# Emission enhancement of plasmonically modified YAG structures co-doped by $Ce^{3+}$, $Bi^{3+}$ and $Yb^{3+}$ ions at low temperature

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## Abstract

In recent years, much attention has been paid to the plasmonic effect of metal nanoparticles formed on the surface of the down-converting phosphors [1, 2]. Combination of thin conversion layer, with silver plasmonic nanostructures leads to increase donor absorption and emission capacity.

High enhancement factors are caused by a close matching of the maximum of plasmon extinction and $Bi^{3+}$ and $Ce^{3+}$ emission bands. The enhancement in PL intensity can be explained by the interaction between the spontaneous recombination and surface plasmon in metal nanoparticles.

According to the FDTD simulation, near surface of NPs exhibits dipole and quadrupole resonance modes LSPR which high enhancement factor can lead to the high PL efficiency. The position of dipole mode of Ag NPs is in close vicinity to $Ce^{3+}$ luminescence and leads to 300% of enhancement [3]. However, experimental research shows negligible changes in its PL enhancement with temperature decreasing. On the other hand, quadrupole mode of Ag plasmon resonance could be used for $Bi^{3+}$ emission enhancement. However, because the relatively short penetration depth of SPR electric field of NPs gives rise to the limitations of luminescence enhancement efficiency.

## Methodology

Structure YAG: Bi, Yb with silver NPs and $SiO_2$ spacer and passivation layers prepared by a magnetron sputtering method

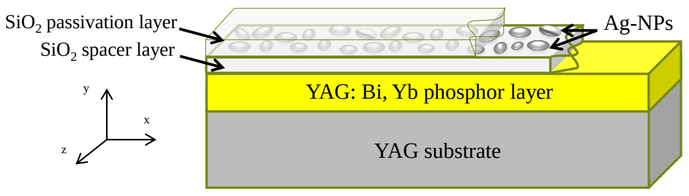
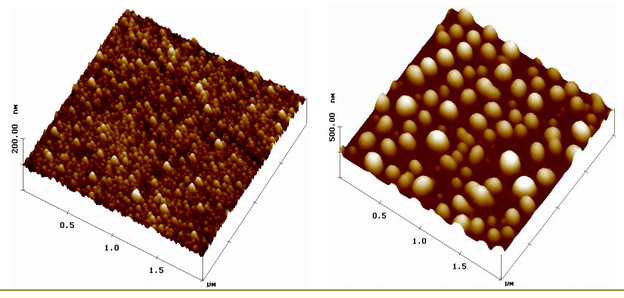



**Table 1.** Preparation parameters of samples

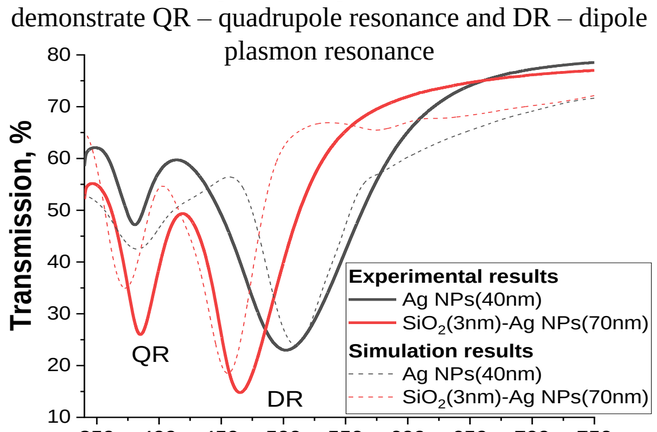
| Sample | $SiO_2$ thickness, nm | Ag mass thickness, nm | Annealing parameters | $SiO_2$ passivation | Mean diameter, nm |
|---|---|---|---|---|---|
| 3YYb-1-1 | 6 | 10 | T=500 °C, t = 15 min | No | 38.43 |
| 2YYb-2-1 | 10 | 50 | T=400 °C, t = 40 min | Yes, 3 nm | 70.8 |
| 2YYb-2-2 | 3 | 100 | T=500 °C, t = 40 min | Yes, 3 nm | 123.5 |
| 3YYb-2-2 | 15 | 150 | T=500 °C, t = 40 min | Yes, 3 nm | 181.6 |

Morphology of silver NPs on surface of YAG: Bi, Yb with $SiO_2$ spacer layer for "small" NPs (*d*<50nm, *left image*) and "large" NPs (*d*>100nm *right image*)

