Metal Ion Sensor with Catalytic DNA in a Nanofluidic Intelligent Processor

Conservation
CS-1459

Background:

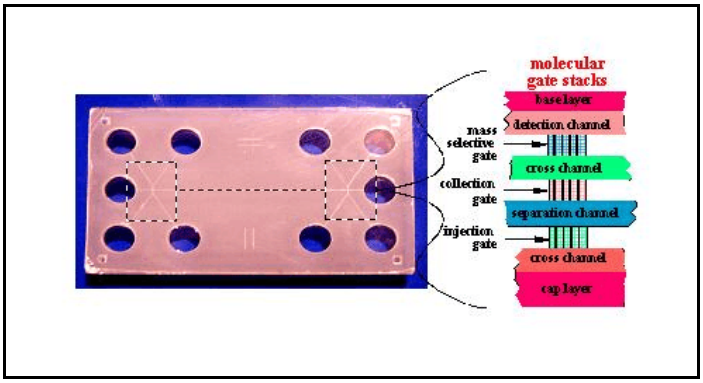
Heavy metals are a ubiquitous and troublesome class of pollutants, and lead occupies a prominent position as a contaminant requiring constant attention due to its numerous toxicological effects over a wide range of exposure. Lead is a Resource Conservation & Recovery Act (RCRA) metal and an Environmental Protection Agency (EPA) urban air toxic. Anthropogenic sources of lead from military operations require active monitoring to ensure environmental compliance and protection. Despite the adverse effects of lead on aquatic and terrestrial biota, its presence is not actively monitored, in large part due to the lack of a field product that meets all requirements for in situ measurement of lead in groundwater.

Objective:

The objective of this project is to develop a highly selective and sensitive miniaturized sensor for lead by combining two recent advances: (1) catalytic deoxyribonucleic acid (DNA) that is reactive only to lead and can be tagged to produce fluorescence and (2) nanoscale fluidic molecular gates that can manipulate fluid flow and perform molecular separations on tiny volumes. This work builds on SERDP SEED project CS-1265, which demonstrated the proof of concept for combination of these breakthroughs onto an integrated device. This project will further develop the chemistry and engineering needed to create a microfluidic device for separating, sensing, and quantifying lead in a complex matrix, as well as manipulate the sensor platform for separation and detection of other heavy metals.

Process/Technology Description:

Capillary electrophoresis columns, now microfabricated in polydimethylsiloxane and polycarbonate, are capable of precisely controlled fluidic movement by application of an electric field across distal ends of the columns. A three-dimensional arrangement of these channels can induce a user-selectable fraction of a sample to pass through a novel molecular gate consisting of a thin polymeric membrane perforated with a number of long narrow channels, typically on the order of 100 nanometers in diameter. Specific recognition elements that cause a measurable response in the presence of a particular species can be incorporated into these channels. In this case, the interior of the channels can be chemically modified with a unique sequence of catalytic DNA that cleaves an associated strand of substrate DNA in the presence of lead. Tagging the substrate DNA with a fluorophore allows for detection of the substrate DNA fragments, thus providing a sensitive optical signal for the presence of lead. This research is concerned with all chemical aspects of design and function for a rugged miniaturized sensor that is capable of remote, selective, and sensitive detection of bioavailable lead.



Top of a fabricated nine-layer chip with dual vertical stacks of three molecular gates, a key component of the metal ion sensor.

Expected Benefits:

This project will produce a prototype sensor having all desired characteristics of a remote field sensor. Several key operating characteristics make this sensor modality stand apart. Repetitive analyte delivery cycles can be realized, meaning that the catalytic DNA can react with the analyte for as long as is needed to generate a usable signal, increasing sensitivity. The substrate DNA can be released and regenerated, allowing repeated unattended use in the field. Unlike other chemically based sensors, the waste stream produced from operation of this device is exceedingly small, and only non-toxic DNA fragments are added. Finally, the sensor can be extremely rugged. In particular, it is insensitive to episodic loss of liquid analyte stream so it can survive periods without liquid input, such as might be encountered with groundwater sources that periodically dry up. The strategy outlined here can apply to any analyte for which a combinatorial binding sequence can be identified. (Anticipated Project Completion - 2008)

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