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PAPER-BASED ION-SELECTIVE POTENTIOMETRIC SENSORS

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Paper-Based Ion-Selective Potentiometric Sensors

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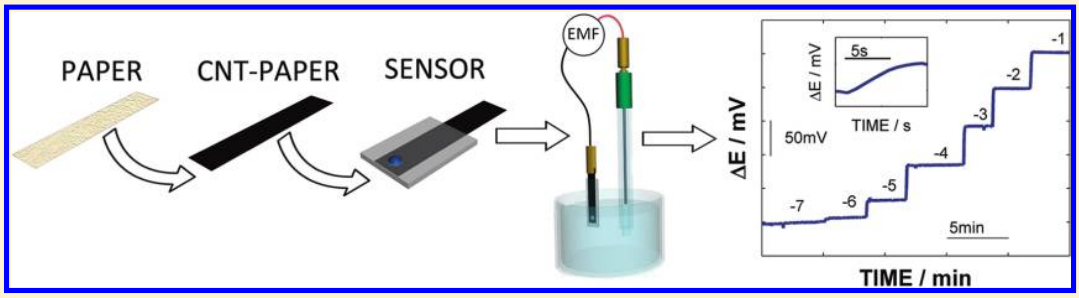
Supporting Information



ABSTRACT: A new approach to develop ultra low-cost, robust, rugged, and disposable potentiometric sensors is presented. A suspension of carbon nanotubes in a water−surfactant mixture (carbon nanotubes ink) is applied on conventional filter papers to turn them into conductive papers, which are then used as a substrate to build ion-selective electrodes. The electrodes are made by drop casting a membrane on a small circular area of the conductive paper. In this way, the carbon nanotubes act as both electric conductors and ion-to-electron transducers of the potentiometric signal. Electrodes for sensing K^+, NH_4^+, and pH were built and tested using this approach, and the results were compared with classical solid-state ion selective electrodes using carbon nanotubes as transducers and glassy carbon as a substrate. In all cases, the analytical performance (sensitivity, linear ranges, limits of detection, selectivity, etc.) of these disposable paper electrodes was similar to that obtained for the more conventional type of ion-selective-electrodes. This opens new avenues for very low-cost platforms for generation of chemical information.

Having access to robust, rugged, and low-cost chemical sensors is becoming of paramount importance in a growing number of situations. There are well established needs, such as diagnostic tools for poor regions of the planet.[1] Additionally, the development of chemical sensing networks[2,3] and the increasing role of approaches such as point of care[4−6] and telemedicine[7,8] are pushing the demand for fast access to bio(chemical) information. The term "vanguard analytical approaches"[9] has been proposed to refer to these new platforms that allow low-cost, rapid, on site chemical analysis.

In these new platforms, traditional performance parameters, such as stability, detection limits, etc., must be balanced with the need for speed, cost, and simplicity. Under these new lenses, some techniques, such as potentiometry, are regaining new value. Potentiometry has traditionally displayed an unrivalled simplicity of operation and instrumentation.[10] For this reason, it is still one of the workhorses in clinical laboratories and almost the universal approach to measure pH. Ion-selective electrodes have also become the standard procedure for measuring several ions. Furthermore, the development of solid contact ion-selective electrodes (SC-ISE) during the last few decades has produced a "silent revolution"[11] that has led to drastic improvements of the limits of detection (LOD), increased range of applications, and simplification of the sensor construction, operation, and maintenance. Recent works have also shown the advantages of miniaturization of the electrodes,[12] and the development of the electrode arrays[13,14] that could be remotely operated. All in all, potentiometric sensors are ideal "vanguard" tools for the remote, out of the lab generation of chemical information.

Some limitations, such as the cost of the sensors, still remain as a challenge when dealing with large scale applications. Despite being among the most affordable instrumental approaches, current potentiometric sensors are still too expensive for large scale operations. Screen-printed electrodes[15,16] have partially addressed this problem, but the need for lower cost sensors still remains a challenge. The search for new substrates to build electrodes as well as the use of mass manufacturing techniques are crucial to further reduce the cost of the sensors. For this reason, recent breakthroughs in areas such as bendable electronics can be key to finding new substrates and processes to fabricate rugged, robust, and extremely low-cost potentiometric sensors.

Regarding the search of new substrates, paper has been widely used to make simple, cost-effective analytical tools. Paper dipsticks and lateral flow systems have been used for decades for qualitative and semiquantitative analysis, and many new applications on this area are still being developed.[17,18] Whitesides et al.[19,20] have recently expanded the analytical usefulness of paper based devices exploiting the ability of papers to produce pump-free capillary flow of liquids. Through

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