Development of a Fluidic Biosensor for Detecting Hydrogen

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Start Date = Nov. 01, 2003
Completion Date =Jul. 30, 2006

Research Goals and Objectives

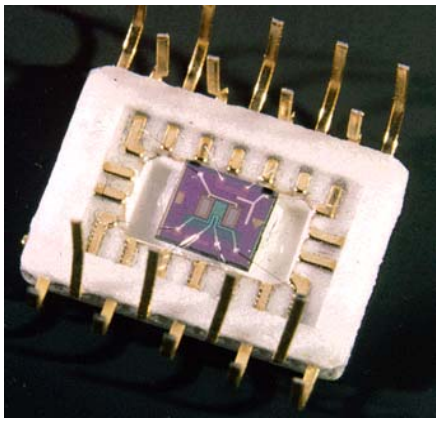
- Goal:
  - To develop a novel, room temperature, hydrogen sensor
- Approach: Use biological or chemical assays to detect hydrogen, e.g.

$$H_2 + BV^{2+} \xrightarrow{hydrogenase} H^+ + BV^+$$

  - Electron acceptor: benzyl viologen (BV)
  - Catalyst: hydrogenase (an enzyme)
  - Detection: electrochemical
- Expected benefits
  - Catalyzed reactions tend to be more efficient; sensitive and rapid detection is thus expected
  - Sensor selectivity likely enhanced by enzyme's specificity
  - Optimum performance is anticipated by implementing the assay in a miniaturized device
- Objectives:
  - Prove the concept; study the figure of merits; adapt to a miniaturized device

Relevance to Current State-of-the-Art

- Current H_2 Sensors involve a palladium (Pd) alloy Schottky diode microfabricated on a Si substrate
  - Pd alloy is a H_2-sensitive metal
  - Other sensitive materials includes gallium nitride (GaN), nanowires, etc.
  - An elevated temperature (100 - 600 ^oC) for the sensing element is often required



by Hunter, NASA Glen

Relevance to NASA

- H_2 is used as the rocket propellant, and as the primary energy sources in space mission.
- A H_2 sensor is needed wherever it is produced, stored, and used due to its explosive nature.

Budget, Schedule and Deliverables

- Budget
  - $35K for fiscal year 2004, $70K for year 2005, $65K for year 2006
- Schedule
  - Nov. 1, 2003 to Jul. 30, 2006
  - Year 1: prove the concept
  - Year 2: investigate the figure of merits of the sensor
  - Year 3: adapt to a miniaturized format
- Deliverables
  - Quarterly reports
  - Device design, results, and publications

Anticipated Technology End Use

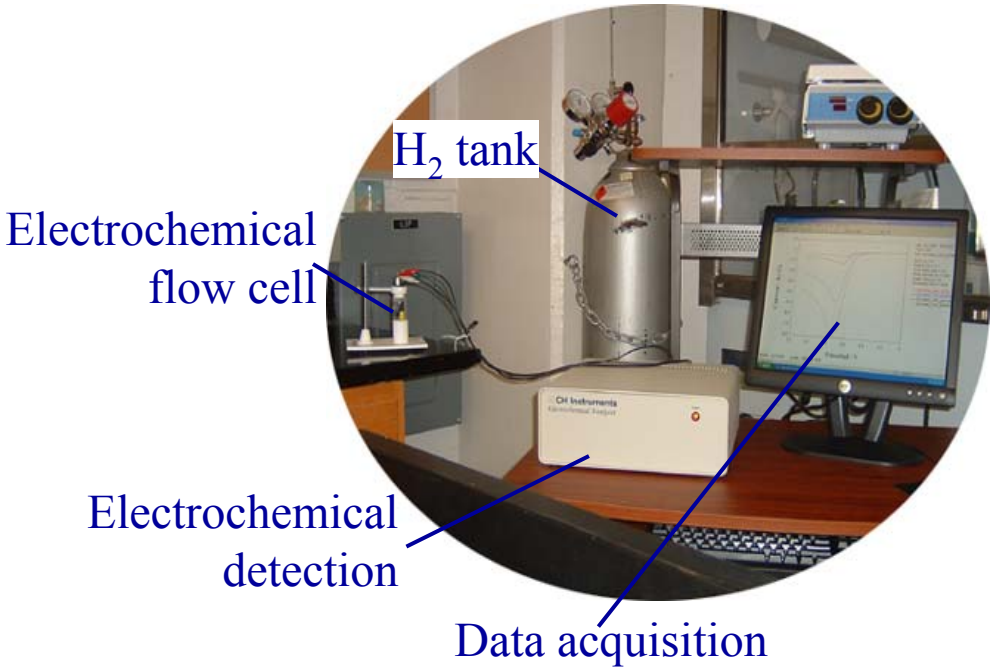
- After the technology is successfully developed, we expect possible usage in the following applications:
  - Hydrogen leakage monitoring in launching pad
  - Hydrogen leakage monitoring in H_2 storage tanks
  - Hydrogen leakage monitoring in H_2 ground transportation
  - Possible integration in the H_2 fuel cells