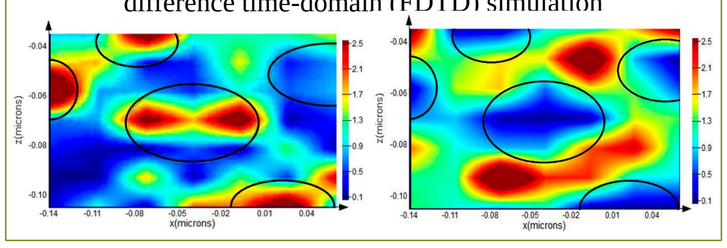


## Simulation Results

Transmission spectra samples with silver NPs that demonstrate QR – quadrupole resonance and DR – dipole plasmon resonance

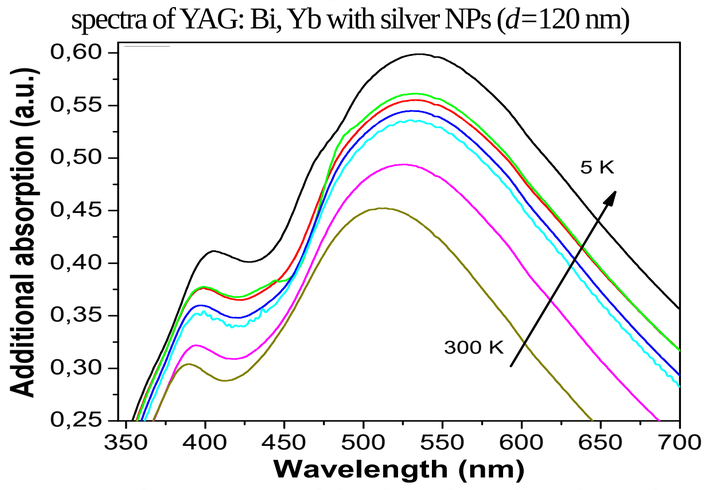



Map of the local electrical field on the samples surfaces for dipole (λ = 510 nm, *left image*) and quadrupole (λ = 375 nm, *right image*) resonances respectively obtained by finite-difference time-domain (FDTD) simulation

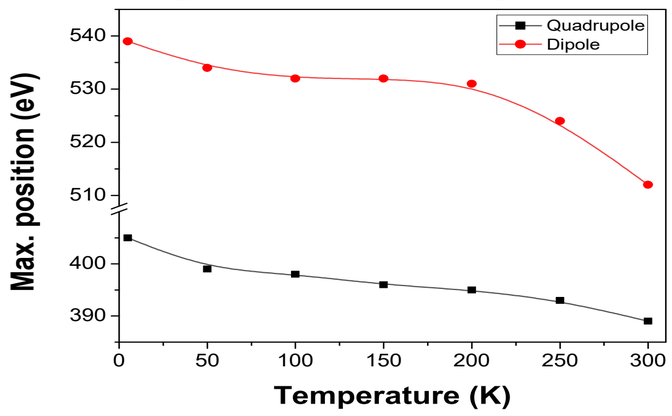



## Optical Properties of SPR

Temperature dependence of plasmonic additional absorption spectra of YAG: Bi, Yb with silver NPs (*d*=120 nm)

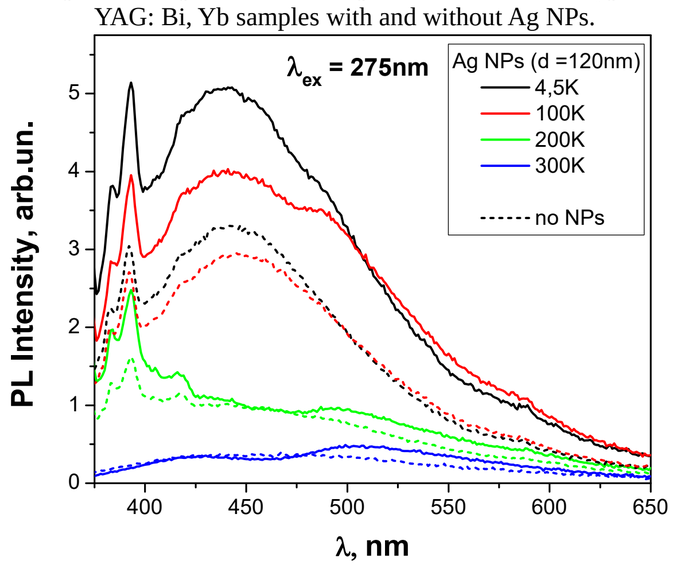



Position of maximums of dipole and quadrupole modes of SPR peaks as a function of temperature

