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A novel miniaturized radiofrequency potentiometer tag using ion-selective electrodes for wireless ion sensing†

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Instrumental approaches to remotely and wirelessly monitoring chemical species are increasingly needed. Together with the electronic developments, efforts to optimize and validate the performance of these new devices are required. In this work, the analytical performance of a recently developed potentiometer-radiofrequency tag connected to ion-selective electrodes is evaluated. This credit card sized and extremely low power consumption device yield results that are comparable to those obtained with more sophisticated, lab-based tools. Advantages such as portability and autonomy, together with unique features, such as the ability to be read through the walls in a closed vessel are demonstrated. Future perspectives opened by this new generation of devices, such as their use in wearable devices and in decentralized settings are discussed.

Introduction

Due to the explosive growth of mobile communication technologies over the last two decades, there is an increased social need for real time access to (bio)chemical information. This need to generate data from vast and usually widespread points is creating a growing demand for robust, fast, simple and low-cost analytical devices. Two major and growing trends in healthcare – such as telehealth or point of care – require diagnostics tools that can be applied in a remote, decentralized fashion.[1,2] Similarly, environmental analysis, food production, homeland security, *etc.*[3,4] are also increasingly relying on this type of decentralized measurements. As disposable, low-cost sensors are quickly gaining terrain,[5,6] efforts to develop instrumental approaches that can match simplicity and cost are needed. Additionally, as the world of smart objects – such as intelligent textiles – evolves,[7] and sensors become embedded into objects, analytical instruments that can adapt to different environments and generate chemical data *in situ* will be required. All in all, to respond to these needs, the analytical sciences must adapt and develop new detection strategies as well as new ways in which data is acquired, processed and transmitted.[8]

From a detection point of view, potentiometric sensors have several advantages compared to other sensing approaches because of their simplicity of operation, low power consumption, wide linear dynamic range and robustness. The "*silent revolution*"[9] initiated almost two decades ago by solid-state technology, which led to massive improvements in the construction, operation and analytical performance of potentiometric sensors, has recently been enhanced by the use of nanomaterials,[10] such as carbon nanotubes,[11] gold nanoparticles[12] and graphene[13] as ion-to-electron transducers. Today, solid-contact (SC) ion-selective electrodes (ISE) are one of the preferred approaches to monitor the levels of different ions outside the laboratory.[14]

Developing effective solutions to monitor chemical substances outside the lab is a multifaceted challenge that requires looking at the whole analytical process, *i.e.*, the performance, the cost and the simplicity of the whole procedure – from the measurement step to transmission and interpretation of the data – must be equally considered. Indeed, in a typical lab-based routine, samples are properly conditioned to be analyzed by an instrument. This instrumental centred approach is not valid anymore for remote monitoring. Instead of the "one size fits all" instrument, outside the lab is the tool that must be adapted to fit the analytical problem. Therefore, as the demand for out-of-the-lab chemical sensing tools grows, a proliferation of different types of analytical devices that could monitor similar chemical parameters but show different contextual advantages are needed. In general, these "adaptive analytical tools" must follow some basic rules, such as reduced human intervention (particularly minimal skills required to operate the devices), reduced cost and small footprint. Evidently, traditional performance parameters that guarantee the reliability of these measurements are also of utmost importance.

Diamond *et al.* (WCSN)[15–19] have pioneered the development of autonomous devices in the form of wireless chemical sensing networks (WCSN). Ideally, in this approach a fully autonomous

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