Influence of the temperature on the spectral resonances of β-Ga_2O_3:Cr nanowire-based optical microcavities

Daniel Carrasco*, Emilio Nogales, Bianchi Méndez
*daniercar@ucm.es

Departamento Física de Materiales, Fac. CC Físicas, Universidad Complutense de Madrid, Madrid 28040, Spain

ESCUELA DE DOCTORADO
UNIVERSIDAD COMPLUTENSE DE MADRID

Motivation

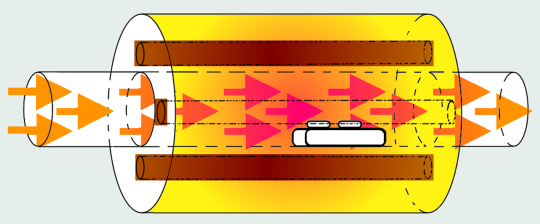
Optical microcavities are a keys elements for many photonic devices. One of the most interesting way to obtain a tunable resonant optical cavity is combining distributed Bragg reflector (DBR) structures with a Fabry-Perot (FP) cavity along a 1D semiconductor structure, such as micro- and nanowires (NW).
β-Ga_2O_3:Cr is a material of great interest thanks to its high thermal and chemical stability making it suitable for use in harsh environments and high-power electronics and photonics. Besides, it is an efficient emitter of the red-IR range due to the intraionic transition of the Cr^{3+}.

Objectives

- Study how the temperature affects the position of the R-lines and FP resonance peaks on a β-Ga_2O_3:Cr NW by increasing the environment temperature and changing the irradiation power of the laser.
- Study the anisotropic refractive index using FDTD simulations and compare its validity with the PL results.

Synthesis

- β-Ga_2O_3:Cr doped NW obtained by thermal evaporation method, vapor-solid (VS) mechanism. Precursors: metal Ga and Cr_2O_3 powders.
- Two DBRs patterned with focused ion beam (FIB) in the NWs.

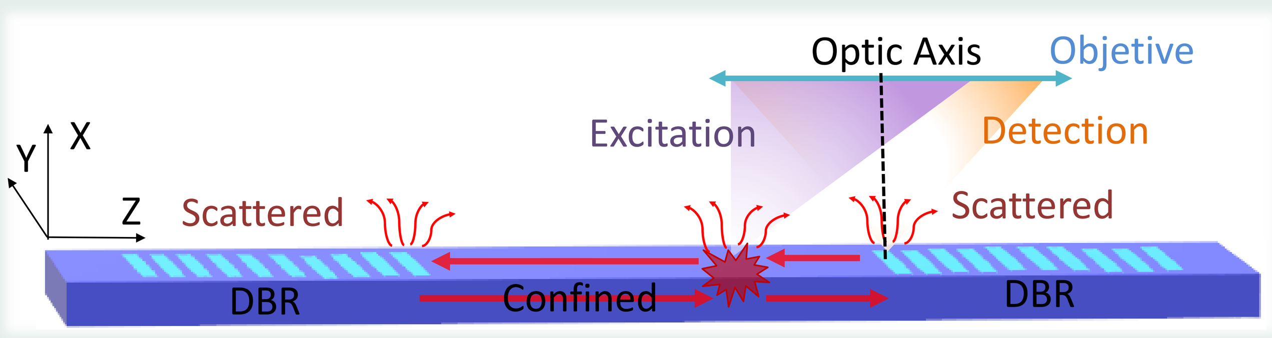


T=1200ºC for 7 hours

Methodology

Local Photoluminiscence (PL) and Raman

Confocal microscopy, exciting with two different lasers and changing its irradiation power to increase the local temperature:



