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Model of polarization selectivity of the intermediate filament optical channels

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Abstract

Recently we have analyzed light transmission and spectral selectivity by optical channels in Müller cells and other transparent cells, proposing a model of their structure, formed by specialized intermediate filaments [1,2]. Our model represents each optical channel by an axially symmetric tube with conductive walls. Presently, we analyze the planar polarization selectivity in long nanostructures, using the previously developed approach extended to structures of the elliptic cross-section. We find that the output light polarization degree depends on the *a/b* ratio, with *a* and *b* the semiaxes of the ellipse. Experimental tests used a Cr nano-strip device to evaluate the transmitted light polarization. The model adapted to the experimental geometry provided an accurate fit of the experimental results.
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1. Introduction

The celestial distribution of the angle of the skylight polarization, being the same under all possible sky conditions (clear, fog, clouds, etc), is used for the orientation by polarization-sensitive animals, including many vertebrates [3]. There is considerable behavioral and physiological evidence for polarization-based navigation in vertebrates, including fish, reptiles and birds, but not in mammals, while it is known that mammals, including humans, can still perceive the polarization of light to some extent [4,3]. The search for the physical mechanisms of the polarization sensitivity has taken two different paths: some researchers are looking for optical polarizing filters in front of the photoreceptors; while others suggest that photoreceptor cells themselves may have different intrinsic sensitivity to differently polarized light [3].

Photoreceptors would be intrinsically sensitive to polarization, if they had some dichroic absorbance at the molecular level. Indeed, it was shown for the invertebrate rabdomeric photoreceptors that their chromophore is preferentially aligned along the axis of the microvillus and immobilized, allowing for robust polarization sensitivity [3]. On the other hand, the first spectroscopic measurements found rhodopsin dipoles in the vertebrate photoreceptors free to rotate within the photoreceptor membrane without any preferred orientation to the incident light, thus rejecting the possibility for their polarization sensitivity [5,6]. These earlier results have been criticized later. Namely, a preferred orientation of rhodopsin was discovered in some fish species (anchovy cone photoreceptor outer segments), where it is contained in transversely-oriented lamellar membranes [7–9]. Additionally, rhodopsin mobility was significantly restricted in some species [10], explained by its possible oligomerisation [11]. These data suggest that the photoreceptors may be intrinsically sensitive to polarization, at least in some vertebrate species.

On the other hand, the same anchovy and some other fish have specialized guanine crystals surrounding the outer segments that may work as polarized light reflectors [12,13]. The suggested polarization sensitivity in birds is due to specialized oil droplets present in the optic path of only one of the cone photoreceptors in the specialized cone pair [14–17]. All of these additional elements present in the optical path may work as specialized filters. Here we suggest a novel possibility that the specialized optical channels inside the transparent cells may work as additional polarization filters in front of the photoreceptors.

We have earlier proposed that bundles of nanoscale filaments (with each filament 10–12 nm in diameter) in the transparent cells of the optical tract may directly participate in the transmission of light energy, and developed a physical model of the light energy transfer in long carbon-based conductive nanostructures [1,2]. We developed a quantum mechanism (QM) of the electromagnetic field (EMF) transmission by a waveguide [1,2], a capillary with conductive walls, with the diameter significantly smaller than the EMF wavelength. We suggested that the intermediate filaments found in the transparent cells may be the ideal match to the nanotube-based model, because of their diameter (10–12 nm) and because their axial structure resembles that of nanotubes, with a low-density core and high-density walls, according to the X-ray diffraction data [18]. Thus, our models provide the theoretical background for the experimental results obtained earlier by different authors that implicate the specialized intermediate filaments in the cell transparency [1,2]. Note that genetic deletions or mutations, or chemical modifications of these intermediate filaments may lead to transparency loss [19–23], underlining the importance of their structure for their light-guiding properties.

Interestingly, the retinal Müller cells (MC) and their intermediate filaments should be included into the optical path before photoreceptors in vertebrates, as they were found to transfer light to the cones in their inverted retina [24]. We found [1,2] that the QM reproduces the high efficiency of the EMF transmission by the nanoscale tubes, provided their shape is optimized. We also proposed that such mechanism may explain light transparency of the MC, without the exact knowledge of the waveguide chemical structure [1,2]. Generically, we model each of the waveguides/channels in the bundle by an axisymmetric tube with conductive walls. Note that extended π-conjugated carbon systems are electric superconductors, typical examples being single-wall carbon nanotubes and graphene [25–32].

The optical selectivity in different nanoscale systems has been explored quite intensively before [32–44]. Recently we applied an approach proposed by Makarov et al. [1] to explore the spectral selectivity in axisymmetric nanoscale waveguides [2]. We reported that the transmission spectra of the model waveguides have a well-defined spectral band, its width dependent on the waveguide diameter and wall thickness. Thus, we concluded that the MC waveguides composed of bundles of specialized intermediate filaments may transmit visible light within a determined spectral range, dependent on the geometrical parameters of the individual filaments. Presently, we extend the modeling approaches developed