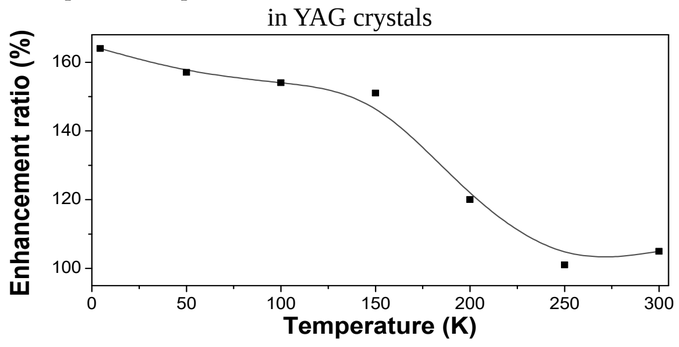



## PL Enhancement

Temperature dependence of PL spectra of $Bi^{3+}$ for two types of YAG: Bi, Yb samples with and without Ag NPs.

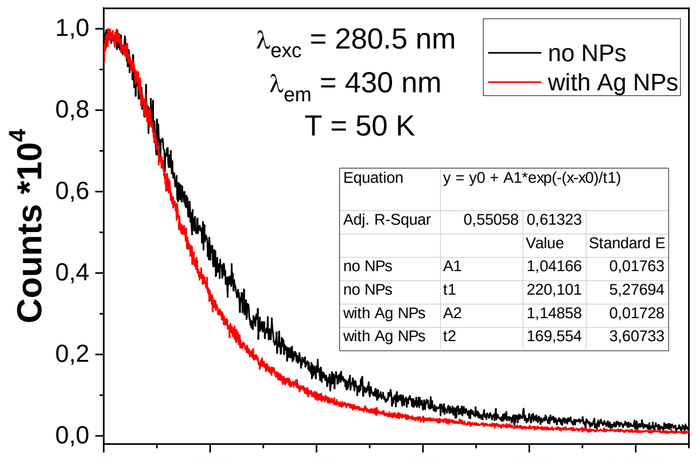



Temperature dependence of enhancement ratio of $Bi^{3+}$ emission in YAG crystals

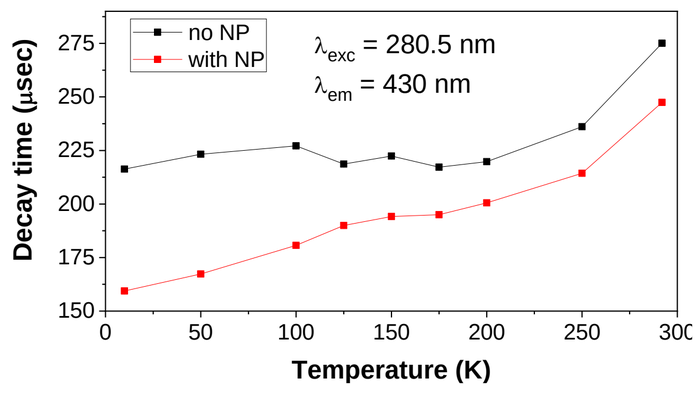



## Decay Kinetics

Decay kinetics temperature dependence of $Bi^{3+}$ for two types of YAG: Bi, Yb samples with and without Ag NPs.




Temperature dependence of decay time of $Bi^{3+}$ emission in YAG crystals with and without Ag NPs.




## Conclusions

According to the FDTD simulation, near surface of NPs exhibits dipole and quadrupole resonance modes LSPR which high enhancement factor can lead to the high DC efficiency. Quadrupole mode of Ag plasmon resonance could be used for $Bi^{3+}$ emission enhancement. However, because the relatively short penetration depth of SPR electric field of NPs gives rise to the limitations of luminescence enhancement efficiency. Two competing processes of enhancement and quenching of PL were obtained as a function of NPs mean size. Enhancement process prevails in case of NPs size larger than 50 nm.

Enhancement of $Bi^{3+}$ emission in YAG epitaxial films with Ag NPs during cooling the samples below 200 K was observed. We obtained maximum value of enhancement factor near 170% at 4 K temperature. Such enhancement arises as the result better matching of quadrupole mode of SPR maximum with $Bi^{3+}$ emission wavelength. The observed redshift of quadrupole peak is suggested to be caused by temperature changes of Ag, $SiO_2$ and YAG dielectric constans.

## Acknowledgements:

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