For PL:
He-Cd 325 nm
He-Ne 632.8 nm

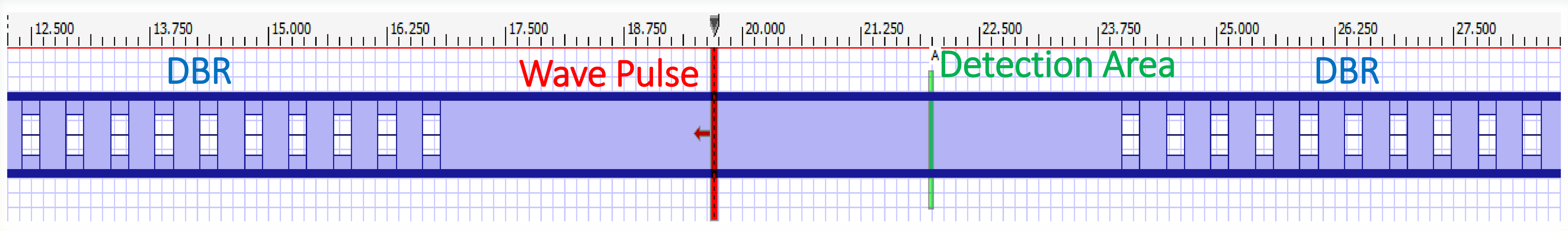
For Raman:
He-Ne 632.8 nm

FDTD Simulations

- The anisotropic refractive index (i = x, y, z) of the material is defined with the Sellmeier expression:

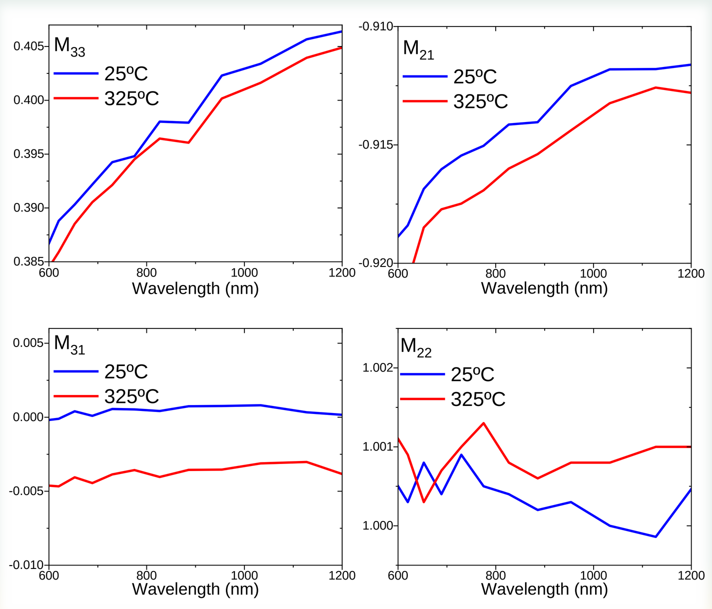
$$\varepsilon_i = \varepsilon_{0,i} + \frac{A\lambda^2}{\lambda^2 - \lambda_1^2}$$

- Propagation of a short (Gaussian frequency profile) linearly polarized 3D pulse.

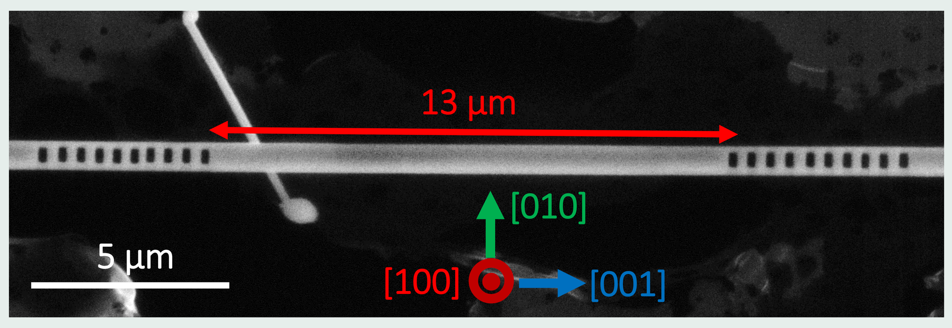


Futher Work

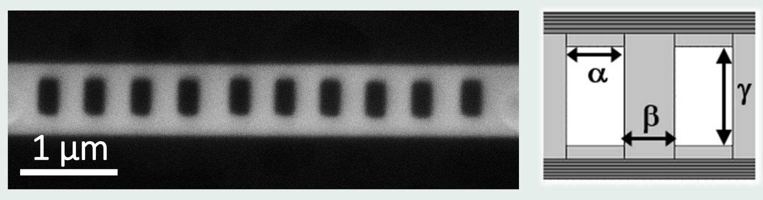
- Measure the effect of the temperature on the anisotropic refractive index of a β-Ga_2O_3 bulk cristal by ellipsometry and through the formulation of Muller Matrix[3].
- Design new optical microcavities to explore the possible use of the native UV emission of the β-Ga_2O_3 for photonics.
- Explore the use of β-Ga_2O_3 thin films for photonics applications.



