Student project at Complex Photonic Systems (COPS), MESA+ Institute

Black scatterers to improve white LEDs!

The Nobel prize-winning technology of the blue semiconductor light emitting diode (LED) allowed to create energy-efficient white LEDs. White LEDs are mechanically robust, thermally stable, possess excellent temporal stability, and have a long lifetime. A typical white LED consists of a blue semiconductor LED in combination with a dielectric matrix (polymer) that contains phosphor particles (see Figure 1).

Industry is now looking for better LED designs to get more diffuse or directional light depending on the lighting application. Knowing what is going on inside the scattering medium of the LEDs (specifically how energy density behaves) is an important aspect to improve LED designs. Current analytical theory to describe light transport in scattering media (diffusion theory) fails for scattering medium with predominant forward scattering and absorption and predicts negative energy density [1].

In this project, we will work on forward-scattering and absorbing samples that contain carbon black scatterers. The scattering samples will also contain fluorescent particles at known depths, that will enable us to measure energy density inside the sample. We will find out which parameters such as density of scatterers , density of fluorescent particles, or even the detection method could enable us to measure energy density inside a sample (especially for such an absorbing sample!).

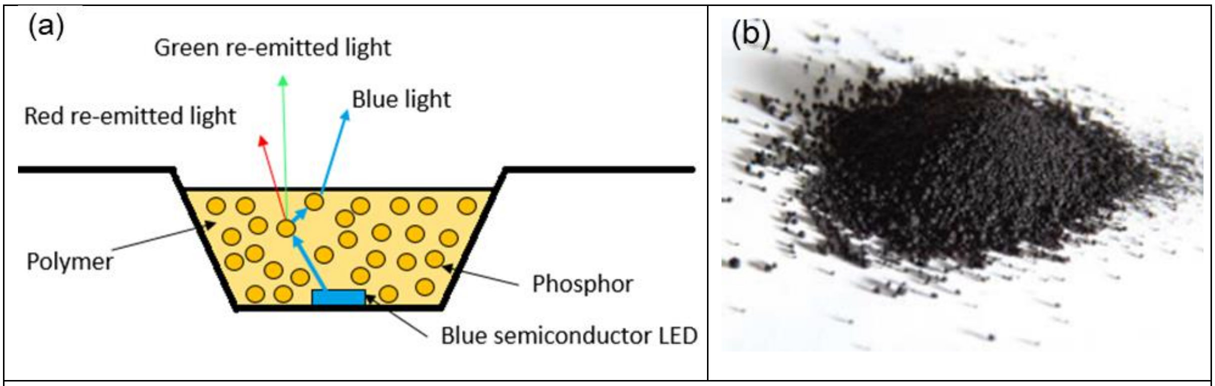

Figure 1: (a) Schematic of the basic construction of a white LED. A cup with reflective walls is filled with a polymer matrix containing phosphor particles. The phosphor particles absorb blue light emitted by the blue semiconductor LED and re-emit light in the red and green parts of the spectrum, yielding the desired white light. **(b)** Carbon black powder as absorbing scatterers for this project. [Taken from supplier: CABOT]

References:

1. Meretska, Uppu, Lagendijk & Vos, arXiv:1904.02784 [physics.optics] (2019)

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Steering light in any direction!

The principle of anisotropic scattering of light is employed to direct light towards an intended target. The concept is envisioned by, engineering the scatterers of the medium with specific orientation, using nano-lithographic methods. Industrial applications would benefit significantly from directional light delivery by these complex media.

Can we direct light optimally towards a target?

