The Silky Way: Biomimetic sensing through changes in structural proteins

Study Reference Number: 14-6401
Type of activity: Standard study (25 k€)

Project Summary

Objective

This project will investigate the feasibility of a new type of biosensor based on silk optical fibres to detect chemical and biological components, with an emphasis on label-free sensing.

Target university partner competences

Fibre optical sensors, resonators, chemical sensing, experimental facilities, reeling and tensile testing facility, spider breeding facilities

ACT provided competences

Structural proteins, material science, chemical biology, optical fiber sensing, photonics, physics

Keywords

Biosensing, structural proteins, sensitivity, detection limit, esters, silk optical fibres, structural conformation, label-free sensing, nano-fibre loops

Study Objectives

This study will investigate the feasibility of a new type of biosensor:

- Develop a new biosensor that can detect a multitude of environmental components in a single device and to provide a first estimation of the sensitivity and detection limit.
- This will include; a) assessing the sensing capability with classes of compounds (like esters, alcohol, etc.) that can be detected with the current device, b) evaluating the impact of radiation on the silk fibres.

Background and Motivation

Optical sensors are powerful tools that have applications in various fields such as environmental hazard detection, structural health monitoring, and biological research. Current optical sensors have been developed following recent advances in fibre optics communications and silicon wafer manufacturing [9, 10].

One of the limitations of current sensors is typically that there are very few intrinsic interactions between the waveguide structure and the surrounding environment, which makes current optical sensors not optimal for practical sensing. The current approach to overcome these limitations is to increase the light-matter interactions, with the aim of increasing the sensitivity of sensors. Typical solutions envisaged are to decrease the optical fibre size (from 125 microns to ~300 nanometers) forcing part of the electromagnetic (EM) field to propagate outside the nano fibre, to add a thin slot to silicon chips, to change the group velocity of the light beam or to add metal nanoparticles to benefit from surface plasmon resonance [4, 11-15]. All these solutions however still rely on the evanescent part of the EM field for detection and are therefore limited in their effect. This is because conventional waveguide material such as fused silica is very little affected by its environment.

By using materials that change mechanical and optical properties according to its environment, multi-component sensitive sensors could be obtained with lower energy requirements. Nature uses this approach in many biological receptors, like smell, taste, etc. These are based on transmembrane receptor-peptides that change structural conformation upon binding to a certain ligand in the extracellular space. This conformational change triggers an action potential in the receptor neuron via a second messenger pathway sending a signal to the nervous system that then identifies the smell, taste, etc. [5] These bio-receptors work at the nanoscale level with minimal energy occupying very small spaces, high sensor density, accuracy and robustness.

Biomimetic approaches of these biological sensors are been made at this very moment with the integration of specific transmembrane proteins in synthetic membranes. However this research and a working first principle will take a few more decades to develop. Moreover this entire system is extremely complex which is a serious disadvantage for space applicability.

Here we propose to uncouple the conformational change of the receptor-peptide from the second messenger pathway responsible for the cascading final signal, seriously reducing the complexity of the entire sensing system. Instead we look at the change in material properties of structural “receptor”-proteins upon interacting with molecules. Such changes can be measured much more easily. In these receptor-proteins different molecules will induce characteristic conformational changes resulting in distinct material property changes. These can be associated with specific compounds.

The advantages of this approach are firstly to reduce the complexity of the system and secondly to increase the sensitivity of the “sensor”.

Additionally more chemicals can be identified in this way as every interaction will result in a change in material properties, whereas this is not the case in the original receptor-proteins as these tend to be ligand specific and not every molecule results in an action potential.