Accomplishments and Results

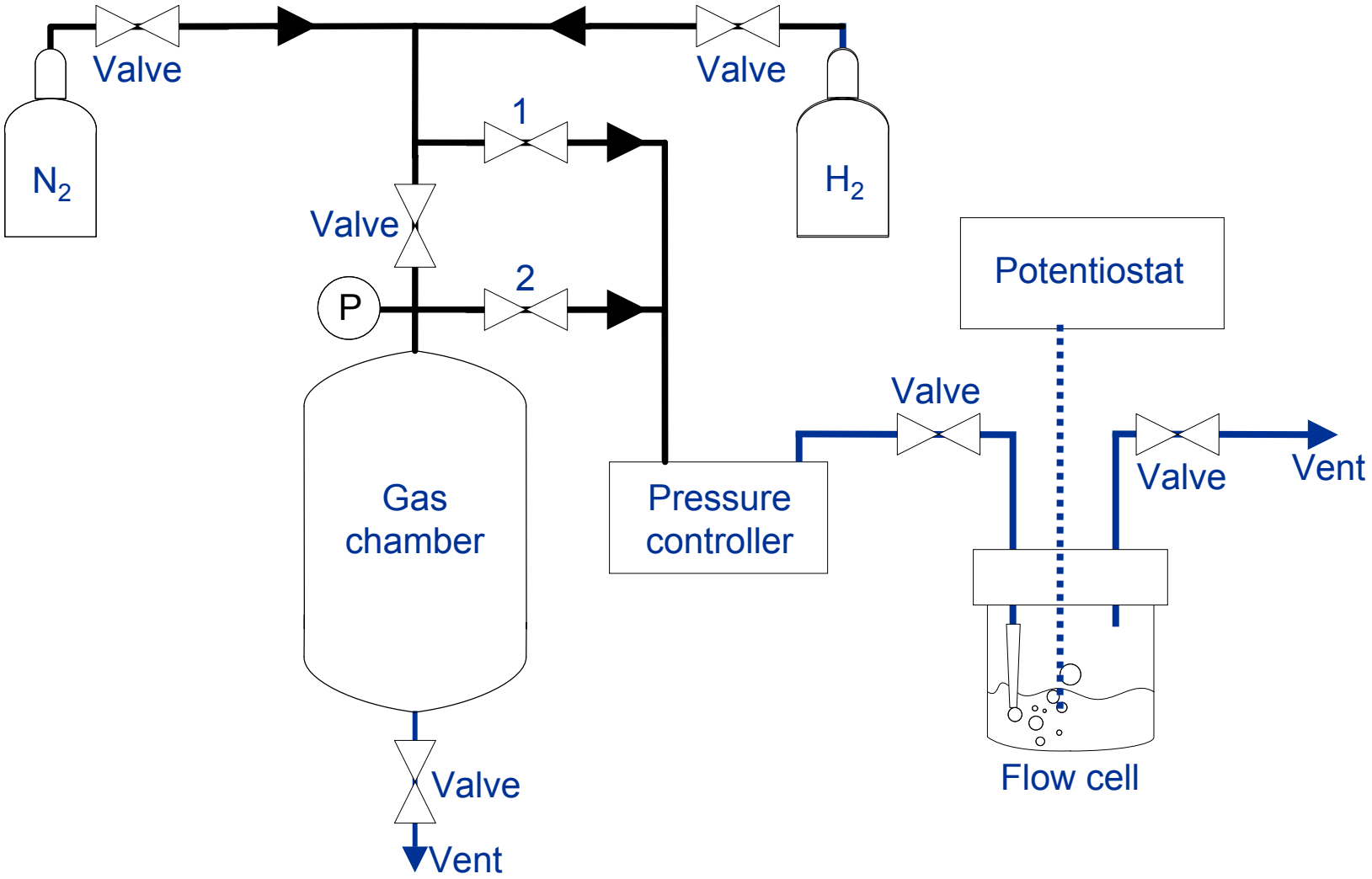
- Accomplishments:
  - Demonstrated the feasibility of H_2 detection using a biological assay
  - Investigated enzyme reaction kinetics
  - Established a calibration curve for quantification
  - Fabricated microscale devices for next-generation H_2 sensors

