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Laser-induced processes in chemistry and material sciences

The significance of laser light sources for the development of chemistry was appreciated immediately after their design in the 1960s when Arthur L Schawlow, the Nobel Prize Laureate in physics of 1981, formulated the key principles of the new area — laser chemistry as a science of laser-induced transformations of matter. Owing to unique laser beam characteristics such as monochromaticity, coherence, high intensity and radiation directivity, it was possible to perform totally new experiments in the chemistry and material science.

The year 1972, which marked the appearance of the first, fairly powerful, lasers operating in the ultraviolet and infrared ranges, is regarded as a milestone in the progress of laser chemistry. The development of laser methods for isotope separation was the first important achievement, which demonstrated the fundamentally new potential of lasers in chemistry. Another key point in the progress of laser chemistry was the advent of femtochemistry at the end of the 20th century. Femtochemistry provided the possibility of not only studying the dynamics of fast chemical processes but also solving the problem of controlling the subtle mechanisms of chemical reactions. The attosecond lasers, which appeared recently, created prerequisites for experimental investigation of even faster processes — motion of electrons rather than atoms. The pioneering works of Ahmed H Zewail in the field of femtosecond spectroscopy were recognized by awarding him the Nobel Prize of 1999 in chemistry. A review of O M Sarkisov and S Ya Umanskii devoted to the prospects of development of femtochemistry was published in Russian Chemical Reviews in 2001 (see issue 6, 2001).

Recent years have witnessed extensive development of laser chemistry marked with the appearance of numerous new trends of research. In 2007, a review written by Ben Smith considering 25 years of lasers in analytical chemistry was published in the journal *Analytical Chemistry*. The author pointed out that the impressive results obtained by means of laser analytical methods are due not only to the advances of laser spectroscopy but also to the development of laser sampling techniques. Among highly diverse methods of using lasers in qualitative and quantitative analysis, of particular note is laser-induced breakdown spectrometry, which may soon become one of the most demanded analytical tools.

The area of laser-induced modification of substances is evidently much broader than its analytical applications and refers to laser material science, which originates, to some extent, from laser chemistry. The first works in the laser material science were reduced to simple mechanical processing of industrial materials. However, with time, more knowledge-intensive trends appeared in the laser material science. They are mainly related to the production of new materials upon the interaction of a laser beam with matter. An example is the production of nanomaterials as a result of laser ablation of a substance in a vacuum or in a liquid. These processes are not limited to dispersion but, in some cases, they are accompanied by chemical reactions. The interaction of a laser beam with matter gives rise to a broad spectrum of carbon materials, including nanotubes, fullerenes and graphene.

An interesting trend is the preparation of thin films by laser ablation in vacuum. This technique allows sputtering of layers with an accurately controlled thickness owing to the fact that deposition of a 1 nm-thick layer requires several hundred pulses (depending on the laser parameters). By switching the laser beam from one target to another, it is possible to instantaneously change the chemical composition of the sample being deposited. Modifications of laser evaporation have been devised. An example is provided by matrix-assisted pulsed laser evaporation (MAPLE), which makes it possible to avoid the destruction of organic and biological substances during the preparation of their films.

A new area of laser chemistry is laser-induced synthesis of molecules upon photoassociation of ultracold atoms. Atoms and molecules devoid of kinetic energy are of fundamental scientific interest for ultra-high-resolution spectroscopy and metrology, experimental verification of the postulates of quantum electrodynamics and other fundamental applications. The coherent optical excitation of crystalline gas gives rise to electronically excited atoms, which react with other atoms to form excimer molecules. The first steps have already been made in the experimental research of chemical reactions in the ultracold environment.

Thus, laser chemistry covers a very broad spectrum of modern research areas at the intersection of chemistry, physics and material science. There is quite a number of chairs and research laboratories in the world that are engaged in solving laser chemistry problems. There is a Chair of Laser Chemistry at Moscow State University and a Chair of Laser Chemistry and Laser Material Science at Saint Petersburg State University. The present special issue was prepared by the employees of these divisions. The content of the issue reflects the key directions of the research such as laser synthesis of ultracold molecular assemblies, laser spectroscopic diagnostics of environmental samples, laser-induced metal deposition from aqueous and aqueous-organic solutions.

The authors of reviews and the issue editors are hoping that all presented reports would be of interest for a wide range of readers.

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