PEPTIDE NANOPHOTONICS – FROM BIO-WAVEGUIDES TO INTEGRATED PHOTONIC DEVICES

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Optical waveguiding phenomena in bioinspired chemically synthesized peptide nanostructures can be used to revolutionize emerging fields of precision medical trials and health monitoring. New biomedical light therapy tools and implantable optical biochips can be produced using bioinspired peptide nanostructures due to a unique combination of their intrinsic biocompatibility and remarkable multifunctional optical properties. This essay highlights a new field of peptide nanophotonics. It covers peptide nanotechnology and fabrication processes of peptide integrated optical circuits, basic studies of linear and nonlinear optical phenomena in biological and bioinspired nanostructures, and passive and active optical waveguiding in peptide nanostructures. We show that optical properties of this new generation of biooptical materials are governed by fundamental biological processes. Refolding of the peptide secondary structure is followed by wideband optical absorption and visible tunable fluorescence. In peptide optical waveguides, such a new biooptical effect leads to switching from a passive waveguiding mode in native α -helical phase to an active one in β -sheet phase. Discovery of an active waveguiding effect in β -sheet fiber structures below the optical diffraction limit opens an avenue for future development of new bionanophotonics devices using ultrathin peptide/protein fibrillar structures for advanced biomedical and nanotechnology applications.

Keywords: bioinspired peptide nanostructures, optical waveguides, photonic integrated devices.

INTRODUCTION

The field of nanophotonics combines fundamental physics, advanced optical materials, and nanotechnology. Optical waveguides (Hunsperger, 2009), which confine and guide light within their structures, are the basic components of integrated chips that can be used in various applications. Such integrated devices that include optical waveguides and combine linear and nonlinear optical and electronic circuits can be used as building blocks of optical communication devices (Prasad, 2004). Medical analysis techniques and disease monitoring are other examples of applications that can benefit from integrated chips that include optical waveguides and photonic devices (Yun and Kwok, 2017).

Nowadays, both biomedical research and clinical research are focused on development of nano- and micro-tools and advanced methods of diagnosis, therapy, and surgery (Vanneman *et al.*, 2012). Photonic technologies are crucial in such new developments for rapid application of the emerging precise light theranostics in medical trials (Humar *et al.*, 2016). Light strongly influences basic biological processes that stimulate application of new biomedical photonic techniques that exploit diverse photochemical, photobiological, and photothermal (Mohammad-Hadi *et al.*, 2018) effects and methods of light-induced therapies, such as photodynamic and optogenetic therapies in addition to traditional optical bioimaging and diagnostics (Paragios *et al.*, 2014).

Here we present a new paradigm of emerging biooptical physics and nanotechnology based on multifunctional bioinspired peptide nanomaterials toward new biomedical nanotherapy tools and implantable integrated optical biochips. Recent research revealed that peptide nanostructures poses unique set of optical properties

such as nonlinear optical, electrooptical (Gilboa *et al.*, 2017), and optical waveguiding effects (Handelman *et al.*, 2016; Handelman *et al.*, 2018). These newly discovered properties of peptide nanostructures paved the way toward new physics of light propagation in biological and bioinspired nanostructures followed by nanofabrication of optical peptide waveguides. Such nanoscale light waveguides of biological origin can be applied in biomedical theranostics and optical implantable biochips where they are integrated with operating electronics. This new field of peptide nanophotonics (Handelman *et al.*, 2018) is the main subject of my talk.

EXPERIMENTAL

Light waveguiding is observed in two different regimes passive and active¹⁰. The passive mode guides the injected light through its optical transmission window and is described by the classical optics of reflection, refraction and diffraction. The key problem in passive optical waveguiding circuits is effective coupling of a light beam to POW. To provide light coupling in our peptide rectangular structures, we designed and fabricated a planar FFF-POW-based Y-splitter for the blue spectral range by incorporating of diffractive grating coupling elements at all of its three ports using FIB-tool (Figure 1a,b). The FDTD simulations were performed by the use of the grating coupler realistic 3D model imported to the FDTD simulation software from AFM image data (Figure 1a). Figure 1 demonstrates the experimental results of effective light coupling, waveguiding, splitting and outcoupling under broadband white LED illumination of the input grating.

Figure 1. Experimental and simulation observation of the efficient optical coupling, waveguiding and outcoupling in the 1x2 optical-power Y-splitter under white LED illumination of the input grating.

RESULTS AND DISCUSSION

Two elongated, blue light spots observed at the output gratings (Figure 1c) indicate selective wave coupling through grating elements, acting also as an optical filter. The FDTD simulations setup with reproduced experimental conditions shows a good agreement with our experimental data (Figure 1c,d).

CONCLUSIONS

We introduced all-peptide photonic integrated splitter, composed of bioinspired planar peptide wafers of a large area treated by high resolution patterning. This development opens the avenue for a new field of peptide integrated biooptics where multifunctional peptide optical materials can be fabricated as optical integrated circuits combined with electronic components and interconnections towards lab-on-biochips. Further feature of these peptide structure is their ability to transform from passive to active waveguiding regime in peptide materials by reconfirmation of their secondary structure.

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