- Other Activities:
  - Hosted a lab tour for Dr. Gary Hunter from Glen Research Center on Mar. 15, 2005
  - Hosted a lab tour for scientists from NASA and FL during the review meeting (May, 2005)
  - Published a paper in *Analytical Chemistry*, Vol. 77, 4969-4975, 2005, entitled "Hydrogen Sensing by Enzyme-Catalyzed Electrochemical Detection".
  - Filed one provisional patent application on the subject by UF (US patent office application No. 60/662,504)
  - Received one related grant from National Science Foundation (NSF)

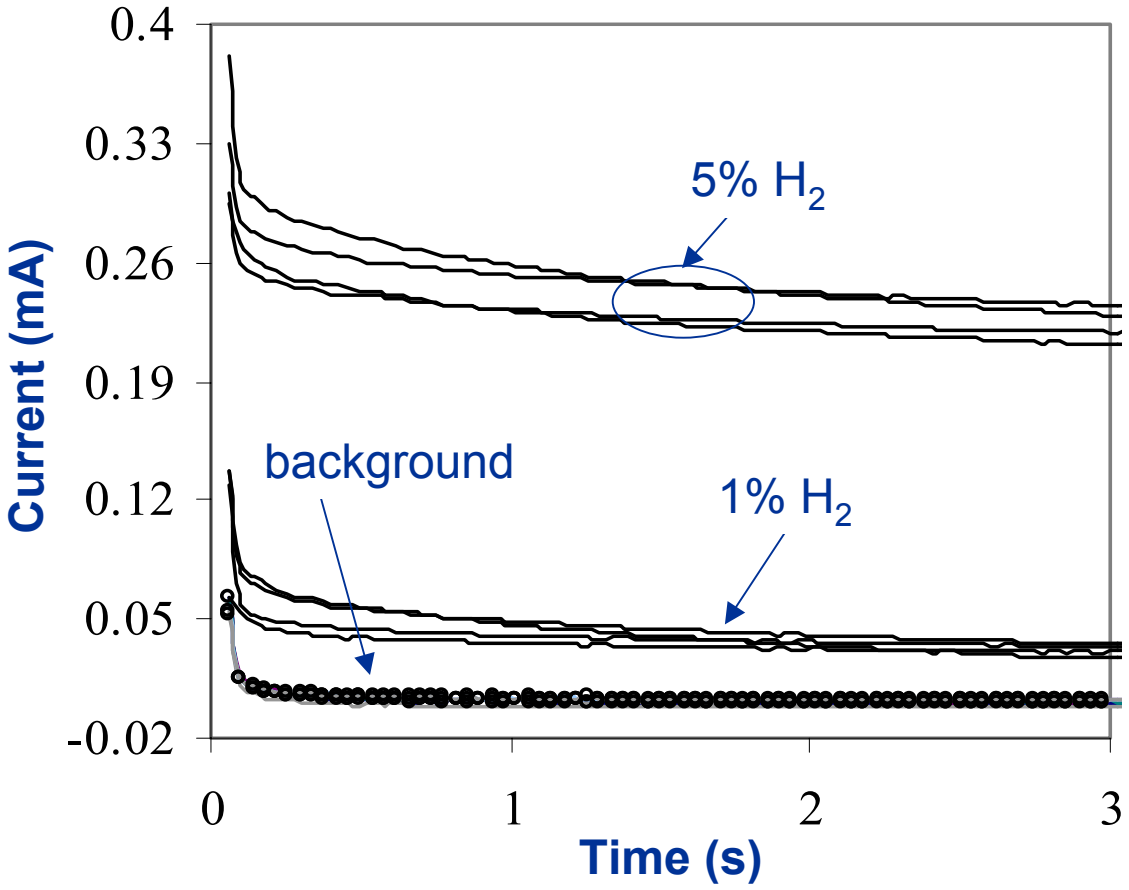
Accomplishments and Results (cont.)



