Combination of photonic tools and nanostructured materials for application in biology and medicine.

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This talk will review the combination of nanostructured materials and photonic tools that can be used for their visualization, navigation and remote-controlled release of bioactive substances, and last but not least, the application of optical sensors for early diagnosis and evaluation treatment efficiancy. There are many biological objects that can be used as markers of various pathological states including cancer. These comprise, but are not limited to, proteins, exosomes, and circulation tumor cells. Exosomes are a very promising marker for early cancer diagnosis and even for evaluating treatment efficiency. An exosome is a small vesical at 100 nm size produced by a cell. Exosomes contain specific proteins and are distributed on the surface of cell membrane. The exosomes can be sent by both normal and pathological cells. It can be used for early diagnosis of neuro, cardio, and onco-diseases [1]. We have already elaborated a different types of photonic based sensors including SERS [2], nanozyme based optical sensor [3,4], hollow-core microstructured fibres [5], and photonic integrated circuits [6]. The combination of a photonic integrated circuits (PIC), a microfluidic devices (MF) and a surface modification can improve not only the sensitivity but also the specificity of exosomes' detection.

Additionaly, the application of photonic and acoustic tools can be used for visualization, navigation of multimodal and multifunctional carriers and remote-controlled release of bioactive substances. These particles will combine the ability to deploy drugs in a controllable manner with physical triggering, multimodal detection, and visualization as well as sensing of important biological markers. It was required to apply a new bottom-up method as layer by layer assembly [7] and freezing induced loading [8] and their combination [9,10]. It can be allowed us to vary the volume fraction of components and their chemical composition led to the control of the optical and thermal properties of multifunctional carriers [11]. Raman spectroscopy is perspective method for *in situ* monitoing of freezing induced loading method [12]. Physical targeting of carriers was realized by the gradient of the magnetic field [13], optical tweezers approach [14]. Acoustics has a good perspective for the same purpose. The carrier sensitivity to external influences such as laser irradiation, ultrasound treatment can be changed by variation of volume fraction and chemical composition of inorganic nanoparticles and/or organic dyes in the carrier shells. The same approach is applied for drug delivery carriers imaging by MRI, FT, US and optoacoustics using inorganic nanoparticles and/or organic dyes as contrast or functional agents [4,9,10]. Additionaly, there are some trends of modern biophotonics: 1) combination of OA and US imaging; 2) combination of OA with fluorescent imaging [15]; 3) transfer to mid-IR [16]; 4) preparation of multimodal contrast agents, that can be provided the contrast by some clinical methods including optoacoustics, fluorescence, MRI, US etc. [9,10,17]; 5) preparation of calibration grids allowed the quick evaluation of OA devices [18]; 6) using minimally invasive otoacoustics [19,20]; 7) developing PIC based US transducers [21] using a biomimic approach for preparation a sensitive part (membrane) of such type of sensors [22]; 8) optical clearing approach [23].

In report will be presented the results of in vivo optoacoustic applications and besides both optoacoustic mesoscopy and tomography. Particular attention will be devoted to the implementation of near and mid-IR for OA microscopy and endoscopy and the prospects for its application for in vitro and in vivo studies, for example, for the analysis of histological sections, as well as for determining the type of atherosclerotic plaques, respectively.

Thus, the combination of photonic tools with microstructured materials has a good perspective for application in biology and medicine.

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References

[1] A.A. Merdalimova, et al, Applied Sciences-Basel, **9**,6,2019, 1135

[2] J.Cvjetinovic, et al, Phys. Chem. Chem. Phys., **24**, 2022, 8901
[3] M. Slyusarenko et al, Biosensors, **12**, 2022, 23.
[4] J. Mujtaba et al, Advanced Materials, 2007456, 2021, 1
[5] T. Ermatov et al, Light: Science & Applications, **9**, 2020, 173
[6] A. Kuzin, et al, Optics Letters, **47**, 9, 2022, 2358
[7] M.V. Novoselova *et al,* J. Biophotonics, **12** (4), 2019, e201800265
[8] S.V. German, et al. Scientific Reports, **8**, 2018, 17763
[9] M.D. Mokrousov, et al,. Biomedical Optical Express, **10**, 9, 2019, 4775
[10] M.V. Novoselova, et al, Colloids and Surfaces B, 2021, 111576
[11] R. E. Noskov, et al, Adv. Mater. 2021, 2008484
[12] S.V. German, et al, Langmuir, 2021, **37**,4, 1365
[13] D.V. Voronin *et al*, ACS Applied Materials & Interfaces, **9**, 2017 6885
[14] I.Y. Stetciura *et al,* Analyst, **140**, 2005, 4981
[15] M.D. Mokrousov *et al*, Biomedical Optics Express, **12(6),** 2021, 3181
[16] M.A. Pleitez et al, Nat. Biotechnol., **38(3)**, 2020, 293
[17] E.A. Maksimova et al, Laser & Photonics Reviews, 2023, https://doi.org/10.1002/lpor.202300137
[18] M. R. Chetyrkina et al, ACS Photonics, **9 (10)**, 2022, 3429
[19] H. Guo et al, J. Biophotonics, **13(12)**, 2020, 1–20
[20] N. Kaydanov et al, ACS Photonics, **8, 11**, 2021, 3346–3356
[21] W. J. Westerveld et al, Nature Photonics, **15**, 202, 341
[22] J. Cvjetinovic, et al. Scientific Reports, **13**, 2023, 5518
[23] M.V. Novoselova et al, Photoacoustics, 2020, 100186