

Detection of Heavy Metal Contamination in Biological Fluids

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Abstract.

In the Bioengineering, Chemical, Semiconductor & Biotechnology fields there are increased needs for microfluidic systems with several requirements and functionalities as: smaller sizes, lower dead volumes, shorter response time, lower power consumption, better sensitivity, integration with other fluidic devices with multi-sensor possibilities and low cost. A FIA (Fluid Injection Analysis) analytical technique consists of a fluidic manifold; reservoirs, valves & pumps, micro-channels, electrochemical sensors and electronics interface for communications, can be used to fabricate such systems. In this technique a sample is injected in a continuous flowing carrier and is transported downstream into a detector. On its way to the detector, the sample fluid is mixed with the carrier and reagent solutions and is dispersed in a reaction coil. A detector measures the result of this reaction by means of an electrochemical sensor and the operation can be repeated all over again. Most of the modules needed for a FIA system such as manifold, micro channels and fluid management devices can be fabricated and integrated using the LTCC (Low Temperature Cofired ceramics) ceramic tapes. This work gives a short description of how LTCC technology is a suitable material system for meso-analytical system fabrication of heavy metal detection system for biological fluids. Design and fabrication issues are discussed. Preliminary bench results, using a pre-concentration scheme, for mercury concentration indicates a detection limit lower than 10 ($\mu\text{g/L}$), which is much lower than the maximum tolerable concentration acquired for urinary fluids.

Keywords. LTCC, FIA, MEMS, MST, Microfluidics, Water quality, Electrochemical sensors

1. Introduction

The advent of MEMS/MST technologies provided the means for system fabrication with decreased size and cost as well as increased performance and reliability. MEMS/MST development has shown steady growth, pushing the frontiers of new materials and processes for applications like: Microsystems for chemical analysis, Wegeng (1996), micro Total Analytical Systems and Microsystems for Biomedical and environmental data acquisition.

LTCC ceramic tape technology was developed manufacturing of monolithic packages and hybrid microelectronics circuitry and recently its being used for implementing Meso-Systems as described by Gongora-Rubio (2001, 2002).

This paper addresses LTCC applications in order to obtain a FIA Biomedical Meso-System. More information on FIA please report to Hansen (2000) and Ruzicka (1975).

In this work we would like to report an LTCC manifold. The device is integrated with sensor electrodes for heavy metal detection and is suitable for biological and environmental fluids.

2 LTCC Technology

LTCC ceramic tapes are glass-ceramic composite materials, Chowdhry (1987). Main reasons for using LTCC green ceramic tapes techniques as a MST technology are:

- Simplicity of tape machining with feature size of 50 μm to several mm;
- Mass production methods can be applied;
- Thermo-physical properties can be promptly modified;
- Tapes of different compositions can be formulated to obtain desired layer properties,
- Multilayer interconnections (electric or fluidic) can be easily outfitted;
- Embedded passive components is standard;
- Integration with electronic circuits can be readily done;
- Layer count can be high;
- Possibility of auto-packed devices fabrication;
- Fabrication techniques are simple, inexpensive and environmentally benign.

They are produced in flat tapes of thickness usually in the range of 100 to 300 μm . One important feature of LTCC technology is the possibility of fabricating 3D devices using multiple layers fabricated in the green (before firing) with whatever feature in the form of vias, cavities and channels needed for the overall function of the structure.

The processing of the green ceramic tapes is usually done in three steps:

- 1) Machining and patterning of individual layers with vias, cavities, resistors, conductors or dielectric pastes;
- 2) Collation and lamination of the tapes under pressure and temperature and
- 3) Co-firing of the entire laminate to sinter the material.

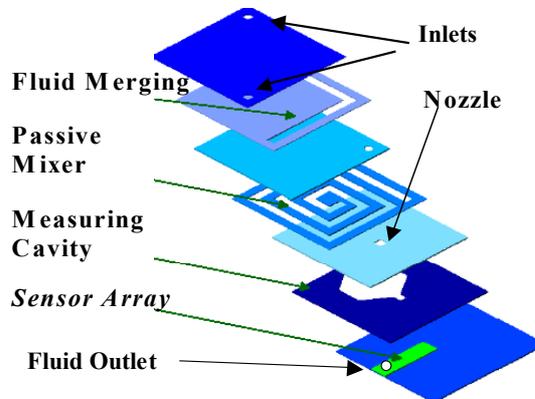


Fig. 1. LTCC layers for Manifold and sensor array.