Accomplishments and Results (cont.)



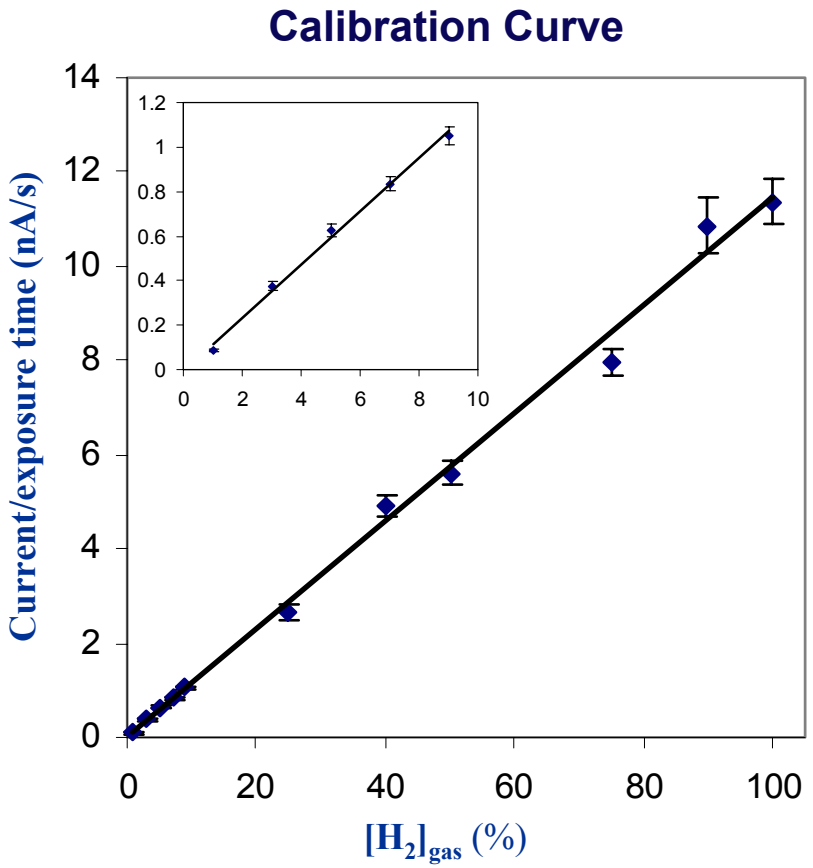
Accomplishments and Results (Cont.)