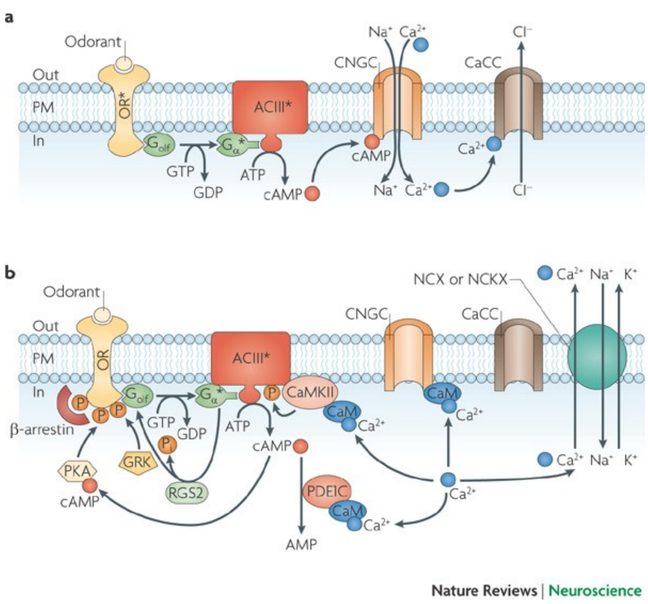

Figure 1: Biochemical pathway of an odorant binding to a protein receptor in the cell membrane and the cascading event to trigger an action potential, the signal [5].

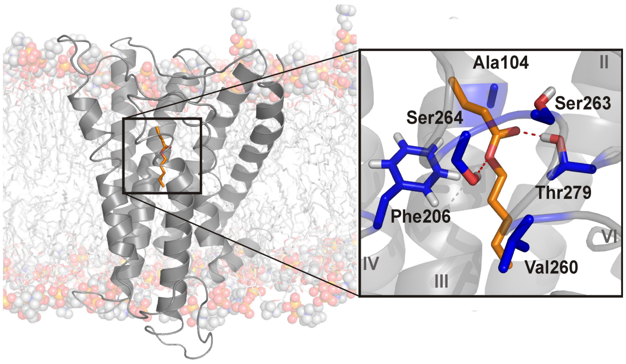

Figure 2: The binding of a chemical in the protein and the changing protein configuration resulting in a different amount of bonds between groups hence resulting in a signal [16].

However measuring the material properties of a single receptor-protein is technically challenging requiring sophisticated equipment, but nature produces many more materials that offer a solution, like structural proteins similar to these receptor-proteins. The most elegant appearance of these proteins is in the form of a fibre, like collagen, silk, wool, etc. easily measurable with existing techniques and very responsive to environmental conditions due to their small dimensions.

The ultimate fibre is of course silk where the properties can be consistently tuned as necessary for receptor applications. In contrast to natural fibres like wool which is cross-linked, silk fibres are held together by reversible hydrogen bonding, making them ideal for measuring [6, 7]:

- ions
- small molecular weight molecules: alcohols, acids, aldehydes, esters, alkyl cyanides, etc.
- water
- temperature

We propose here to use spider silk as natural example of structural proteins, i.e. proteins that change their conformation according to a given stimulus. Currently, silk sensors are a topic of research as food sensors for food monitoring [8].

Proposed Methodology

There are many different ways of detecting structural changes in proteins or materials like X-ray scattering, neutron scattering, NMR, etc. Some of these techniques are not easily available on-board spacecraft. We propose the following approach based on optical silk fibre sensing to obtain sensing in structural proteins, though universities are invited to propose better suitable approaches to achieve the main goals.

1. Select the best silk with the right ratio of crystalline/amorphous regions and prepare fibres for the light coupling setup as single or bundles of fibres.
2. Identify an efficient way of coupling light into the silk fibres and build the appropriate experimental setup.
3. Study the optical response of the sensor, focusing on photon absorption in the mid infrared range.
4. Identify other appropriate ways to monitor changes induced by the environment (e.g. silk refractive index, polarization changes due to chemicals), focusing on VIS wavelengths.

The optical setup should include a silk fibre with an IR or VIS optical beam shining through to look at changes in the protein conformation. The silk filament could be integrated on a photonic chip made of polymer microstructures to make the device small and practical for sensing applications (as in [2]).

In this Ariadna project a first evaluation of the detection limit and sensitivity of the silk-based optical sensor should be provided. Since the molecule properties are different (e.g. polarity) the optical response of the silk proteins to various chemicals is likely to be different, providing a mean to distinguish various contaminants. The experiments should be performed under controlled laboratory conditions to remove the dependence of the sensor's response on humidity and temperature.

ACT Contributions

The project will be conducted in close scientific collaboration with ESA researchers. In particular ESA researchers will provide technical expertise in optical fibre sensing, structural proteins, chemical biology and could provide laboratory facilities to test the impact of radiation on the silk fibres.

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