Microoptodes: the role of fibre tip geometry for the sensor performance

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Summary

Established sensors for fine scale measurements in natural environments are based on electrochemical measuring principles for e. g. oxygen and pH. The preparation of such electrochemical sensors is, however, a time consuming process. Based on the technical progress in the field of fibre optical measuring techniques many well-known chemical principles can now be used for the preparation of optical sensors, e.g. the oxygen measurement by luminescence quenching, and the pH-measurement with absorption based dyes. The use of optical fibres offers a high potential for miniaturisation of sensors [1]. For high spatial resolution measurements, the sensor chemistry has to be immobilised on the fibre tip, and the excitation and emission light has to be guided via the same fibre.

Measurements in the gas phase or in a measuring cell with constant optical conditions are possible to do without additional manufacturing steps. For applications in natural environments optodes are however often overcoated by an additional layer – the optical insulation. This layer has to be highly permeable for the analyte in order to avoid a significant increase of the response time. In the past, the optical insulation was also necessary to enable measurements at ambient light. The modern lock-in technology is able to separate the modulated signal of the sensor from the background signal, which comes from ambient light. There are, however, additional influences on the signal in the same modulation frequency, which cannot be filtered out completely, e. g. back scattered light from gas bubbles or particles. Furthermore, there can be additional luminescence in the measuring medium. Chlorophyll, carotenoids, bioluminescence and many other substances exhibit changes of their optical properties in the same part of the light spectrum as optical chemosensors. In Figure 1 the luminescence spectrum of a microbial mat in approximately 2 mm depth is shown. The natural luminescence of the probe and back scattered light will also influences the life-time measurements, leading to a lower signal to noise ratio. Also, the light emitted from the sensor tip can influence

the natural conditions, in the probe. For example, the often used blue or bluegreen excitation light for oxygen optodes can stimulate photosynthesis and therefore a change of the oxygen concentration. Therefore, an optical insulation is still useful for many applications.

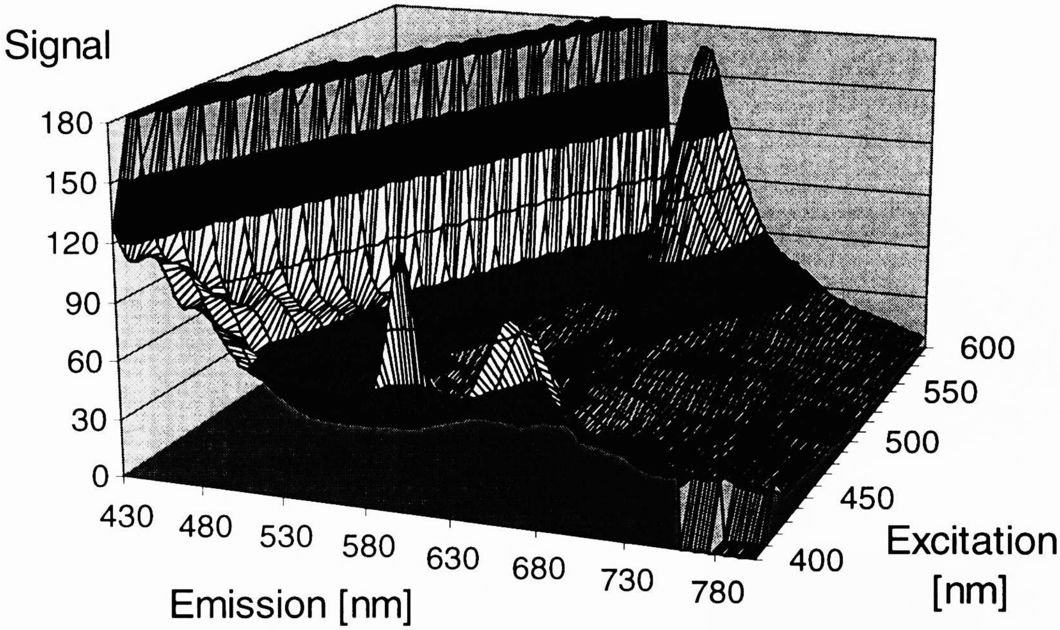
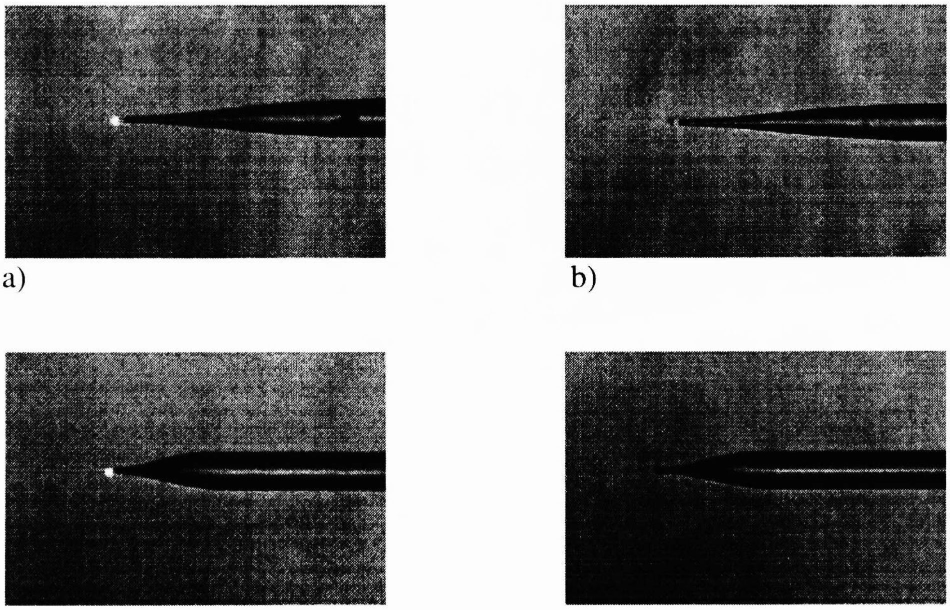