Before

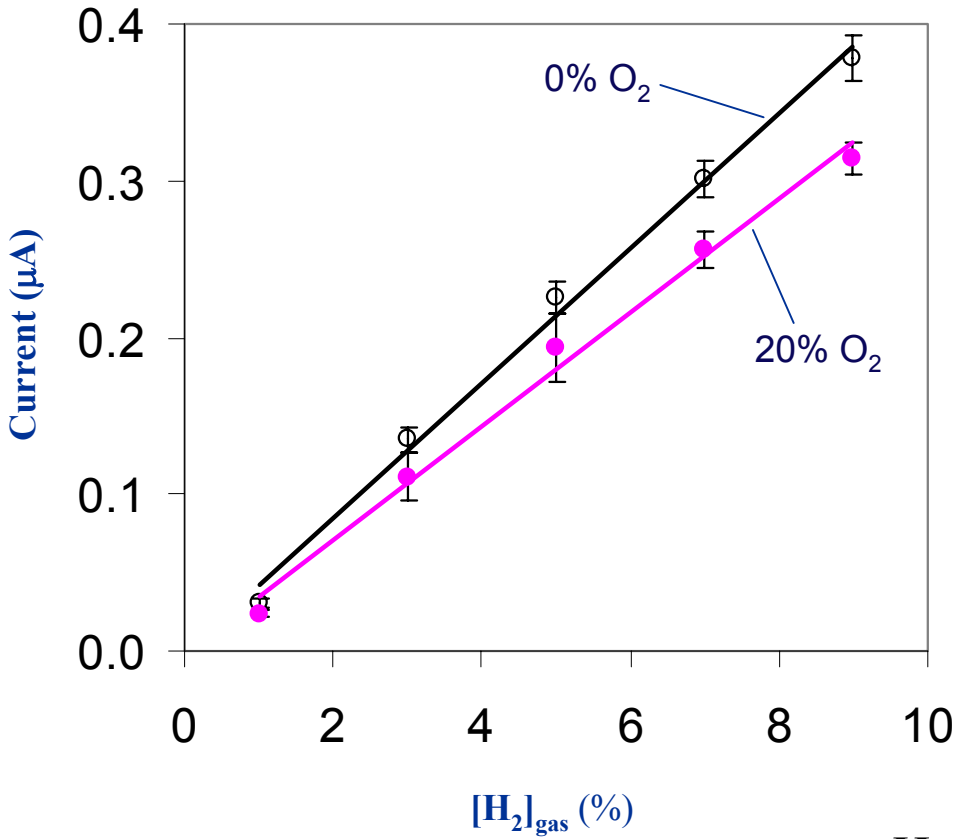
After H_2 exposure

Accomplishments and Results (Cont.)



- Demo'ed detection range : 1 to 100%
- Current detection limit: 1%
- Target detection limit: 0.1%

Accomplishments and Results (Cont.)



Effects of O_2:

- ~19% reduction
- Linear calibration curve
- No enzyme inhibition
- Due to oxidation of BV^+

$$H_2 + BV^{2+} \xrightarrow{hydrogenase} H^+ + BV^+$$

Accomplishments and Results (cont.)

