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Oxide nanostructures doped lanthanide or transition metals for biomedical imaging

The aim of this dissertation was to report and discuss the synthesis and characterization of luminescence markers. The markers were based on the oxide nanoparticles doped with rare earths (Er^{3+}, Yb^{3+}, Gd^{3+}), transition metals (Zn^{2+}, Mo) or alkali metals (Li^{+}). The nanoparticles permit optical and magnetic imaging of biological cells. Bio-imaging is now an essential tool in clinical diagnostics. The optimal bio-marker should be characterized by:

1. a small size (from a few to several dozen nanometers) compared to the size of biological cells (about 10 micrometers)
2. it should be chemically inert
3. it should be separated for effective passivation and bio-labeling for targeted therapy
4. it should exhibit photoluminescence stability in the spectral region of low light scattering, low absorption and low biological autofluorescence. The excitation light should have a high ability to penetrate the tissues.
5. possess low cytotoxicity

As first, I investigated oxide matrices $ZnAl_2O_4$ spinels doped with lanthanide ions (Er^{3+}, Yb^{3+}). I examined how technological process affects the upconversion efficiency of the rare earth ions in the zinc-aluminum spinel matrix. In particular, obtained a strong red emission, by placing the most efficient upconverting ion pairs (Yb^{3+}, Er^{3+}) in the spinel matrix. Due to the large phonon energy value in $ZnAl_2O_4$ (240-840 cm^{-1}), emission in the Er^{3+} ion, as a result of the non-radiative transition, from the $^4S_{3/2}$ level on the level $^4F_{9/2}$, was predominantly in red (660 nm).

To improve upconversion efficiency, through reducing energy phonons in the zinc-aluminum spinel matrix and to get paramagnetic properties, I undertook an attempt to replace light aluminum atoms (atomic weight of 26.98) by heavy gadolinium atoms (atomic weight of 157.25), but obtained polyphasic zinc- aluminum- gadolinium ($Zn(Al_{1-x}Gd_x)_2O_4$: Er^{3+}, Yb^{3+}) materials. I found empirically the optimal amount of zinc to be added to the constituents of the biomarkers (Gd_2O_3: Er^{3+}, Yb^{3+}, Zn^{2+}), to achieve the highest efficiency of the upconversion process. I showed the relationship between the efficiency of the upconversion process and the distance between the Er^{3+} and Yb^{3+} ions, by introduction of Zn^{2+} ions in the Gd_2O_3 crystal lattice.

I applied the precipitation method in order to obtained completely separated $Gd_2O_3:Er^{3+},Yb^{3+}$ nanoparticles. An increase of the green luminescence was achieved by addition of molybdenum ions. In this dissertation I showed, that the $Gd_2O_3:Er^{3+},Yb^{3+}$,Mo nanoparticles are potential sensors sensitive to the environment prevailing inside (photoluminescence decay times shorter) and outside the HeLa cells (the decay times longer).

Additionally, an important aspect of the study was to test biocompatibility of the nanoparticles on HeLa cells and astrocytes.

The obtained nanostructures, based on the oxide matrix, can contribute to the development of potentially diagnostic materials. They can become promising materials for a personalized oncology. In particular, the use of fluorescence for optical imaging allows us to examine the molecular events and structures in living cells and tissues. Used for this purpose the nanoparticles should have high dispersion, efficient luminescence and superparamagnetic properties.

The synthesized luminescent markers, besides their bio-detection and bio-imaging properties, may be used as a new drug delivery systems and, because of their paramagnetic properties, may contribute to the destruction of tumors by hyperthermia. In addition, they are potentially useful for Magnetic Resonance Imaging due to Gd^{3+} ions presence, where they can serve as contrast agents.

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