Mechano-chemical modification of β-Ga_2O_3 and β-Ga_2O_3:Eu micropowders by plasmonic nanoparticles

M. Kushlyk[1], D. Slobodzian[1], A. Luchechko[1], Ya. Shpotiuk[1,2], M. Baláž[3]

[1]Ivan Franko National University of Lviv, 79017, 107 Tarnavskoho Str., Ukraine
[2]Institute of Physics, University of Rzeszów, 1, Pigonia str., 35-959 Rzeszów, Poland
[3]Institute of Geotechnics SAS, Watsonova 45, 04001 Košice, Slovakia

Abstract

In recent years, increasing interest has been given to the synthesis of metal-oxide-semiconductors, such as monoclinic gallium oxide (β-Ga_2O_3). Especially, β-Ga_2O_3 semiconductor nanomaterials are attractive candidates as active elements for advanced nanoscale devices due to their unique electronic and optical properties, low effective density, high specific surface area, and shell permeability that are important in many technological applications such as photonics, sensors, solar energy conversion, and electrochemical energy storage, etc. On the other hand, much attention has been paid to the plasmonic effect of metal nanoparticles (NPs) formed in close vicinity to the recombination centres. Combining a thin conversion layer with silver plasmonic nanostructures leads to increased donor absorption and emission efficiency.

Methodology

Table 1. List of the structure for pure Ga_2O_3 samples and milling parameters

Sample ID	RPM	Time, min	Weight (Ga_2O_3), g	Chamber	Milling ball diameter, mm
G-1	300	180	7	WC	10
G-2	500	120		WC	
G-3				ZrO_2	

Table 2. List of Ga_2O_3:Eu samples prepared by mechanosynthesis

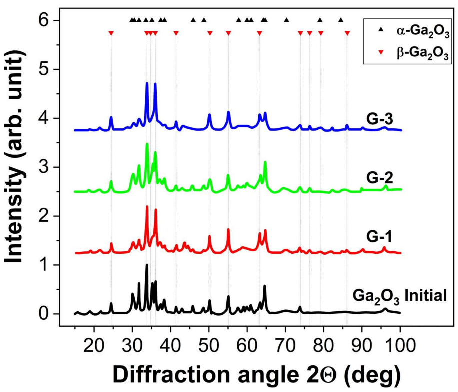
Sample ID	RPM	Time, min	Milling balls diameter	Chamber	Weight Ga_2O_3	Weight Eu_2O_3
G-E-1	300	120	10 mm	WC	6,93 g	0,07 g
G-E-2	500					
G-E-3	300			ZrO_2		
G-E-4	500					
G-E-5	300		7 mm			
G-E-6	500					

Table 3. List of Ga_2O_3 + Ag NPs samples and their synthesis condition

Sample ID	RPM	Time	Weight (Ga_2O_3), g	Weight (Ag), g	Chamber	Milling balls diameter
G-A-1	500	4x30 min	6,986	0,014	WC	10 mm
G-A-2			6,965	0,035		
G-A-3	300	6x30 min	6,986	0,014		
G-A-4			6,965	0,035		
G-A-5			6,993	0,007		
G-A-6		8x30 min	6,93	0,07		
G-A-7	500		5,61	0,0112	ZrO_2	

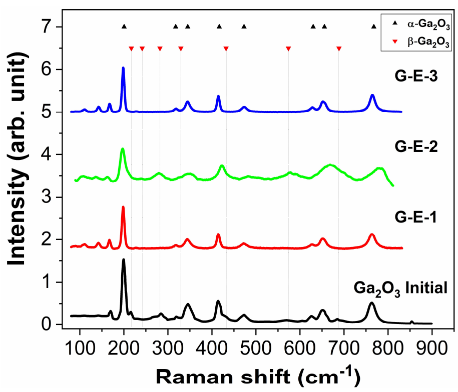
Structural characterization

XRD patterns for β-Ga_2O_3 samples ball-milled according to parameters on Table 1

