Development of Water Splitting Catalysts Using a Novel Molecular Evolution Approach

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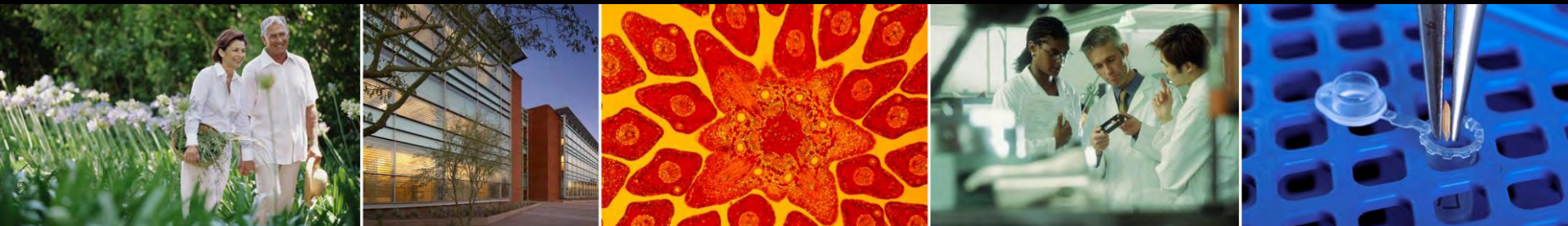
June 10, 2008

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PD12

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Nature has Developed a Very Efficient Water Splitting Catalyst – How Can We Mimic this?

- **Based on protein/metal interactions**
- **Runs near the thermodynamic limit**
- **Very specific**

Can we develop an iterative chemical evolution method for generating a metal peptide catalyst with similar activity?

Overview

Timeline

- **Start - July 1, 2005**
- **Finish - June 30, 2009**
- **60% Complete**

Barriers

- **Barriers addressed**
  - H. System Efficiency
  - J. Renewable Integration

Budget

- **Total Project Funding**
  - DOE - $1,200,000
  - Contractor - $300,000
- **Funding for FY08**
  - $150,000 DOE
  - $43,000 Contractor

Partners

- **CombiMatrix Corp., Mukilteo, WA**
- **Prof. Bill Armstrong, Boston College**

Objectives

- **Design and synthesize a peptide based electrocatalyst for water splitting using principles learned from photosystem II**

- **Optimize the function and stability of this electrocatalyst through iterative creation and analysis of libraries**

- **Efficient water splitting catalysts are required for effective electrolysis**

Milestones

|	Description	Completion Date	% Complete
Task 1	Optimize light directed peptide synthesis	9/30/2006	100
Task 2	Develop electrochemically directed synthesis	7/30/2008	80
Task 3	Measure Electrochemical Baseline	6/30/2006	100
Task 4	Fabricate electrode arrays for light directed synthesis	6/30/2007	100
Task 5	Develop high throughput electrochemical analysis	6/30/2008	80
Task 6	45% Increase in catalysis over baseline	6/30/2009	

Approach

- **Design and validate initial metal binding peptides**
- **Synthesize large arrays of peptide variants on electrodes**
- **Characterize the activity of each of the metal binding peptides**
- **Use analysis of initial array to develop a new array**
- **Iteratively optimize catalytic function**

