Electrophoretic deposition to develop new optical sensing materials: application to a wireless oxygen sensing microrobot

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Abstract

Molecular oxygen is one of the most important gases in our environment since it is present in a variety of reactions with industrial, medical and biological applications [1, 2]. In the field of clinical diagnosis and treatments, an inadequate oxygen supply is related with major eye diseases such as diabetic retinopathy, glaucoma, retinopathy, age-related macular degeneration and retinal vein occlusions [3]. However, their relationship is not well known and *in vivo* oxygen measurements are essential for a better diagnosis and treatment. In this aspect, optical detection of oxygen combined with microrobots offer an interesting tool for *in vivo* measurement of oxygen concentration inside the eye. Firstly, optical methods are a good alternative towards electrochemical methods due to its advantages such as no oxygen consumption and minimally invasive, among others. In addition to this, wireless microrobots have the potential to revolutionize many aspects of medicine, since they can develop minimally invasive procedures.

Therefore, an intraocular optical oxygen sensor using a luminescence coating can be developed with a magnetic platform which is controlled wirelessly with magnetic fields and tracked visually through the pupil, as can be seen in Fig. 1 [4].

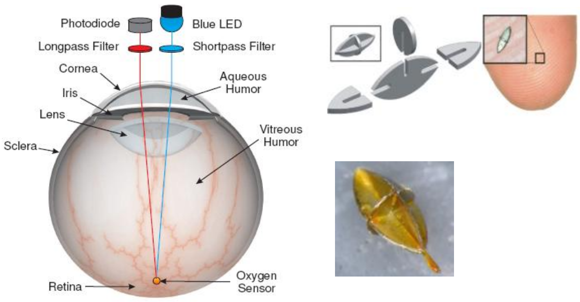

Fig 1. Scheme of the wireless oxygen sensing microrobot.

This sensing microrobot is based on the quenching of luminescence produced by oxygen over a luminescent dye, which is normally deposited on a matrix that acts as coating. Fig. 1 also shows the magnetic microrobot, which was first coated with gold by electroless plating for biocompatibility.

In order to obtain the sensing surface it became necessary to develop a method to make surface coating compatible according to the shape and size of the microrobot. To address this issue, gold chips were first used to simulate the gold surface of the microrobot and evaluate the deposition of oxygen sensing nanoparticles by electrophoretic deposition (EPD). This type of film pretends to conjugate the properties of classical polymeric films (in terms of solubility of the dye and selective permeability to oxygen [2]) and the advantages of nanoporous materials (which normally produce a better efficiency of the quenching [5].)

Polymeric sensing nanoparticles were produced by precipitation-evaporation method.[6] After optimization, polystyrene-co-maleic anhydride polymer and the oxygen sensitive dye PtTFPP (Platinum tetrakis(penta-fluorophenyl)porphyrin) were dissolved in THF and the cocktail was subsequently drop over water under stirring. Monodisperse 140 nm nanoparticles were obtained after the evaporation of the THF, showing a zeta potential of -40 mV.

The EPD was performed straight forward from the solution of nanoparticles, using a self-made electrophoretic cell. The cell consists of a platinum sheet acting as the negative electrode (cathode), a plastic container where the solution is added, and a gold chip, acting as the anode, inserted opposite to the platinum electrode. As the maleic groups of the surface of the sensing nanoparticle are negatively charged, the particles move towards the gold surface when a voltage is applied between the platinum and the gold surfaces.

By changing the applied voltage and deposition time it is possible to tune the nanostructured arrays of particles. Therefore, different voltage were applied from 20 V to 5 V, since no deposition was found with lower voltage, while the formed polymer became dark with voltages higher than 20 V. Deposition time was also limited to 15 minutes, since for longer times the darkening of the chip also occurred for all the selected voltages. For each experimental condition, three replicas were done in order to evaluate reproducibility.

After the electrophoretic deposition, each gold chip was measure at different oxygen concentration using a fiber optic measurement system based on a phase-modulation technique [7]. The results show good response to oxygen in all the cases, with a slight increased in oxygen sensitivity when lower voltage or times are used. This could be explained by the thickness of the film, which allow the oxygen to better penetrate the pores if the layer is thinner. In fact, as can be observed in the SEM photograph of Fig. 2, the nanoparticles seems to form a single layer, although no total assembly of the particle was reached. This could explain that the sensitivity to oxygen is enhanced when comparing to a film produced by dropping and drying 30 µL of the solution of nanoparticles onto a gold chip.

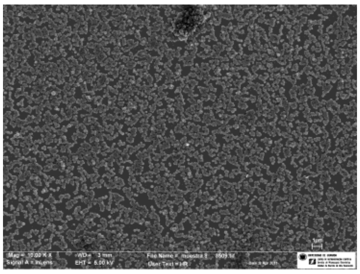

Fig 2. SEM picture of the surface of nanoparticle coated gold chip.

Further optimization of the coating in the real microrobot will be carried out. Nevertheless, electrophoretic deposition of sensitive nanoparticles opens a new field in the development of optical materials that can easily adapt to any surface, regardless of the size and shape, while improving the performance of the sensor, which is of great interest in the development of nanometric scale devices.

References

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