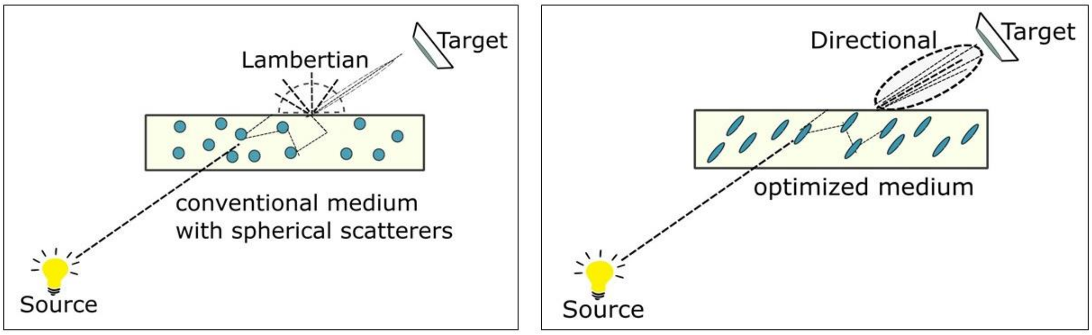

Figure 1. *Illustration of directional light delivery. In a conventional medium of spherical scatterers, light escaping the medium has a Lambertian intensity distribution. An optimized medium with specially designed scatterers direct light towards a target.*

In this project, specially designed ensemble of scatterers are fabricated using an advanced direct laser writing (DLW) technique in MESA^{+}. The project will include characterizing the fabricated samples using a scanning electron microscope (SEM), building a new setup for performing optical experiments and demonstrating the first-ever delivery of light towards a target using anisotropic and oriented scatterers.

References:

1. W. L. IJzerman, M. Sikkens, H. Cornelissen, A. Lagendijk, and W. L. Vos, Blazing light-engine for area, sports and theatre lighting (internal report, 2012).
2. B. C. Kaas, B. A. van Tiggelen, and A. Lagendijk, Phys. Rev. Lett. **100**, 123902 (2008)

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Computational Nanophotonics

State-of-the-art technology enables the COPS group to create world-class photonic crystals – periodic metamaterials with refractive index changing at the scale of hundreds of nanometers. These materials allow us to control light – modify its path, slow it down or even trap it at a given location. If perfected, they are not only of high value in the fundamental research but can also enable multitude of applications, ranging from better optical components to highly-efficient solar cells to quantum computers.

Nevertheless, the intrinsic complexity of photonic crystals makes it extremely difficult to understand what precisely is happening with light passing through such a material and which physical phenomena take place in the process. Obviously, we cannot look inside the crystal without destroying it and the equations describing these processes are too complicated to be solved analytically. This is where numerical computations come into play [1]. COPS collaborates with Mathematics of Computational Science (MACS) group to unravel the mysteries of photonic crystals.

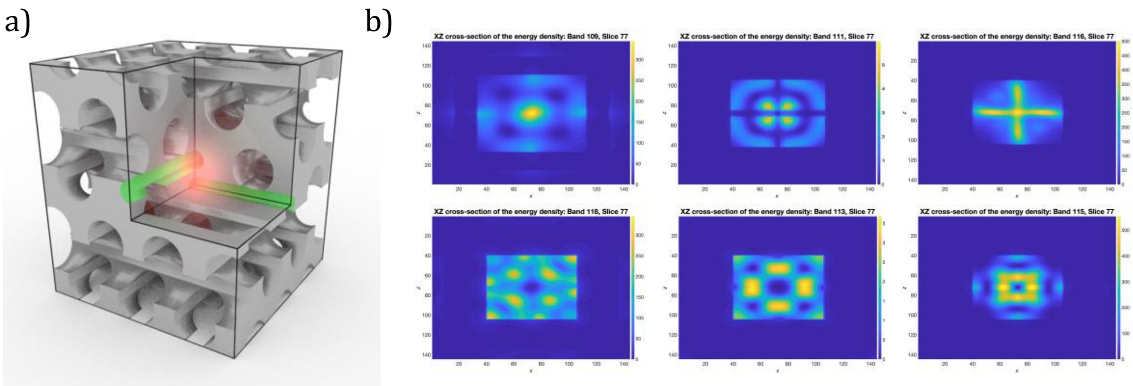

***Figure 1.** a) Illustration of a photonic crystal with a defect cavity. The structure consists of two sets of pores etched into the silicon backbone. Defect pores (green) have reduced radius. At their intersection, a cavity appears (red), allowing us to trap light. b) Computational results of energy-density distribution for localized modes inside such a cavity photonic crystal. The modes are localized in the center of the computational cell and exhibit various symmetrical patterns.*

In this project, numerical methods will be used to understand the behavior of light inside 3D photonic band-gap crystals. A high-performance computer cluster will be made available for this purpose.