# RESULTS 1: Design and validate initial metal binding peptides
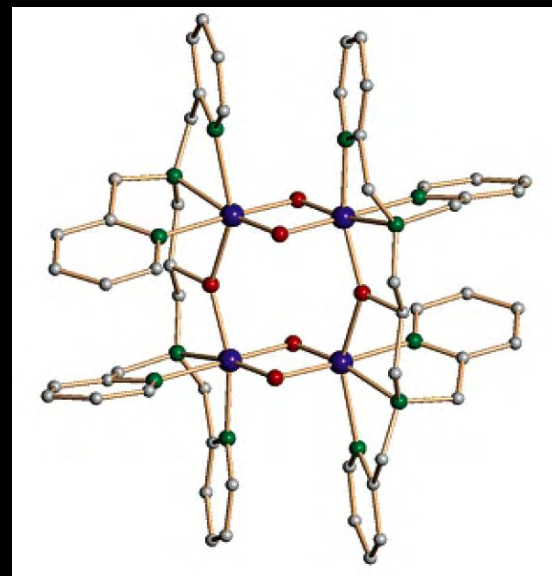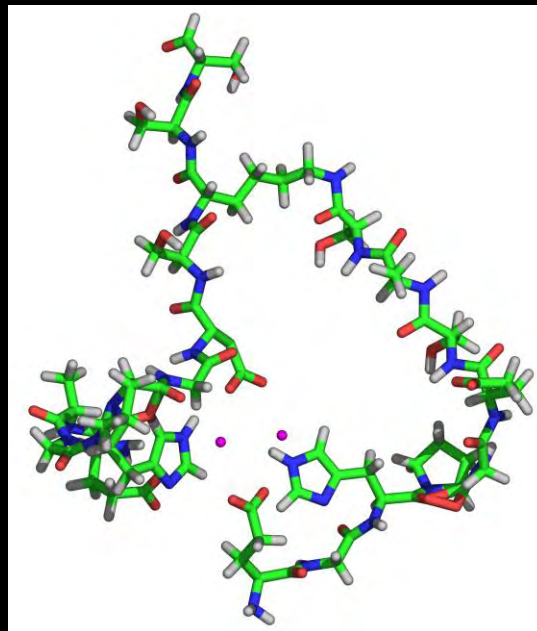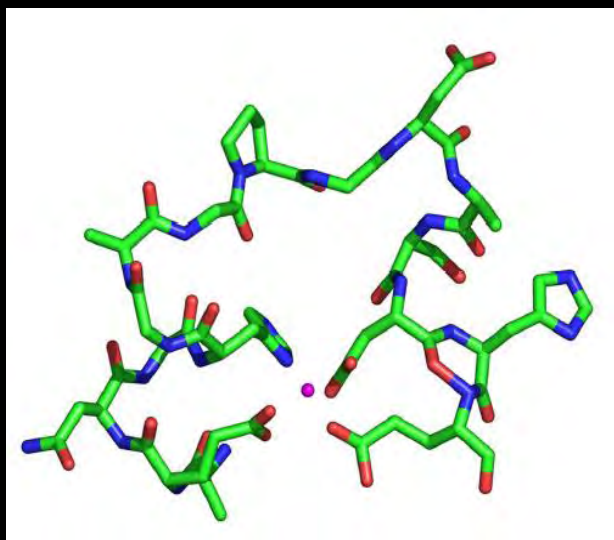
- **Started with single Mn binding peptides, then designed and synthesized double binders. More recently established a collaboration with Bill Armstrong, Boston College, to incorporate Mn clusters into peptide designs.**