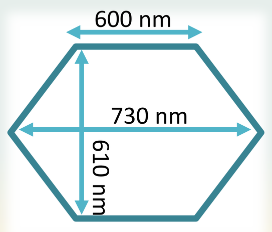
Morphology and Structural Characterization



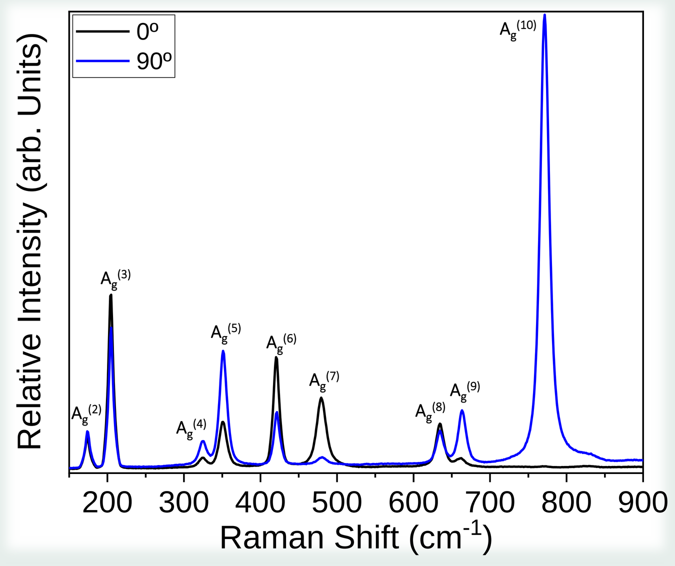
SEM images of the β-Ga_2O_3:Cr nanowire on a TEM grid, showing the optical cavity and DBRs.



DBR Parameters
α = 190 nm
β = 280 nm
γ = 360 nm



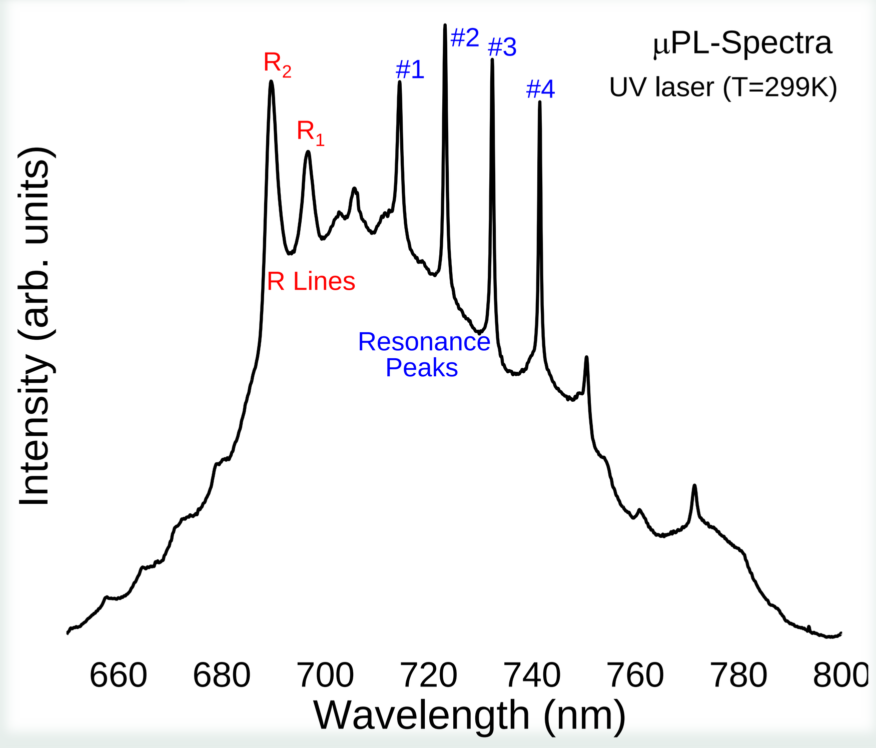
By tilting the TEM grid, we have observed the hexagonal structure and measured the transversal dimensions of the nanowire.



Raman Spectra allows us to know the crystal orientation and relate it with the anisotropic refractive index for NW by angle-dependent Raman analysis.