Reference:

1. D. Devashish, O. S. Ojambati, S. B. Hasan, J. J. W. van der Vegt, and W. L. Vos, Phys. Rev. B 99, 075112 (2019).

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Light through the jungle

The Wavefront Shaping (WFS) technique – invented in our group - can be used to convert an opaque flat sample into a transparent lens by modifying the wavefront of the incoming light [1]. This technique is based on spatially dividing the incoming light into segments and controlling their phases in order to optimize the intensity in the target point. For real world application, a perfectly flat and static surfaces cannot be assumed anymore [2]. Is it possible to use this technique in a free-formed sample, which is relevant for industry?

Can we control light inside a wild shape?

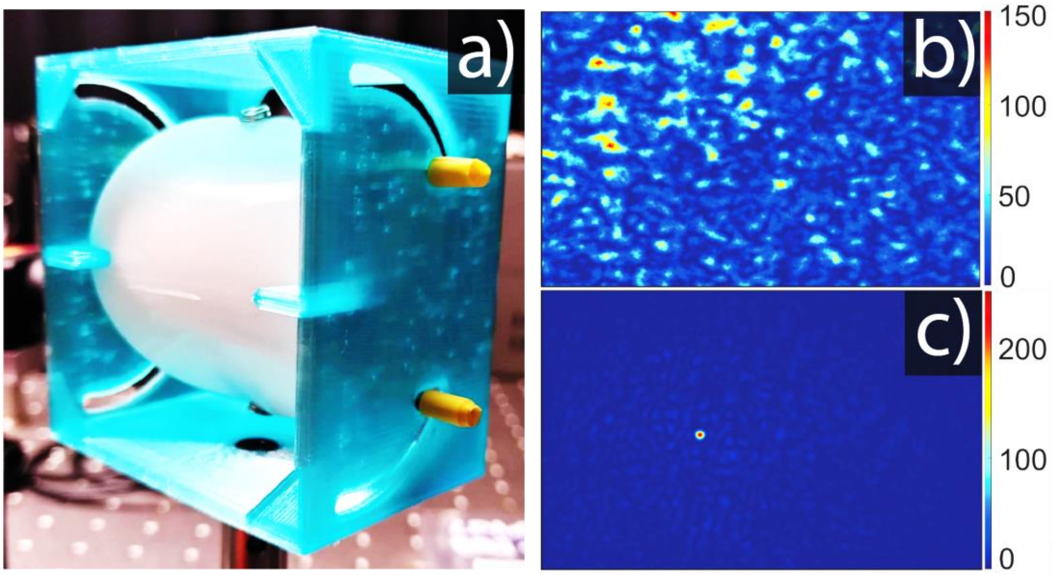

Figure 1. a) Photo of a free-formed (bent) sample of TiO_2 nanoparticles in silicone. b) Speckle when illuminating the bent sample with plane waves. c) Wavefront shaping leads to a brighter spot even when transmitted through a free-formed scattering sample.

In this project, the WFS technique will be used in a flexible sample made of TiO_2 nanoparticles in silicone. Changing the sample geometry, let's see how well the transmitted intensity will be optimized. This assignment includes sample characterization, holder design and fabrication, and implementation of state-of-the-art algorithms.

References:

1. I.M. Vellekoop and A.P. Mosk, Opt. Lett. **32**, 2309-2311 (2007).
2. J. Brake, M. Jang, and C. Yang, J. Opt. Soc. Am. A **33**, 270-275 (2016).

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