Spectroscopic Properties of $Cr^{3+}:Al_2O_3$ Nanoceramics with Highly Disordered Local Structure

Dominika Czekanowska[1*], Pellouin Victor[1,2], Paweł Głuchowski[1], Nathan Kerkad[3], Rémy Boulesteix[3], Mykhailo Chaika[1].

[1]*Institute of Low Temperature and Structure Research PAN, Okolna 2, Wroclaw 50-422, Poland*
[2]*Université Clermont Auvergne, Clermont Auvergne INP, CNRS, Institut de Chimie de Clermont-Ferrand, Clermont–Ferrand, F-63000, France*
[3]*Univ. Limoges, IRCER, UMR CNRS 7315, 87068 Limoges, France*

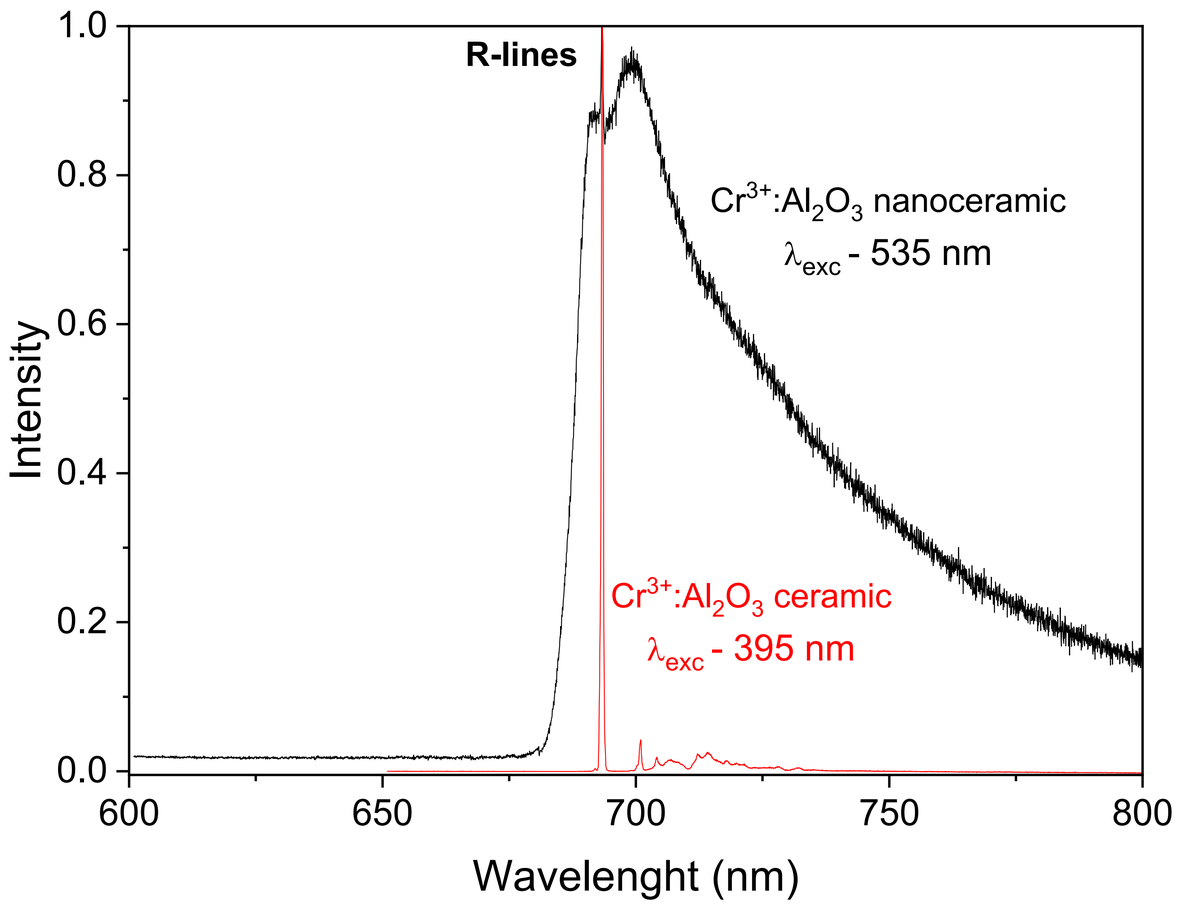
The problem and results

Cr^{3+} (ruby) is a well-established laser material characterized by efficient and thermally stable Cr^{3+} luminescence. Conventional ruby exhibits narrow R-line emission originating from the $^2E_g \rightarrow {}^4A_{2g}$ transition, whereas modification of the local crystal-field environment can lead to substantially broader emission. In this work, we investigate the spectroscopic properties of Cr^{3+} nanoceramics synthesized by cold isostatic pressing at 8 GPa and 770 K and compare them with conventional transparent ceramics.

