7 New Solid State Microsensors in Plant Physiology

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7.1 Introduction

Solid state microelectrodes are being increasingly used in many areas of plant physiology, ranging from classical electrophysiology studies to new applications such as scanning tunneling microscopy or atomic force microscopy. When the size of the sensors is decreased from the millimeter to the micrometer scale, many changes occur in their behavior and use. These changes lead to dramatic improvements in the quality of physiological data and make achievable experiments previously impossible. The major areas of improvement include increased temporal resolution, increased sensitivity and the ability to make spatial resolved measurements.

Electrochemical methods have significant advantages over the other techniques to monitor local concentrations of a chemical compound near plant tissues. In fact, microelectrodes (amperometric or voltammetric) can be positioned close to the cells and provide a means to estimate the local concentration. Electrochemical sensors for use in plants should display high selectivity and sensitivity, long-term calibration stability, and possess a small size. In addition, if assessing concentrations at different distances from a tissue, as in the case of the self-referencing technique (see chapters by Smith et al.; Fejio; Shabala in this book for exhaustive details on the self-referencing technique), it is essential that the tips of the microelectrodes have a planar geometry so that precise concentrations at precise distances away from the source/sink, can be determined with good spatial resolution. Another factor of crucial importance in the use of the microelectrode as a vibrating probe is a fast response time. Indeed, the sensor remains in the two measurement positions for times not longer than few seconds (usually, less than 5 s, often 2–3 s). Ideally, the electrode response time should permits measurements to be made on a subsecond time scale.

In the following pages, four different new solid state microsensors to be used in plants research will be discussed:

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1. The IAA-selective microelectrode
2. The O_2-selective microelectrode
3. The NO-selective microelectrode
4. The Cu^{2+}-selective microelectrode

7.2 The IAA-selective microelectrode

Auxin (indole-3-acetic acid) has its name derived from the Greek word auxein, meaning "to increase". Indole-3-acetic acid (IAA) is a well-known regulator of plant growth and development, which is active in submicromolar amounts and is associated with a variety of physiological processes, including apical dominance, tropisms, shoot elongation, induction of cambial cell division, and lateral root initiation. The IAA content of plant tissues is believed to be regulated by several processes. Currently, the most popular view is that auxin is a hormone-like substance. However, there are several auxin features and actions that can be much better explained if one considers auxin to be a morphogen-like agent (Bhalerao and Bennett 2003) and even a neurotransmitter-like substance (Baluška et al. 2003a,b, 2004). IAA is well known also to be transported from cell to cell in a complex process based on vesicular traffickings (Baluška et al. 2003a; Geldner et al. 2003). The direction of polar auxin transport is essential for both spatially controlled cell expansion as well as for orientation of planes of division in meristematic cells. No other plant molecule is as important for driving pattern formation and shaping of the whole plant.

Researchers studying IAA both in roots and other plant organs need to measure dynamic IAA concentrations locally, directly and continuously. However, the detection and determination of IAA in plant tissue are notoriously difficult, due to its presence in minute amounts, its inherent tendency to be decomposed by heat, light and oxygen, as well as to the presence of a wide variety of molecules which modify IAA biochemically.

Because the traditional methods commonly used to measure IAA levels, such as GC (Hunter 1986; Hedden 1993; Sanchez et al. 1996) enzyme-linked immunosorbent assay (ELISA) and radioimmunoassay (RIA) (Weiler 1984), are either discontinuous or have other drawbacks, it is impossible to determine local in vivo concentrations of IAA in a real time. In fact, these approaches integrate IAA measurement over the entire tissue surface and provide an averaged measurement over a period of time.

Recently, our laboratory has developed a carbon nanotube-modified amperometric microelectrode that serves as very reliable sensor of IAA (Mancuso et al. 2005). To produce this sensor, we used a platinum microelectrode as a substrate electrode immobilizing carbon nanotubes (CNTs).

Carbon nanotubes are cylindrical carbon molecules with a structure similar to the fullerene, but where the fullerene molecule's symmetry is spherical,