Reaction Kinetics

$$E + S \rightleftharpoons ES \rightarrow E + P$$

Michaelis-Menten equation

$$V = \frac{V_{\max} \cdot [S]}{[S] + K_m}$$

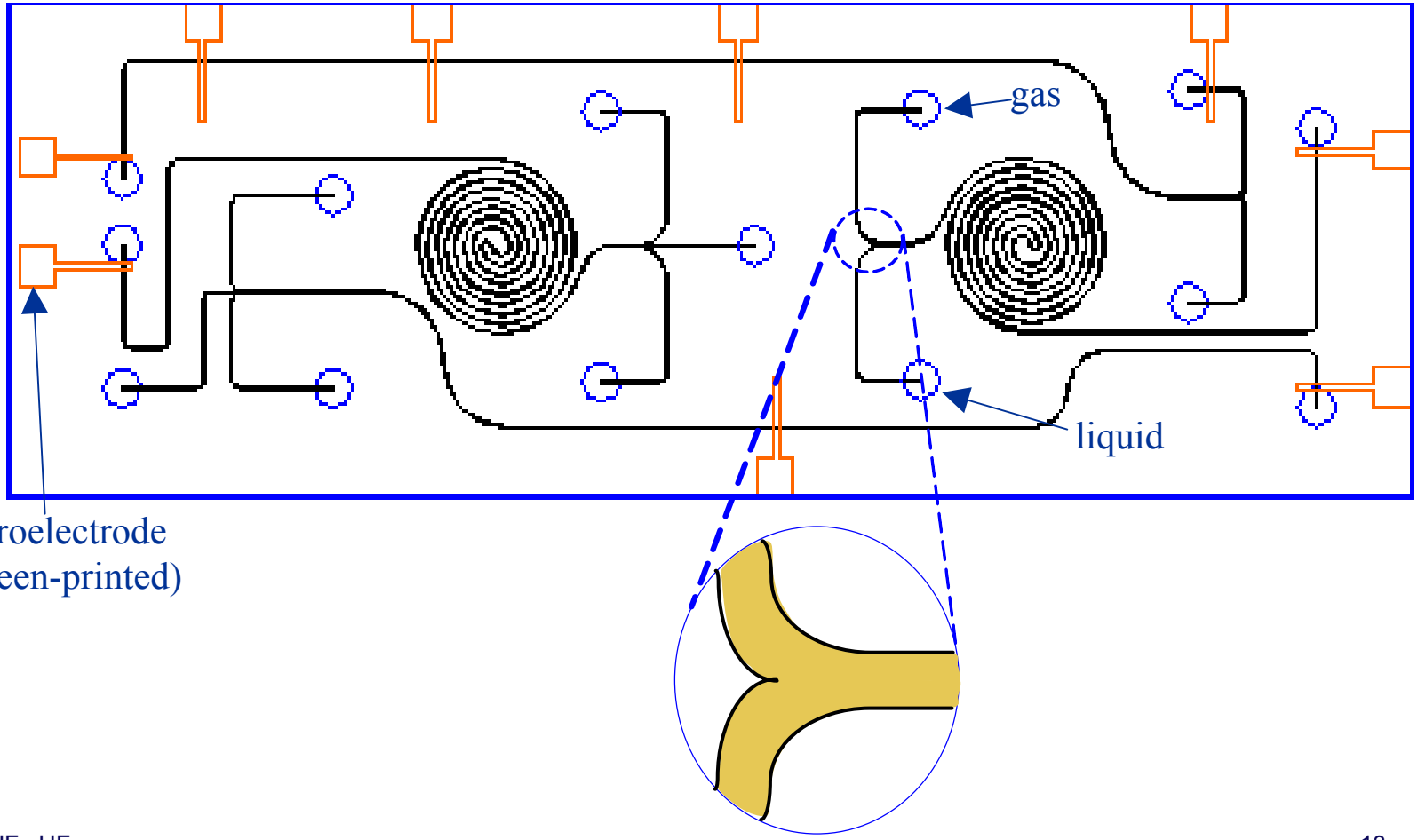
Lineweaver-Burke plot

$$\frac{1}{V} = \frac{1}{V_{\max}} + \frac{K_m}{V_{\max}} \frac{1}{[S]}$$

SH[1]	V_{max} (μM/s)	K_m (mM)	H_2-BV^+ activity[2] (μmol H_2/min)	H_2-NAD^+activity[3] (μmol H_2/min)
A	49.0	3.09	0.88	24.4
B	71.7	3.01	1.3	31.2
C	61.2	3.26	1.0	32.6

