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Magnetic and Plasmonic Nanoparticles for Biomedical Devices

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M. R. Ibarra[1,2] and Nikolai G. Khlebtsov[3,4]

AFFILIATIONS

[1]Institute of Nanoscience of Aragón (INA) and Laboratory of Advanced Microscopies (LMA), Universidad of Zaragoza, Zaragoza 50018, Spain
[2]Departamento de Física de la Materia Condensada, Universidad de Zaragoza, Zaragoza 50009, Spain
[3]Institute of Biochemistry and Physiology of Plants and Microorganisms, Russian Academy of Sciences, Saratov 410049, Russia
[4]Faculty of Nano- and Biomedical Technologies, Saratov State University, Saratov 410012, Russia

Note: This paper is part of the Special Topic on Magnetic and Plasmonic Nanoparticles for Biomedical Devices.

I. INTRODUCTION

The design of magnetic, plasmonic, and hybrid nanoparticles is a rapidly growing multidisciplinary field that has found various promising biomedical applications, including bioimaging and focused thermal cancer therapy, targeted delivery of drugs, DNA and siRNA molecules, clinical analytics and chemical and biosensing, etc. In particular, magnetic and plasmonic nanoparticles have led to an emerging trend in nanomedicine, theranostics, which combines diagnosis and therapeutic modalities in a single hybrid nanostructure. In principle, such simultaneous diagnostic and therapeutic capabilities can be tailored for a particular organ, disease, or patient. The "Magnetic and Plasmonic Nanoparticles for Biomedical Devices" Special Topic in *Journal of Applied Physics* presents recent advances in nanoparticle synthesis and application of theranostics.

II. BACKGROUND

Plasmonic gold nanoparticles (GNPs) with controlled geometrical, optical, and surface chemistry properties are the subject of intensive studies and applications in biology and medicine because of two specific properties: (1) unique optical properties related to so-called localized plasmon resonance (LPR); (2) convenient functionalization by using simple physical adsorption or chemical modification with thiolated molecules.[1] By variation, the particle shape and the structure of the plasmon resonance of GNPs can be easily tuned across UV-Vis band from 520 to 1200 nm. In particular, the LPR can be tuned to the first tissue optical window (700–900 nm), where the attenuation of probing light is minimal. Under LPR excitation, gold nanoparticles can convert the incident light into heat, thus causing photothermal damage of target cells and tissues. In addition, the LPR properties provide strong elastic light scattering, two-photon luminescence. Another remarkable property of plasmonic particles is the strong enhancement of the local electromagnetic field. This leads to strong excitation of nearby molecules, the exhibit surface enhanced Raman scattering (SERS), metal enhanced fluorescence (MEL), and other interesting optical properties.

The unique properties of magnetic nanoparticles (MNPs), coupled with versatile surface engineering techniques, have led to a rising class of screening methods that enable magnetic separation of specific biomoieties. The magnetic interaction also allows targeting specific organs by using steady magnetic field gradients.[2] MNPs are able to adsorb energy from electromagnetic radiation in the radiofrequency range allowing such nanostructures to act as nanoheaters at the tumor, destroying the cancer cells (magnetic hyperthermia).[3] The MNPs are also applied as magnetic resonance imaging contrast agents. There is a promising field of research for the design of new drug controlled release of drug using liposomal encapsulation of MNPs.

The field of applications that covers both plasmonic and magnetic functionalities is developing very fast, given the capability to fabricate core/shell magnetoplasmonic based nanoparticles. They can be sensitive to light and simultaneously to external magnetic fields. The main advantage of magnetic function is that the external magnetic field permeates biological tissues without attenuation, in contrast to strong absorption and scattering of light in a living body. The magnetic and hybrid magnetic/gold nanoparticles allow us to manipulate the internal state of living cells and to monitor their return to equilibrium in a manner that is unique to such approaches. The synthesis of these nanostructures and their physical applications in the field of biomedical engineering are discussed in the Special Topic, "Magnetic and Plasmonic Nanoparticles for Biomedical Devices."