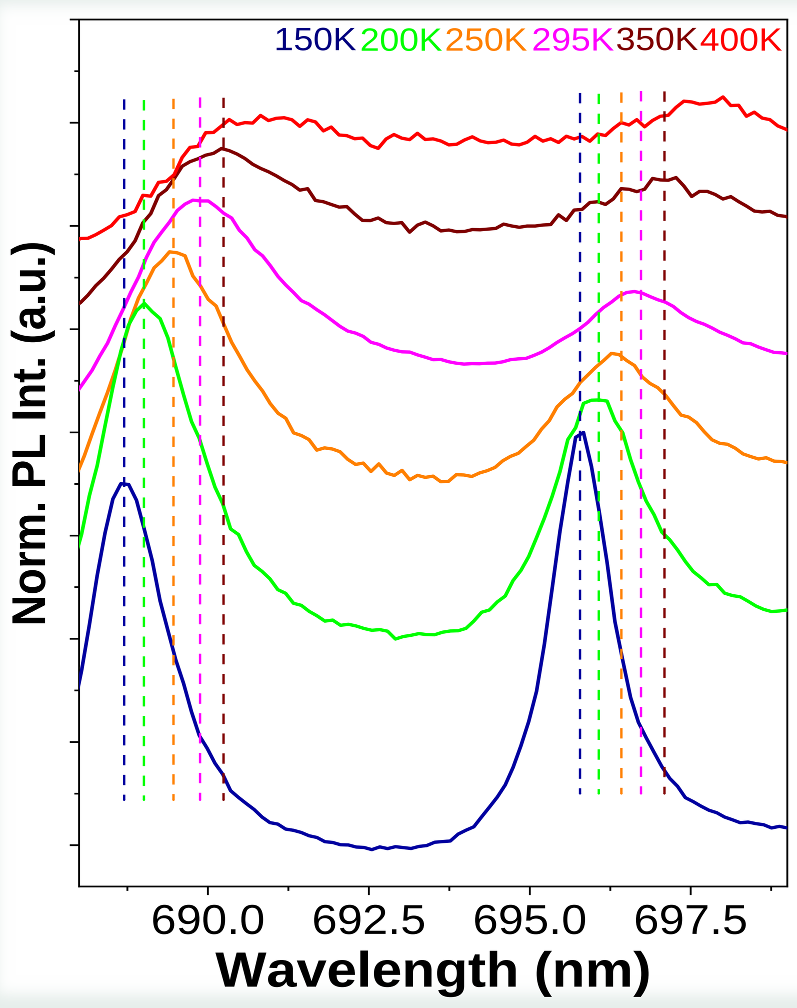
PL and Simulation Results

Photoluminescence (PL) band of the β-Ga_2O_3:Cr on the infrared range showing the characteristic R-lines and the FP resonance peaks.