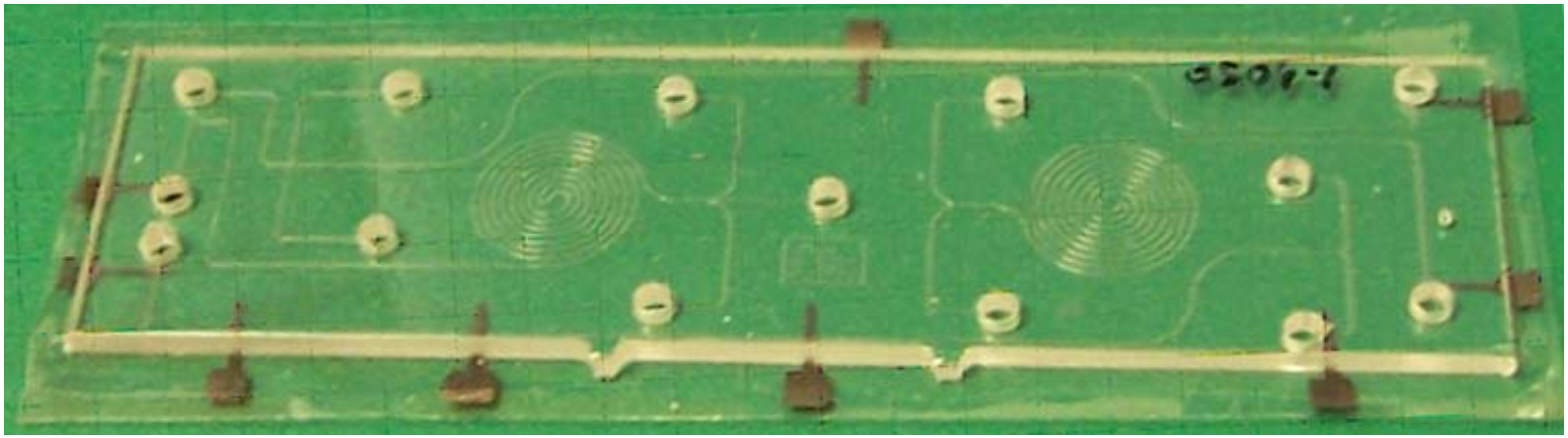
Future Plans

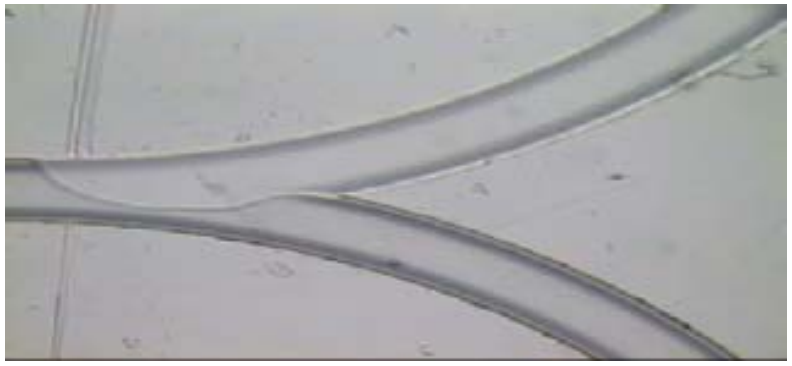
- To Implement the H_2 sensing mechanism in a miniaturized device