The nanoceramics exhibit an unusual broadband luminescence extending from approximately 675 to 850 nm, accompanied by narrow R-lines centered near 693 nm. The broadband component is attributed to the $^4T_{2g} \rightarrow {}^4A_{2g}$ transition, while the R-lines originate from Cr^{3+} ions in more regular crystal-field environments. The coexistence of these emissions indicates a broad distribution of local structural configurations, consistent with the highly disordered microstructure of the nanoceramics. Temperature-dependent spectra remain largely unchanged over the investigated range, apart from a variation in the relative R-line intensity around 80–120 K.

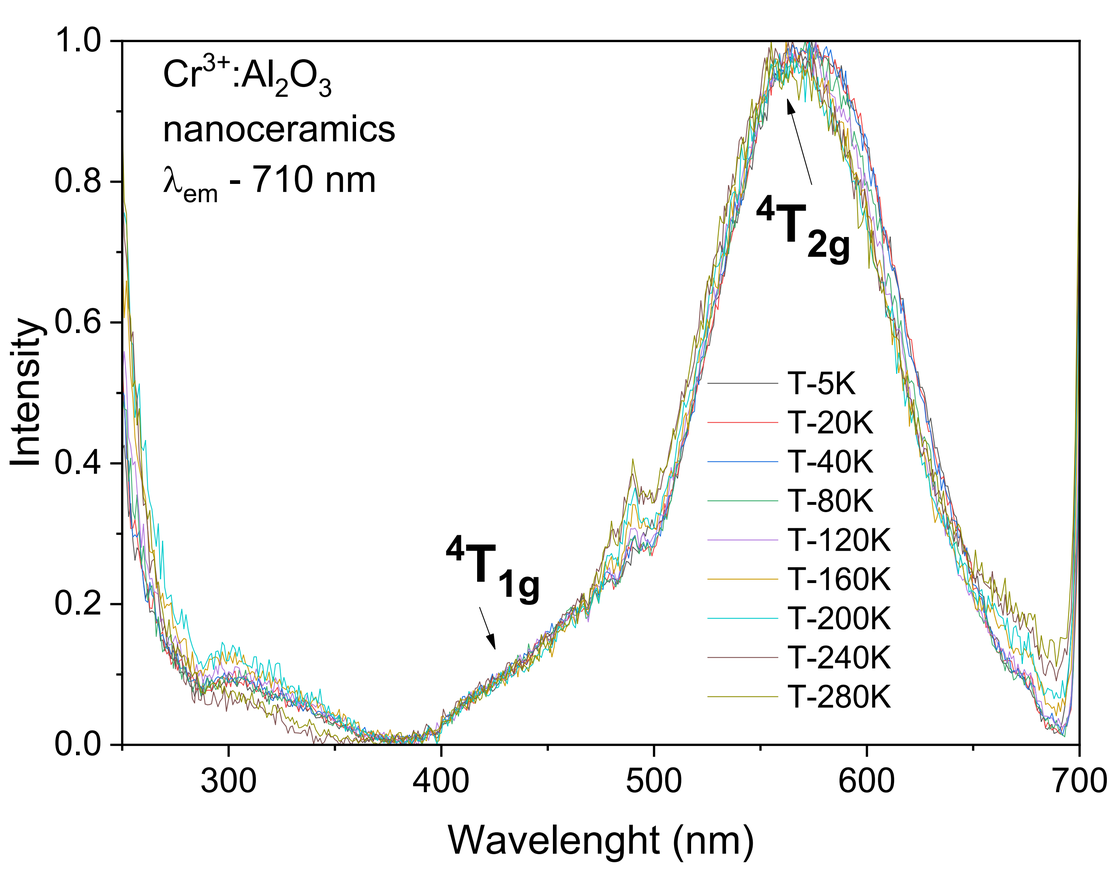
Luminescence decay measurements further confirm the presence of multiple Cr^{3+} optical centers. At 5 K, the decay is described by three components with lifetimes of 0.15, 1.0, and 3.7 ms. The shortest-lifetime contribution increases from approximately 56% at 5 K to 82% at 280 K. These results demonstrate that structural disorder in ruby nanoceramics provides an effective approach for tailoring Cr^{3+} emission toward broadband and potentially tunable laser applications.

