Electroactive β-PVDF Polymer as Fluidic Acoustic Mixer for Lab-on-a-Chip Applications


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Summary

Motivation and Objectives
The Biological Microsystem Advantages

Lab-On-a-Chip Concept
Lab-On-a-Chip Design and Fabrication

Experimental Results
Conclusions
Motivation

Microfluidics:

- Laminar flow regime (no turbulent mixing);
- Surface tension, surface charge become important.
Motivation

Current clinical analysis systems disadvantages:

- Costs;
- Mistake in logistics;
- Delayed results.

Lab-On-a-Chip Concept

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De Melo. 2007. World lab-on-chip congress
The Biological Microsystems Advantages

- **Small components**
  - Reduced weight (portable) and size (implantable, integratable);
  - Reduced energy consumption.

- **Fabrication**
  - Reduced price (disposable).

- **Small amount of samples/reagents**
  - Reduced consumption of (expensive/limited) chemicals;
  - Reduced production of (toxic) waste;
  - Accurate dosing;

- **Complex systems**
  - Integration of sensors, parallel process, automation.

- **Device performance**
  - Scaling law for new effects and better:
  - Increased heat exchange;
  - Fast mass transport (rapid analysis).
Main Objective:

- Lab-on-a-chip with fluidic acoustic microagitation to quantify the concentration of the molecules in biological fluids.
Lab-On-a-Chip Concept

Why lab-on-chip?

- Miniaturization can speed up the reaction;
- Hundreds of assays can be performed simultaneously, saving considerable time and effort;
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Cuvetes:

- 1) Chemical Reagent;
- 2) Mixture Sample + Reagent;
- 3) Standard Sample.

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Why using SU-8?

- Low Cost;
- Biocompatible;
- High mechanical strength;
- Good adhesion on many different substrate materials;
- UV lithography semiconductor compatible;
- Very low roughness → suitable for optical absorption measurements.
Major problems with microscale:

- Miniaturization of biological assays is more complex than just transferring reactions to smaller volume;
- Miniaturization in itself does not help to integrate and automate the tests from the biochemical point of view;
- Lack of turbulence;
- Typical Reynolds $< 10 \rightarrow$ Diffusion mixing is dominant.
Solution:

- Induce the microfluidic die by a mechanism that accelerates the mixing and the reaction, preferably with ANY external apparatus, internal moving parts or valves.
PVDF:

- Semi crystalline polymer;
- Presents four polymorphs (α, β, γ, δ)
- β-phase is the one which shows better proprieties to be applied in sensors, actuators and transducers, due to its higher piezo-, pyro- and ferroelectrics proprieties;
- Show excellent combination of processability, mechanical stress, chemical agent resistance, lightness, moldability, low cost production and chemically inertness;
- More area, more vibration;
- More thickness, less vibration.
Lab-On-a-Chip Design and Fabrication

PVDF:

Monomer

α-PVDF

β-PVDF

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PVDF $\alpha$-β Phase transition:

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Pedro Martins
Lab-On-a-Chip Design and Fabrication
Evaluation of the mixing process based in the incorporation of piezoelectric β-PVDF polymer:

- Sinusoidal signal at 5V amplitude at various frequencies;
- Standards of urine with 30 mg/dl of uric acid concentration;
- Ratio Reagent/Urine $\rightarrow$ 50/1.
Complete and homogeneous mixing:

• Without agitation $\rightarrow \approx 15$ min at room temperature;
• With manual agitation + 5 min at room temperature;
• Mechanical agitation with macroscopic equipments.
**Experimental Results**

\[
\frac{\text{Time}_{\text{frequency } 1 \text{ KHz}} (300 \text{s})}{\text{Time}_{\text{Without oscillation}} (900 \text{s})} = \frac{1}{3}
\]
Influence of the thickness and area of the $\beta$-PVDF on the fluids reaction velocity:

\[
\frac{\text{Time}_{28\mu m\_2.4cm^2}(257s)}{\text{Time}_{28\mu m\_0.6cm^2}(352s)} = \frac{3}{4}
\]

\[
\frac{\text{Time}_{28\mu m\_2.4cm^2}(257s)}{\text{Time}_{110\mu m\_2.4cm^2}(304s)} = \frac{5}{6}
\]
Experimental Results

**Frequency tests:**

<table>
<thead>
<tr>
<th>Without agitations</th>
<th>Gain</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1kHz</td>
<td>12.90%</td>
<td>1/8</td>
</tr>
<tr>
<td>50kHz</td>
<td>22.35%</td>
<td>2/9</td>
</tr>
<tr>
<td>1MHz</td>
<td>24.90%</td>
<td>1/4</td>
</tr>
<tr>
<td>10MHz</td>
<td>56.25%</td>
<td>4/7</td>
</tr>
</tbody>
</table>

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Qualitatively evaluation of the mixing process:

- Reaction between: Solution of Sodium Hydroxide, Sucrose, Potassium Permanganate.
- Sinusoidal signal with 10V amplitude and 15MHz frequency on β-PVDF transducer;
- Reaction time improved in 93%.
Conclusions:

• The incorporation of fluidic acoustic microagitation in a lab-on-a-chip is advantageous when two or more fluids need to be mixed;

• Experimental show that, at 1 KHz, the mixing time is reduced to 1/3 of the time needed without agitation;

• Experimental results show that the thickness and the area of the polymer affects the mixing time of fluids;

• Acoustic microagitation becomes a preferred technology for effective mixing and allows the decreasing of the device sizes.
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Thanks for your Attention!

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