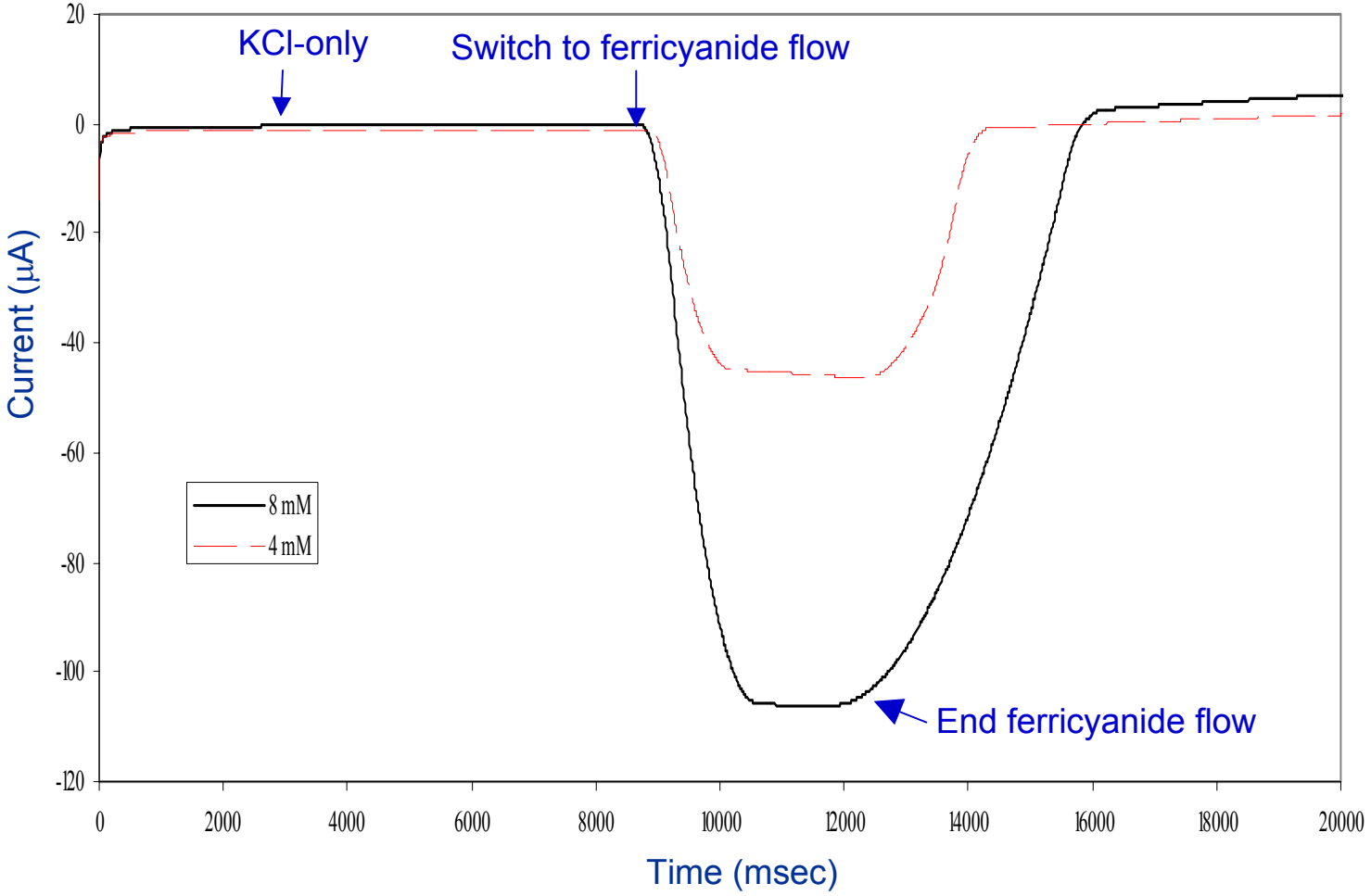
Future Plans (cont.)

A plastic, microfluidic device with integrated electrochemical detection





microscale EC Detection



Acknowledgement

- Students:
  - Brent Lutz
  - Zheng Xia
- Program Management:
  - Dr. Jenshan Lin (Dr. Mark Law)
  - UF, FSEC, and NASA
- Funding:
  - NASA
  - NSF