Journal of Photochemistry and Photobiology C: Photochemistry Reviews 17 (2013) 26–49

Contents lists available at ScienceDirect

Journal of Photochemistry and Photobiology C: Photochemistry Reviews

journal homepage: www.elsevier.com/locate/jphotochemrev

Review

Plasmonics for pulsed-laser cell nanosurgery: Fundamentals and applications

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ARTICLE INFO

Article history:
Received 18 December 2012
Received in revised form 9 June 2013
Accepted 28 June 2013
Available online 9 July 2013

Keywords:
Nanoparticles
Nanophotonics
Plasmonic nanobubbles
Ultrafast laser
Biomedical applications

ABSTRACT

This review describes the fundamental aspects of pulsed laser interaction with plasmonic nanostructures, and its applications to cell nanosurgery, including the destruction, modification or manipulation of molecular, sub-cellular and cellular structures. The review assumes no prior knowledge of the field of plasmonics and begins with a short review of the basic theory of plasmon excitation and optical properties of nanoscale metallic structures. Fundamentals of short and ultrashort laser pulse interaction with plasmonic nanostructures in a water environment are then discussed. Special emphasis is put on the consequences of the irradiation on the surrounding environment of the nanostructure, including heating, low-density plasma generation, pressure wave release and formation of vapor bubbles. The paper is concluded with a review of different applications of pulsed-laser interaction with plasmonic nanostructures for cell nanosurgery, including photothermal therapy, plasmonic enhanced cell transfection, molecular surgery and drug delivery.

Contents

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1389-5567/$20.00
http://dx.doi.org/10.1016/j.jphotochemrev.2013.06.001

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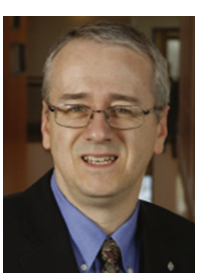

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1. Introduction

The past few years have seen the unfolding and rapid evolution of the field of plasmonics and in particular of the field of nanoplasmonics. The ability to produce and control electric fields on nanoscale dimensions below the light diffraction limit [1,2] allows the development of novel science and technology that find applications in a wide variety of domains. Plasmonic nanostructures are for instance being involved in the design of light-harvesting components to enhance the efficiency of solar cells [3] and photodetectors [4]. They also enter in the development of new techniques aiming to improve current data storage capability [5,6] and are used as nanometric optical tweezers to trap and manipulate nanoscale objects [7]. Near-field optical spectroscopy enables optical measurement at dimensions below the diffraction limits [8]. DNA-based strategies are currently being developed to self-assemble them into plasmon molecules and tridimensional complex structures [9,10]. They can be assembled to construct optical components [11], new sources of coherent highly localized optical fields known as spaser [12,13], or even nanoscale laser sources [14–16]. Very precise biochemical sensors [17] can also be realized, with resolution down to the single molecule [18], by exploiting either the plasmon resonance of nanoparticles arrays [18–20], the so-called Fano resonance of more complex systems [21,22] or the localized enhancement of the Raman signal (Surface Enhanced Raman Spectroscopy, also known as SERS) [23,24].

Nanoplasmonics also offers new therapeutic possibilities, in particular concerning cancer treatment. Continuous wave laser interaction with functionalized nanospheres [25–28], nanorods [29–32] and nanoshells [28,33–36] is used to generate heat [37–39] and destroy cancer cells. Hybrid structures coupling plasmonic enhanced cell laser heating to conventional chemotherapy further increase the efficiency of the hyperthermia treatment [40–44].

This review covers the interaction of short and ultrashort laser pulses with plasmonic nanostructures. The high intensity optical fields involved can be exploited to interact very precisely with the environment. When nanostructures are deposited on solid surfaces, irradiation may produce sub-wavelength ablated features that could provide alternative to current nanolithographic processes. When nanostructures are in the vicinity of cells, pulsed laser irradiation yields to nanoscale vapor bubbles that can be used for diagnostic and therapeutic purposes. Sub-cellular and molecular structures can be affected with unrivaled precision. Cell membranes may be disrupted, enabling the transfer of drugs, DNA, or RNA molecules into the cytoplasm without inducing any permanent damage. More drastically, selective lysis of the cell may also be induced. Nanoplasmonics hence offers new therapeutic avenues for cancer and other diseases.

This review is divided into three major parts. It begins with an overview of the basic theory of plasmon excitation and optical properties of nanoscale metallic structures. The fundamentals of short and ultrashort laser pulse interaction with a plasmonic nanostructure in a water environment are then discussed, with a special emphasis on the consequences of the irradiation for the surrounding environment of the nanostructure, including rapid heating, low-density plasma generation, pressure wave release and formation of vapor bubbles. The paper is then concluded with