Emission spectra



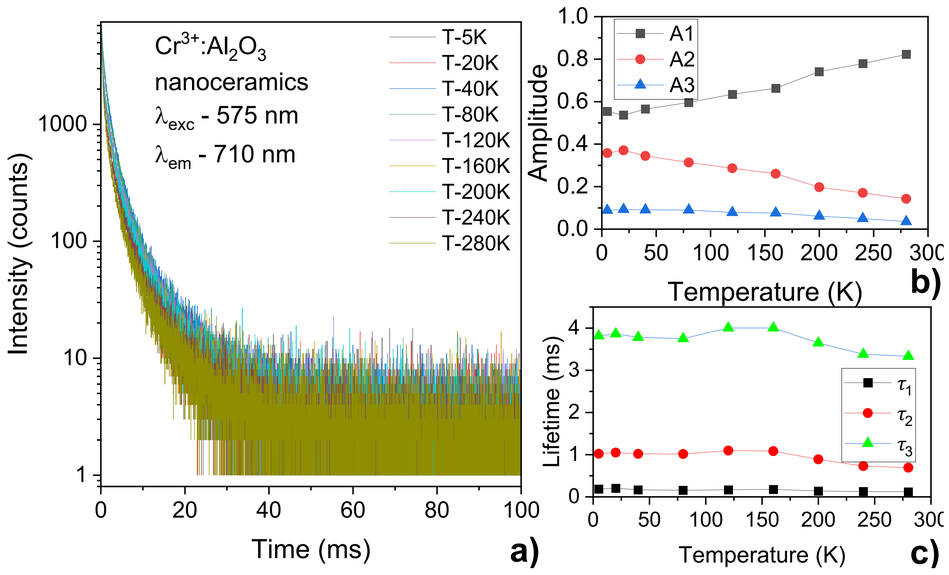
Emission spectra of $Cr^{3+}:Al_2O_3$ nanoceramics measured at λ_{exc} – 535 nm and T – 5K. The red line shows the luminescence spectra of $Cr^{3+}:Al_2O_3$ ceramic measured at λ_{exc} – 395 nm and T – 5K..

Emission spectra



$Cr^{3+}:Al_2O_3$ nanoceramics excitation spectra measured at λ_{em} – 710 nm and T from 5K to 280K.

Lifetime



Luminescence decay curves of $Cr^{3+}:Al_2O_3$ nanoceramics measured at λ_{exc} – 575 nm, λ_{em} – 710 nm, T – 5 – 280K; b) Lifetime amplitude; c) Calculated lifetime

The collected luminescence decay curves for the $Cr^{3+}:Al_2O_3$ nanoceramics were fitted by three exponential decay functions:

$$I = I_0 + A_1 e^{\left(\frac{-t}{\tau_1}\right)} + A_2 e^{\left(\frac{-t}{\tau_2}\right)} + A_3 e^{\left(\frac{-t}{\tau_3}\right)}$$

where I is the luminescence intensity at time t, τ_1, τ_2, τ_3 are the lifetimes, and A_1, A_2, and A_3 are amplitudes. It should be noted that the three exponents are the smallest number which approximately well fits the measured decay curves.