III. SUMMARY OF AREAS COVERED

Professor Jian Ye and co-workers present two papers on plasmonic enhanced Raman scattering. The first paper[4] reports applications of multivariate curve resolution (MCR) methods to SERS bioimaging and Raman scattering detection. The experimental examples are provided with gap-enhanced Raman tags (GERTs), in which the reporter molecules are embedded in a subnanometer gap between metal core/shell structures. In practical measurements, the fluorescence background and peak overlapping result in low efficiency and sensitivity of detection. However, if the specific SERS bands are strong enough, the MCR approach allows overcoming the whole spectrum noise, thus making SERS tags to be robust to the influence of fluorescence/Raman background or partially overlapped Raman peaks.

The second paper by the same group[5] reports on a new type of GERTs, which are based on gold nanotriangle cores. 1,4 BDT molecules were embedded in the gap between core and shell. Typically, the plasmonic cores of GERTs are spherical or quasi-spherical gold or silver nanoparticles, whereas anisotropic cores such as Au nanorods are rare exclusions.[6] Due to the presence of sharp corners and large surface area for absorption of Raman reporters, the fabricated GERTs demonstrated 20-fold improvement in intensity as compared to conventional smooth GERTs. Furthermore, because of improved photothermal properties and biocompatible surface modification with PSS-PDDAC polyelectrolyte, the developed probes can find promising application in intraoperative SERS imaging and guided photothermal therapy.

An important application of plasmonic nanoparticles is related to photoinduced antimicrobial activity. This topic attracted great interest because of growing the number of microbial cultures resistant to antibiotic therapy. In this issue, Méndez-Pfeiffer *et al.* tested Au and Ag nanoparticles against Gram positive and Gram negative genera, *S. aureus* and *E. coli.*[7] LED light irradiated Ag nanoparticles are shown to be more active compared to Au ones, what is in agreement with previous observations. From AFM images, the cellular wall damage for both genera was observed. The observed difference between antimicrobial activity of Au and Ag nanoparticles can be attributed, at least in part, to the difference in their surface charge.

L. fermentum is a healthy bacteria of human microbiota and can be considered as an effective bioplatform to aggregate gold nanoparticles of different sizes and shapes as well as for directly producing gold aggregates by reducing Au(III) ions in the solution.[8] The exopolysaccharide-induced aggregates of AuNPs are water-soluble and can be stored in a powder being lyophilized. It is well known that the aggregates of plasmonic particles can produce enormous electromagnetic hot spots near the particle junction points. This effect is commonly used to enhance the Raman signal from reporter molecules within plasmonic aggregates. In particular, the authors[8] demonstrated two-order increase in SERS intensity from RhB molecules compared to that from the RhB solution.

Magnetic nanocomposites constitute an important field of research with relevant application possibilities. Here, Idisi *et al.*[9] report an extensive characterization of these type of materials.

A hot topic in the field of nanostructured material is the biomedical application of different types of nanodevices. In this review, Guan *et al.*[10] report on the relevance of MNPs for biosensor based on the use of the giant magnetoresistive effects. Functionalized MNPs with appropriate antibodies are able to detect some specific analytes. MNPs are being proposed as therapeutic agents by magnetic hyperthermia.[3] A contribution from Boekelheide *et al.*[11] showed the relevance of the magnetic interparticle interaction in order to optimize the specific energy adsorption of the MNP clusters from the electromagnetic radiation.

The field of multifunctional nanoparticles is an emergent and rapidly developing area of research for theranostic purposes. Two contributions explain different aspect and implication of combine dual properties. Sengar *et al.*[12] showed the relevant properties of nanohybrid systems that combine magnetic and optical properties. This could influence multimodal theranostic applications. Toro-González *et al.*[13] propose new nanodevices based on the fabrication of core-shell nanoparticles acting as radionuclide carriers that combined with the magnetic properties can act as a contrast agent.

IV. CONCLUSIONS

To summarize, we hope that the collection of the papers from the Special Topic, "Magnetic and Plasmonic Nanoparticles for Biomedical Devices" will be useful for researchers in nanoplasmonic and nanomagnetic fields.

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