3 Manifold and sensor array

A manifold for various tasks was designed, we include the possibility of mixing two fluids (if a reagent is needed) and implement a spiral coil used as a mixing/reaction chamber. DuPont 951 LTCC tapes with layer thickness of 200 μm were used to fabricate 1mm width microchannels, see Figure 1. A multi-electrode sensor array for electro-chemical measurement was fabricated using thick film deposition. The sensor array, based on Fontes (1999) work, is composed of a silver/silver chloride reference electrode, a gold counter electrode and two gold detection electrodes ($L=300\mu\text{m}$, $W=2\text{mm}$). Figure 2 demonstrates electrode geometry for chemical sensing.

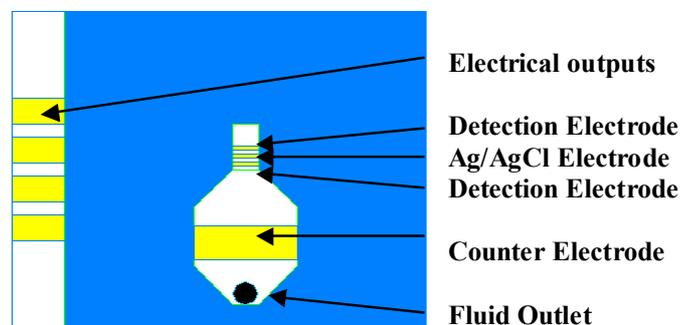


Fig.2. In flow sensor array geometry.

A ceramic green tape manifold will integrate the electrochemical detector using the auto-packaging capabilities of the LTCC technology. Figure 3 illustrates the fabricated devices (four units in a 3 x 3" LTCC tapes).

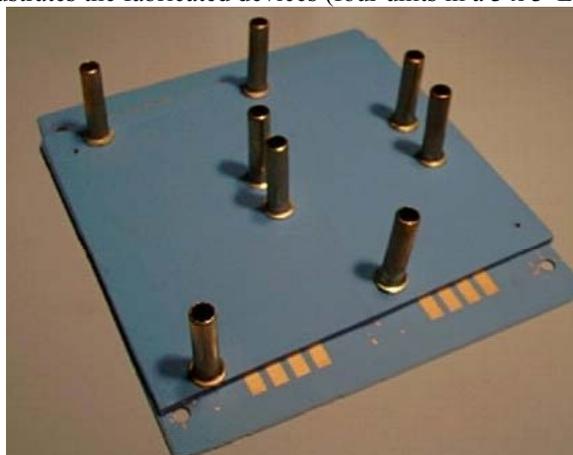


Fig.3. Fabricated Manifold with sensor electrodes.

4. The Analytical technique

Among several electroanalytical methods, differential pulse anodic stripping voltammetry (DPASV) and square-wave anodic stripping voltammetry (SWASV) are candidates for this application due to their inherent characteristics of pre-concentration, achieving part-per-billion sensitivity as pointed out by Reay (1996). Gold is a chosen material for the detection electrode due its sharp and high stripping peaks.

Several methods are proposed in order to obtain the ionic phase of the mercury to be electrochemically detected, such as: mixing the sample with potassium permanganate or using UV radiation, both suitable for in flow analysis. The electrochemical detection starts with a process called “pre-concentration”, where the electrode is held at a cathodic potential (reduction) so that metal ions from the solution are reduced at the electrode surface, concentrating on it, as indicated in Figure 4. (a) As long as the concentration interval, the higher is the material reduction, making this a compromising step.

Next, the potential is scanned in the anodic direction to reoxidize the metal concentrated on the electrode, process called stripping. This causes a current peak at specific reduction potential of the ion and it is proportional to the concentration of the ions in the solution, Figure 4. (a). Increasing the specific ion concentration causes an intensification of the reduction peak, as shown in Figure 4. (b). Finally a calibration curve (current x concentration) can be obtained from the peak current or from the area under the reduction curve, Figure 4(c).

