PAC for CMP, 2-3 July 2020

Speaker: G.M. Arzumanyan

Report on the concluding theme "Modern Trends and Developments in Raman Microspectroscopy and Photoluminescence for Condensed Matter Study" (04-4-1133-2018/2020) and the project "Ultrasensitive SECARS microspectroscopy and luminescent core-shell nanostructures". Proposal for the theme extension and opening of a new project "Biophotonics" for the period of 2021–2023.

Theme leaders: G.M. Arzumanyan, N. Kučerka

Abstract

Activities performed in the period of 2018-2020 were mainly aimed at the development and implementation of modern methods of ultra-sensitive and highly-contrast detection of analyte molecules by surface-enhanced raman spectroscopy (SERS), nonlinear Raman microspectroscopy known as coherent anti-Stokes light scattering (CARS), and the possibility of combining them – SECARS, using ultrashort (picosecond) pulses of laser radiation. Another modern component of the theme was the study of photo- and up-conversion luminescence based on promising phosphor nanostructures of the core-shell type. These structures are known for their multifunctionality, the diversity of their chemical composition and stability. After studying the spectral and structural characteristics of such phosphors, at the final stage of the theme, it was planned to test the effectiveness of core-shell nanoparticles in an applied biomedical problem. Another stage of the theme was the development of a unified and complementary optical platform for spectrally selective visualization / biovisualization of the studied samples using both Raman microscopy and up-conversion luminescence.

Since then, all the main stages of the theme have been completed and reflected both in the presented written report for the period of 2018-2020, and in numerous publications (over 15) and presentations at large international conferences, among which there were 4 invited reports. It should be noted that the study on combining SERS with CARS (SECARS) have become pioneering in Russia, and published in the specialized journal of JRS. In the part related to the ultra-sensitive registration of molecules, the attomolar level of detection was achieved by two methods: by coating the analyte molecules with graphene layer, and using dendritic nanostructures. Optimistic results were also obtained on the synthesis of core-shell nanoparticles, as well as on their testing in conjunction with a sensitizer (chlorophyll) and fibroblast cells.

Together, the results obtained in the period 2018-2020, and, above all, the achieved highly sensitive level of registration of analyte molecules, formed the basis for the proposal to extend the theme and open a new project "Biophotonics". Advances in instrumentation, methodology, and data analysis allow the use of Raman microspectroscopy in a variety of applications, from in vitro cell analysis to in vivo clinical imaging. The main objective of the project is aimed at applying modern Raman scattering methods in some biomedical problems, which are inherently associated with biosensing and diagnostics.

The project comprises fundamental and applied parts. As for basic research, the activities will be aimed at identifying and understanding the mechanisms of the often anomalous ratio of intensities of the antiStokes / Stokes components in the spectrum of surface-enhanced Raman scattering. This will allow to formulate the conditions for obtaining reproducible SERS spectra during the development of biosensors. Applied tasks are related to (i) spectroscopic studies of NETosis, in particular, to search for Raman markers of this phenomenon, as well as to determine the mechanisms for triggering the sterile activation of

NETosis under the influence of UV radiation, and, (ii) lipid-protein interaction using modern membrane mimetic – lipodiscs.

To implement the proposed project, a multimodal optical platform based on the CARS microscope, atomic force microscopy (AFM), dynamic light scattering (DLS), electron microscopy (SEM, TEM), small-angle neutron scattering (SANS) and other instrumentations will be employed. Also, ultra-low frequency (~ 5 cm^{-1}) Raman spectroscopy will become one of the key project methods.