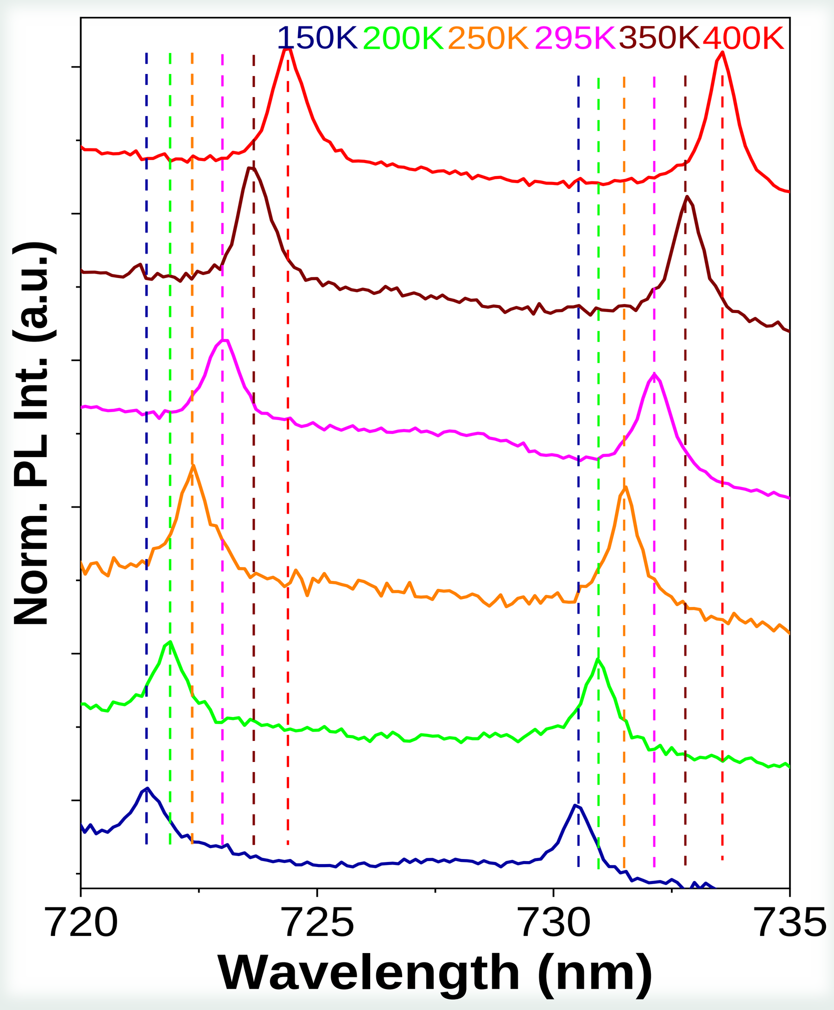


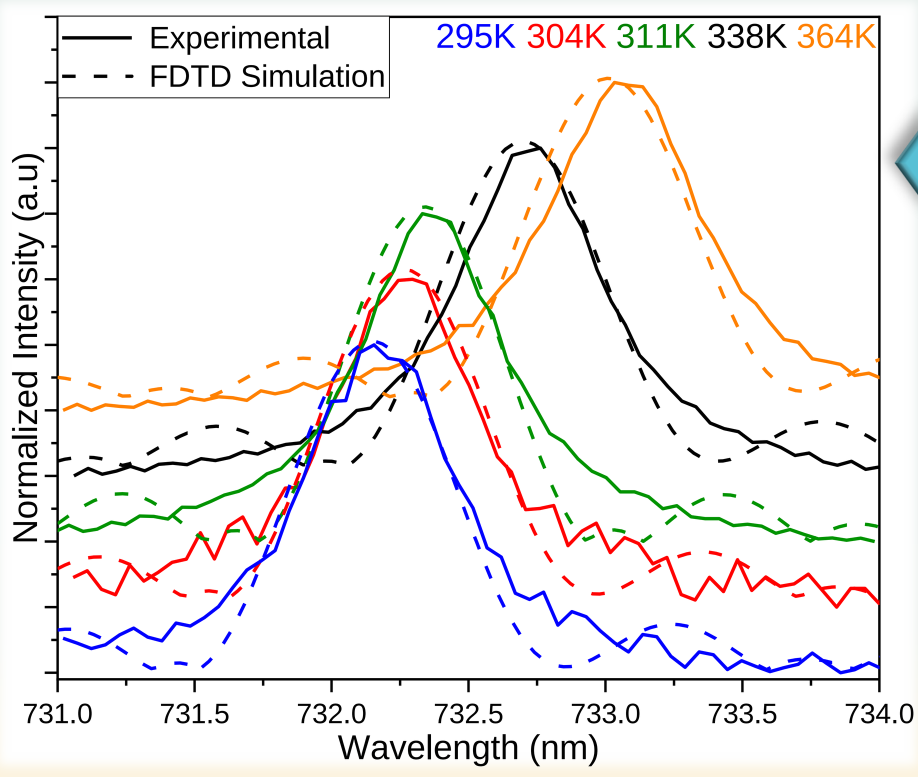
Red shift of the R-lines and FP resonance peaks position due to an increase of the temperature of the NW.

R-Lines Position



Resonance Peaks Position





Comparation between PL results and FDTD simulations (using the refractive index parameters based on Bhaumik et al[2]) and for the #3 peak.

Nanowire-based thermometer[1]:

- **Wide detection range** (at least 150 – 550 K)
- **Spatial resolution ≅ 10 µm**
- **Temperature resolution ≅ 1 K**

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References

[1] M. Alonso-Orts, D. Carrasco, J. M. San Juan, M. L. Nó, A. de Andrés, E. Nogales, and B. Méndez, “Wide dynamic range thermometer based on luminescent optical cavities in Ga2O3: Cr nanowires,” Small 18, 2105355 (2022).
[2] I. Bhaumik, R. Bhatt, S. Ganesamoorthy, et al., "Temperature-dependent index of refraction of monoclinic Ga2O3 single crystal," Appl. Opt. 50, 6006-6010 (2011).
[3] C. Sturm, J. Furthmüller, F. Bechstedt, R. Schmidt-Grund, and M. Grundmann, "Dielectric tensor of monoclinic Ga2O3 single crystals in the spectral range 0.5–8.5 eV", APL Materials 3, 106106 (2015).