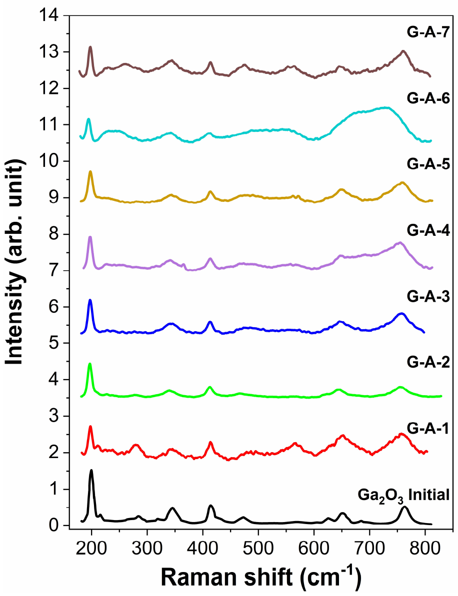


Structural characterization

Raman spectra for β-Ga_2O_3 doped with Eu^{3+} prepared by mechanosynthesis

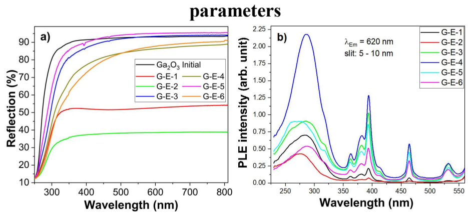


Raman spectra for β-Ga_2O_3 modified by PVP coated silver nanoparticles prepared by mechanosynthesis

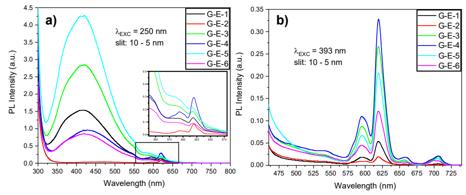


Optical characterization

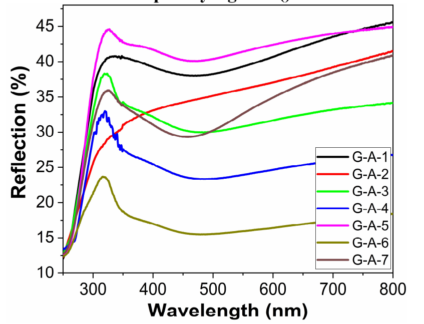
List of the structure for pure Ga_2O_3 samples and milling parameters



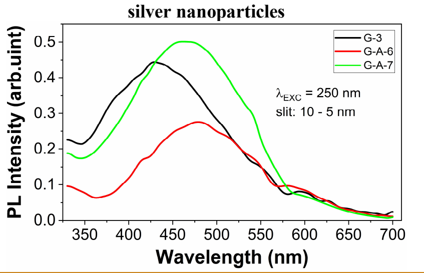
PL emission spectra of Ga_2O_3:Eu samples prepared by mechanosynthesis under different excitation



Reflection spectra of plasmonicaly modified Ga_2O_3 samples by Ag NPs ()



PL emission spectra of Ga_2O_3 samples with and without silver nanoparticles



Conclusions

The results show that the properties of obtained β-Ga_2O_3 composites were strongly influenced by the chamber material and rotation speed. Thus, different crystalline sizes (from 5 um to 300 nm) were obtained, where the bigger particle size show's the greater bulk emission. In the case of β-Ga_2O_3 powder doped with Eu, an opposite result was obtained. Also, it needs to note, that higher luminescence intensity was obtained for the pure composite prepared in the ZrO_2 chamber. It is partially caused by the presence of tungstate and carbon atoms in Ga_2O_3 powders as well as the low content of α-Ga_2O_3 phase.

It is determined that modification with Ag NPs requires increasing the mechanosynthesis time up to 4 h at a low rotation speed (~300 rpm). The absorption spectra show the existence of two modes of plasmon resonance for silver nanoparticles in the β-Ga_2O_3 matrix with relatively high intensity. One of them is a quadrupole mode (with λ_{max} near 360-370 nm) and another one is a dipole mode whose maximum is in the range from 450 to 480 nm. It leads to a redshift of the PL band for plasmonicaly modified Ga_2O_3 powders in the direction of the plasmon resonance maximum, with approximately 20% of intensity enhancement.

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Contact information:

Dr. Markiyan Kushlyk, Email: markiyan.kushlyk@lnu.edu.ua, kushlykmarik@gmail.com

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