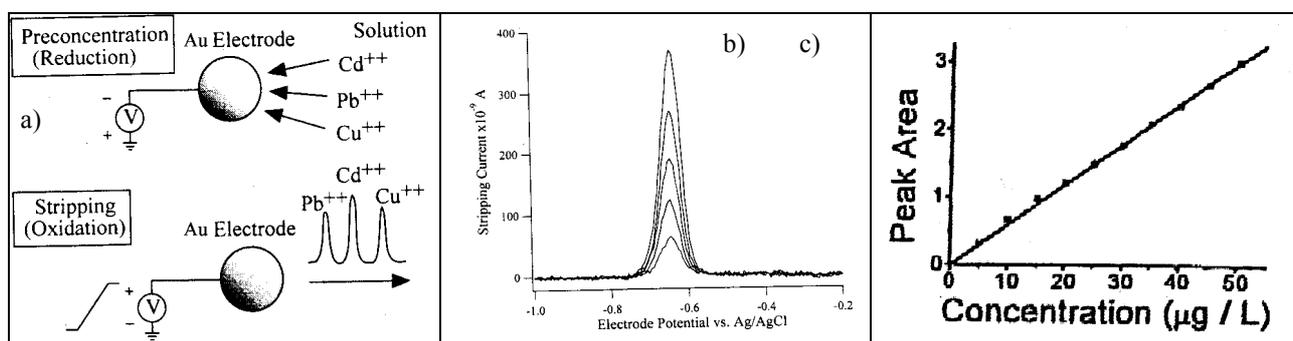


Figure 4. Electrochemical detection of heavy ions: a) pre-concentration and stripping steps, b) oxidation curve for increasing concentration and c) calibration curve, from Reay (1996).

5. Sample preparation, analytical techniques and results

Sample preparation uses a similar procedure as described by Richter (2000). All the solutions were prepared with deionized (18 MW) water obtained from a Milli-Q system (Millipore). The mercury stock solution (1000 mg/L, 1 wt. % nitric acid, atomic absorption standard solution, Aldrich) was diluted as required, just before their use. Hydrochloride acid solution (0.05 mol/L) was used as supporting electrolyte, prepared by dilution of Suprapur grade (Merck) concentrated hydrochloric acid. Nitric acid (Suprapur) and hydrogen peroxide were purchased from Merck and used without further purification.

Potentiometric stripping analysis and cyclic voltammetry were performed with an Electrochemical System (Autolab PGSTAT 20, Eco Chemie - Utrecht) connected to a Pentium 200 MHz computer. We added continuously 10 μg/L of the stock solution to achieve 60 μg/L.

The pre-concentration potential was +0.35V, 30min, and sweep potential from +0.35V to +0.75V. We observed a mercury oxidation peak around 0.626V. The calibration curve obtained shown in figure 5. (b).

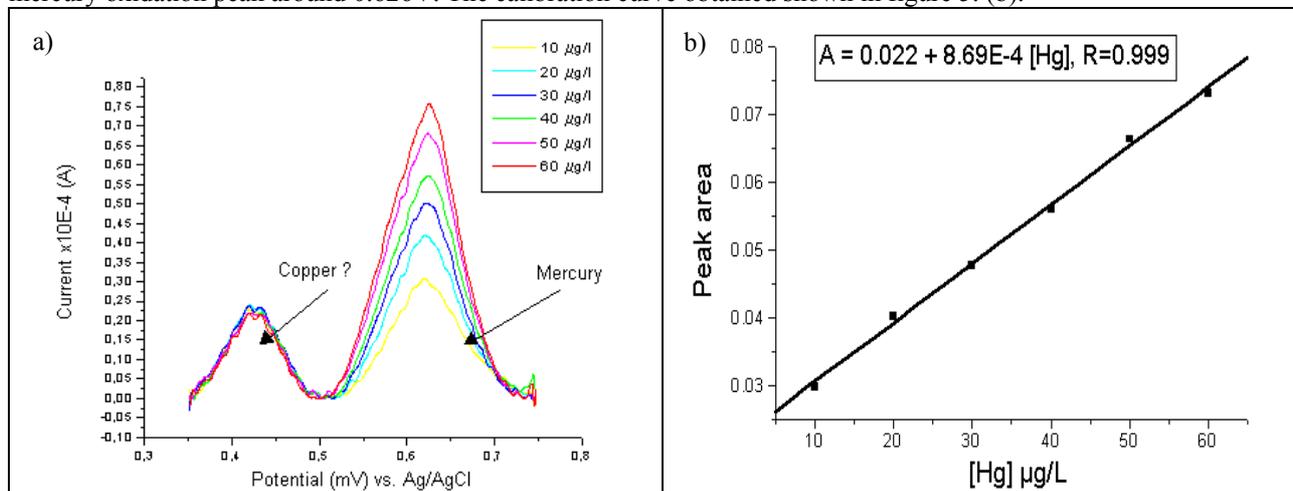


Fig.5. Manifold bench test results: a) stripping current results for increasing mercury addition; b) Calibration curve of the sensor.

6. Discussion

Referring to the figure 5(a), it was observed a second peak at 425mV that did not changed considerably during the addition of the mercury solution. This may be related to some surface contamination of the gold material and could be related to copper or even to lead since both have close oxidation potential.

Some procedures are being used to address this phenomenon: Electrode surface treatment using chemical solutions and electrodepositing of a thin gold films.

7. Conclusions

An LTCC manifold integrated with sensor electrodes for heavy metal detection meso-system suitable for biological and environmental fluids was fabricated and tested. Bench test indicates sensitivities for Hg of about 10 mg/l allowing biological and environmental fluids in-flow tests practicable.

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