Figure 1: Luminescence spectrum of a microbial mat in a depth of 2 mm

In order to increase the spatial resolution of the measurement the optical fibre can be tapered. Microptodes with tip diameters of a few micrometers have been developed. The tapering process influences, however, the working principle of optical fibres. The needed thickness of the cladding material on the fibre core will be reduced also. In the taper, the thickness of the cladding layer can decrease down to a diameter where the light becomes able to pass it. The amount of guided light is, thereby, reduced and the signal decreases. Therefore the geometry of the taper becomes important for the construction of microoptodes especially for measurements in the aquatic phase, which has a refractive index closer to quartz glass.

We present investigations of the dependency of the signal intensity of microoptodes as function of the tip size and geometry. The manufacturing process is described in detail. The width of the heated part and the pulling force are the key parameters in this process. Measurements of the melting process and determinations of the final core to cladding ratio cannot be done in an easy way. Therefore, we looked for empirical correlation. We compared the macroscopic effects like the change in sensor signal from gas phase to aquatic phase. Finally, we give a suggestion for an optimal geometry of the taper, which leads to a high signal. All these investigations were based on a Ruthemium dye immobilised in polystyrene at the fibre tip.

For tapered microoptodes the optical insulation is much more complicated compared to untapered fibre sensors. Normally, black polymers like silicone are used for the optical insulation. The refractive index of these materials is in the most cases not useful to provide the needed difference for the light guiding. The amount of guided light is, therefore, reduced dramatically. Here we present microsensors, where a good compromise between insulation and signal intensity was obtained. In Figure 2 two different tapered microoptodes with tip diameters in the same range are shown, without (Fig. 2a and 2c) and with optical insulation (Fig.: 2b and 2d). Differences in the signals can be measured clearly.



a) b)

c) d)

Figure 2: Oxygen microoptodes without (a and c) and with optical insulation (b and d). The tip diameter is approximately 10 to 15 μm

[1] Klimant, I.; Meyer, V.; Kühl, M.
Fiber-optic oxygen microsensors, a new tool in aquatic biology
Limnol. Oceanogr., 40, 6, 1159-1165, 1995