SAW sensors for the detection of pollutants in groundwater

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Abstract
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To answer the need for rapid, reliable, in situ and representative measurements for onsite groundwater monitoring, direct detection sensors able to selectively detect pollutants without sample preparation have been designed, manufactured, and tested.
The two broad classes of direct detection transducers are optical - converting the detection layer optical thickness into a physical measurement such as surface plasmon coupling angle - and acoustic. The latter transduction technique which is the object of this study uses a piezoelectric substrate to convert incoming electromagnetic power into acoustic waves whose velocity and losses are dependent on boundary conditions, including thin polymer films tailored for reacting with a given compound. Surface Acoustic Wave (SAW) transducers act as piezoelectric transducers, that convert a change in the acoustic wave propagation path velocity - density or Young modulus variations due to interactions with the pollutant in the surrounding fluid - into a measured quantity such as resonance frequency or propagation delay measured as a phase. The selectivity is brought by a thin film tailored towards a given compound of interest for pollution detection and monitoring, deposited on the acoustic path. Most SAW transducers are manufactured in quartz, a piezoelectric material with a low permittivity. However, by using quartz transducers, monitoring of analytes in water has been plagued by packaging issues since the fluid must be allowed to reach the sensing area where the acoustic wave is propagating while preventing capacitively short-circuiting micrometer-sized electrodes patterned on the low-permittivity piezoelectric substrate due to the water high relative permittivity. However, the associated packaging issues are not suitable for in situ monitoring of groundwater. In this work, we demonstrate how using lithium tantalate (LTO) as a piezoelectric substrate provides a solution to measuring pollutant concentrations in the sub-surface environment. Two practical demonstrations include hydrogen sulfide detection using the specific reactivity of sulfur towards noble metals, and toluene detection as part of BTEX pollutant monitoring, answering the challenge of the low chemical reactivity of organic solvents. In both cases, interference of other species found in the groundwater, especially pesticides, is emphasized as a potential source of false positive detection and sensing layer degradation. The detection polymers are also formulated with a composition compatible with cleanroom spin coating techniques for reproducible deposition of sub-micrometer thick sensing layers at the square-inches scale. The tailored thin films not only act as a selective detection layer but also channels the acoustic energy in a Love mode propagation.
Finally, an analog measurement is performed from the surface instrument to the sub-surface acoustic transducer either through a tethered radiofrequency-grade cable or a wireless interrogation by Ground penetrating RADAR, and the relevant measurement (time delay in GPR measurement, resonance frequency in a wired configuration) is then digitally transmitted.

To conclude, after a few years of development and laboratory tests to optimize these SAW sensors for BTEX measurement, field experiments were performed on an industrial pilot site equipped with several piezometers, to evaluate the robustness under real conditions to improve the sensitivity and to challenge the selectivity of BTEX measurements in multi-contaminated groundwater. These first tests have shown promising results for further operational deployment. This new sensor corresponds to the ambition and the strategy to set up reliable in situ monitoring solutions which are easily deployable in network, with remote data transmission, and effective cost-benefit.

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