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Planar Oxygen Sensors for Non Invasive Imaging in Experimental Biology

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Abstract:

The presence of molecular oxygen is a sine qua non for aerobic metabolism. In both plant and animal mitochondria, it acts as the terminal electron acceptor for oxidative phosphorylation occurring during cellular respiration, and is necessary for the generation of ATP, the common energy currency within the living cell (Atkinson, 1977, Cooper, 2000). It is the major by-product of photosynthesis in which plant biomass is accumulated by the conversion of carbon dioxide into polymeric compounds. Since respiration and photosynthesis are so fundamental to life on earth, an understanding of the mechanisms underlying oxygen consumption, production and homoeostasis has become a significant field of both biological and biotechnological research (Volkmer et al., 2009).
Oxygen (micro-) sensors, which are widely used in the life sciences, are designed to provide a precise measurement of the concentration of oxygen within a localized region of a tissue or an organ (Borisjuk & Rolletschek, 2009). Most of these devices have been based on miniaturized Clark-type electrodes (Revsbech & Jørgensen, 1986), in which oxygen diffuses into the sensor via a permeable membrane, following which its reduction at the cathode generates a measurable electrical current. This approach can deliver a spatial resolution at the low µm scale. Increasingly this technology is being replaced by optical oxygen microsensors (micro-optodes) based on fibre optic materials (Klimant et al., 1995; Rolletschek et al., 2009), in which the concentration is assessed in tapered glass fibres of tip size ~50 µm via the dynamic quenching of a luminophore. This approach enjoys several advantages over the electrochemical detection system, as detailed elsewhere (Kühl & Polerecky, 2008; Rolletschek et al., 2009).
Importantly, microsensor-based approaches are invasive, which means that a given biological sample cannot be readily studied over a prolonged time period. furthermore, the internal structure of most biological samples is far from homogeneous, with complex compartmentation being the norm. As a result, whole tissue measurements can only reflect the mean performance of a tissue, and cannot report variation between distinct compartments. This loss of richness compromises the value of such data for elucidating biology of the tissue as a whole. At best, conventional sensor systems assess oxygen concentrations across a transect, leaving its two dimensional distribution unknown. Lifting this limitation requires the development of a planar sensor.

Key-words: cellular respiration, oxygen distribution, photosynthesis, respiring root, oxygen mapping, planar optical sensors