3+} concentration. This broadening suggests an increasing diversity of Cr^{3+} local environments and a larger contribution of ions occupying sites characterized by weaker crystal fields.

References

[1] Mykhailo Chaika, Temperature-Dependent spectroscopy of Cr^{3+}:YGG nanophosphors with multisite emission, *Materials Research Bulletin*, Volume 195, 2026, 113841, DOI:10.1016/j.materresbull.2025.113841.

[2] P. Gluchowski and M. Chaika, Crystal-Field Strength Variations and Energy Transfer in Cr3+-Doped GGG Transparent Nanoceramics, *The Journal of Physical Chemistry* C, Volume 128 (23), 9641-9651
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Results

1. Microstructure

The microstructure of the synthesized Cr^{3+}: YGG with varying dopant concentrations was examined using an optical microscope, as shown in **Fig. 2**.

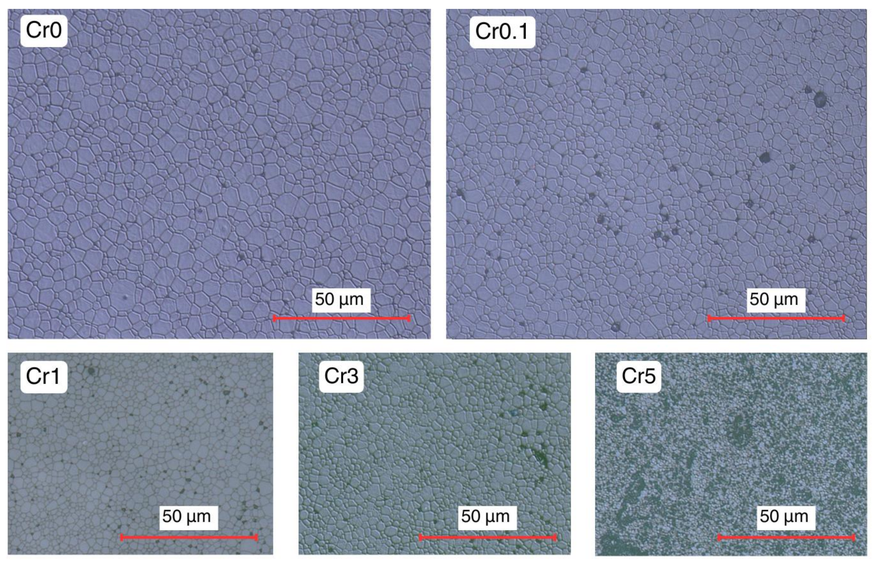

Fig. 2. Microstructure of the synthesized Cr^{3+}: YGG.

2. Diffuse reflectance

Diffuse reflectance spectra of Cr^{3+}: YGG ceramics were collected in the range of 190 nm – 1300 nm and T – 295 K (**Fig. 3**).

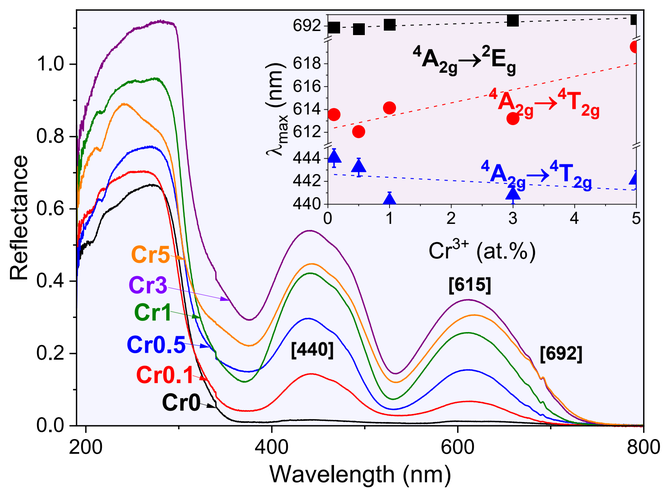

Table 1: crystal field strength (Dq/B) parametr

Cr, at.%	Dq/B	Dq/B (^2E_g=$^4T_{2G}$)
0.1	2.66(5)	2.35
0.5	2.66(5)	2.35
1	2.54(5)	2.25
3	2.58(5)	2.27
5	2.49(5)	2.22

Fig. 3. Diffuse reflectance spectra of Cr^{3+}: YGG ceramic measured at T – 265 K.

3. Photoluminescence properties

Excitation (**Fig. 4**) and emission (**Fig. 5**) spectra of Cr^{3+} doped YGG ceramics were collected in the temperature range from 83 K to 773 K.

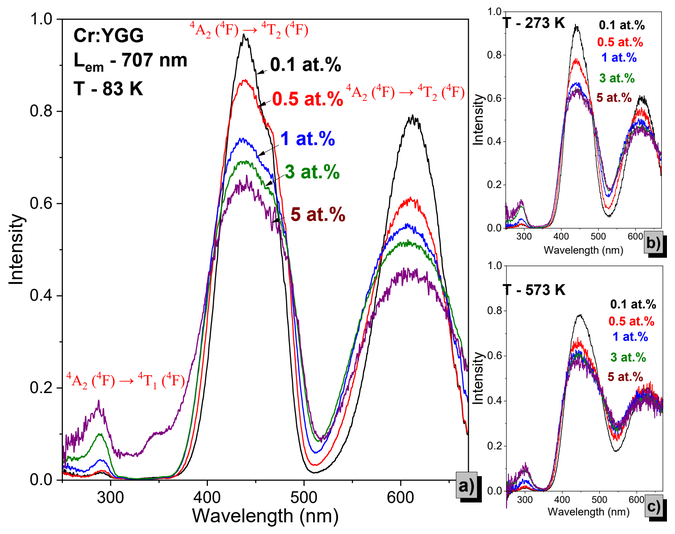

Fig. 4. Excitation spectra of Cr^{3+} ions in Cr^{3+}: YGG ceramic measured at: **a)** T – 83K, **b)** 273 K and **c)** 573 K. The collected spectra were normalized on the overall excitation area.

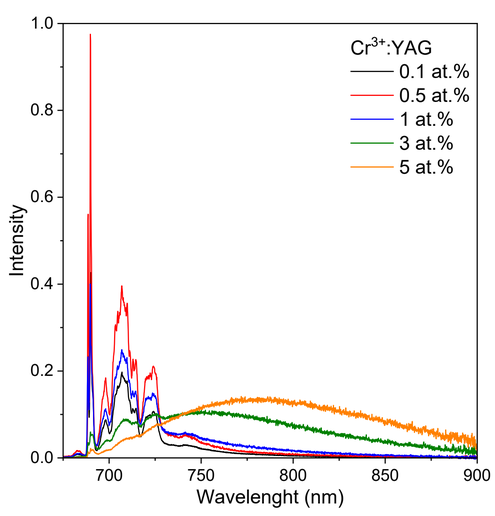

Fig. 5. Emission spectra of Cr^{3+} ions in Cr^{3+}: YGG ceramic measured at T – 83K. The collected spectra were normalized on the overall excitation area.