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CUSTOMER APPLICATION NOTE

Time-resolved Spectroscopy of Phosphorescent Oxygen Sensors in a Relevant in vitro Environment for Biomedical Applications



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This customer-written application note describes how an Edinburgh Instruments FL51000 Photoluminescence Spectrometer can be used to characterize solid sensors in a relevant environment of interest. Specifically, it describes how candidate materials for optical in vivo oxygen sensing were evaluated in a relevant in vitro environment through careful control and monitoring of the solution temperature and dissolved oxygen concentration. Sensor performance was characterized via changes in phosphorescence lifetime; these long lifetime materials were assessed using Multi-Channel Scaling (MCS) and a microsecond flash lamp.

1. Introduction

Optical oxygen sensors generally function based on incorporation of a phosphorescent molecule, such as a transition metal polypyridyl complex or heavy metal porphyrin, into a polymer matrix (e.g., the film, electrochromic fibers, etc.). The long-lived luminescence from the incorporated molecule is dynamically quenched in the presence of oxygen. Considering the phosphorescence quantum yield in the presence or absence of oxygen (Eq. 1) yields the Stern-Volmer relationship (Eq. 2) which governs the dynamic quenching process. K_{SV} represents the Stern-Volmer quenching constant and indicates the sensitivity of a given oxygen sensor to dissolved oxygen in the surrounding environment. This parameter is equal to the product of the lifetime in the absence of oxygen, τ_0 , and the bimolecular quenching constant, k_q (Eq. 3).

$$\frac{I_{\text{observed}}}{I_{\text{observed}}} = \frac{\tau_0}{\tau} = \frac{\tau_0(k_1 + k_2[O_2])}{k_1 + k_2[O_2]} \quad (1)$$

$$\frac{\tau_0}{\tau} = \frac{\tau_0}{1 + K_{SV}[O_2]} \quad (2)$$

$$K_{SV} = \tau_0 k_q \quad (3)$$

Critical oxygen sensors can be used for both gaseous and dissolved oxygen sensing and have a wide variety of applications, such as food packaging,¹ pressure sensitive paints,² assessing oxygen levels in cell culture,³ etc. Many factors, such as the application temperature, the relevant range of oxygen concentrations, and the state of sensor hydration, can vary widely among different applications, and such factors can have a significant impact on sensor behavior. Therefore, if a sensor is developed for a particular application, performing in situ photophysical characterization under relevant conditions is critical.

Specifically, a hydrated 37°C environment is most relevant for many biomedical applications (e.g., in vivo tissue oxygenation sensors). Furthermore, characterization of optical oxygen sensors often takes place over a large range (e.g., 0-100% O₂ for gaseous sensors) but the relevant in vivo range is much smaller. Although expected in vivo dissolved oxygen levels can vary based on numerous factors, such as sea level, a range of 0-90 μM, corresponding to 0-10% O₂, at the appropriate temperature and salinity, should encompass the relevant concentration range for most biomedical applications.⁴ However, the dissolved oxygen ranges of most interest may depend on the intended application in addition to the tissue location. For example, numerous biomedical applications are specifically focused on detecting or monitoring regions of hypoxia (i.e., low oxygen levels, typically <2% O₂/10 μM dissolved oxygen). Hypoxia-focused applications include monitoring critical limb ischemia,⁵ and identification of hypoxic regions within tumors due to their increased tendency to metastasize and resist treatment.⁶

This application note details how we have utilized an Edinburgh Instruments FL51000 Photoluminescence Spectrometer to assess candidate dissolved oxygen sensors. The goal was to assess the performance of these oxygen sensors in a relevant in vitro environment in order to evaluate their potential for use as an implantable sensor that could be used to continuously monitor tissue oxygenation in vivo.

Time-resolved Spectroscopy of Phosphorescent Oxygen Sensors in a Relevant in-vitro Environment for Biomedical Applications

Application note describing how a Photoluminescence Spectrometer can be used to characterize solid sensors in a relevant environment of interest. It shows how candidate materials for optical in vivo oxygen sensing were evaluated in a relevant in-vitro environment through careful control and monitoring of the solution temperature and dissolved oxygen concentration. Sensor performance was characterized via changes in phosphorescence lifetime; these long lifetime materials were assessed using Multi-Channel Scaling (MCS) and a microsecond flash lamp.

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