Green Sensing Platforms for Smart and Sustainable Agriculture

Elena PALMIERI - Institute for Microelectronics and Microsystems (CNR-IMM) - Roma

In recent years, precision agriculture has emerged as a transformative strategy to enhance crop productivity, minimize environmental impact, and optimize resource utilization. At the heart of this approach is the deployment of real-time sensing technologies designed to monitor plant health, soil quality, and chemical exposure with minimal disruption. However, integrating sensors directly onto plants presents significant challenges, particularly in terms of biocompatibility, sustainability, and end-of-life management. Our work introduces the development of flexible, biodegradable sensing platforms specifically designed for precision agriculture. These platforms prioritize plant compatibility and environmental responsibility. Ethyl cellulose (EC), a renewable and hydrophobic cellulose derivative, serves as the base substrate due to its biodegradability, flexibility, and suitability for solvent-based processing. Given their flexibility and biodegradability, EC films can be directly applied to plant leaves, enabling real-time, non-invasive monitoring that does not hinder plant growth. Various sensor types can be fabricated using this biodegradable platform. Capacitive humidity sensors, for example, are realized by combining EC with other cellulose derivatives as the active layer. The same substrate also supports the fabrication of analytical sensors for pesticide detection. In particular, EC films were functionalized with gold-coated MgFe hydrotalcite nanoplatelets to produce SERS-active devices capable of detecting cypermethrin, a commonly used pyrethroid pesticide. To extend sensor functionality beyond active use, the substrate was further engineered to release nutrients at end-of-life. By embedding potassium nitrate within the cellulose matrix, the devices take on a secondary role as soil-enriching materials once they degrade. This multifunctional and degradable sensor system embodies the principles of green electronics and circular design. It minimizes ecological footprint, reduces electronic waste, and transforms expired sensors into resources for plant growth, aligning with the broader goals of sustainable agriculture and responsible technology deployment.