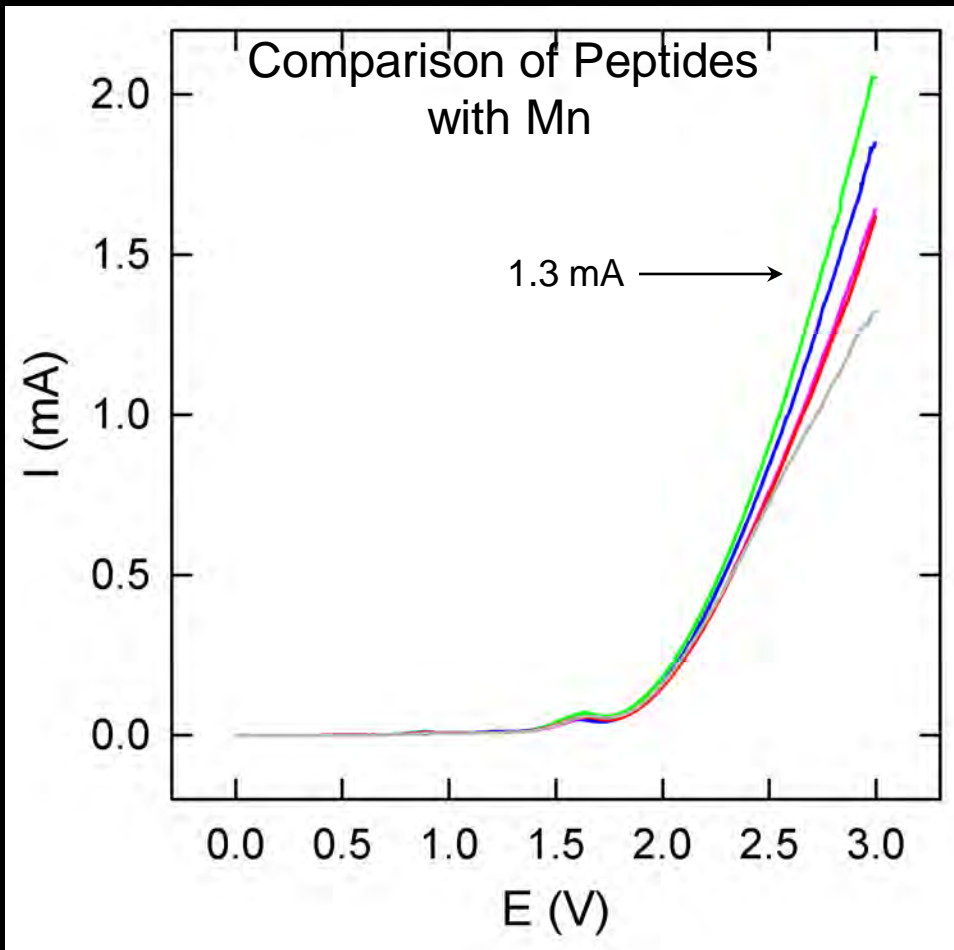# Initial Mn-Binding Peptides
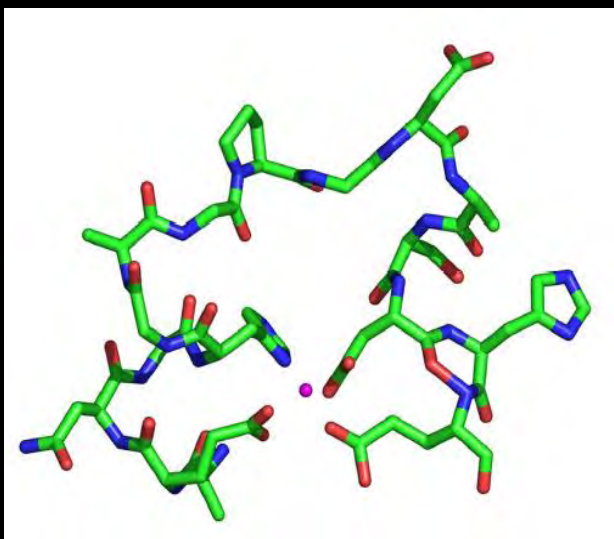
IR spectra showed that we were able to attach the peptides to the electrode surface, deprotect them and that they bound Mn. Control peptides did not bind Mn.
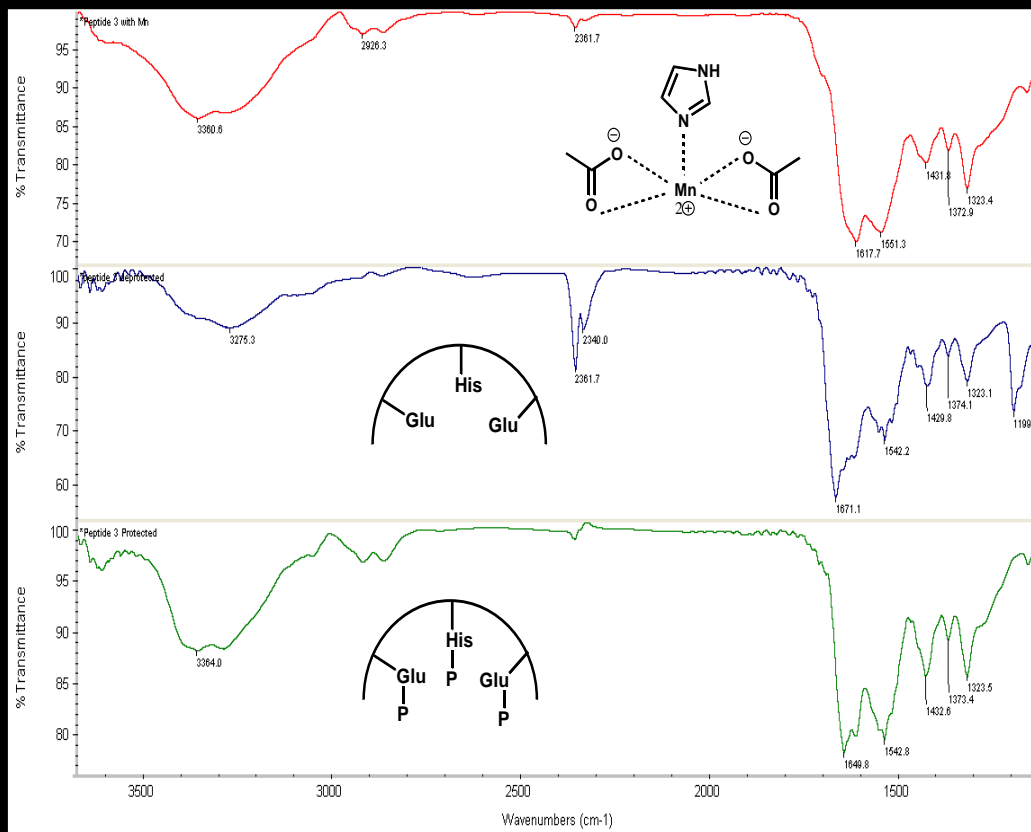
Comparison of Electrolysis Currents

Comparison of Peptides with Mn

1.3 mA →

| Change in potential at 1.3 mA compared to control (V)	
peptide 2	-0.29
peptide 3	-0.23
polyHis	-0.15
peptide 1	-0.13
control	-

In terms of efficiency, one can see that it is possible with peptide 2 to get the same current (same rate of hydrogen production) at 2.7 V that would require 3.0 V with the control peptide. This is a 10% power reduction in that voltage range.

Current Issue: Electrode surfaces not stable to chemical synthesis procedures

- **Gold or Platinum Electrodes**

- **Polyindole Layer**

- **Peptide deprotection chemistry usually damaged surface**

- **Catalytic activity results were not reproducible**
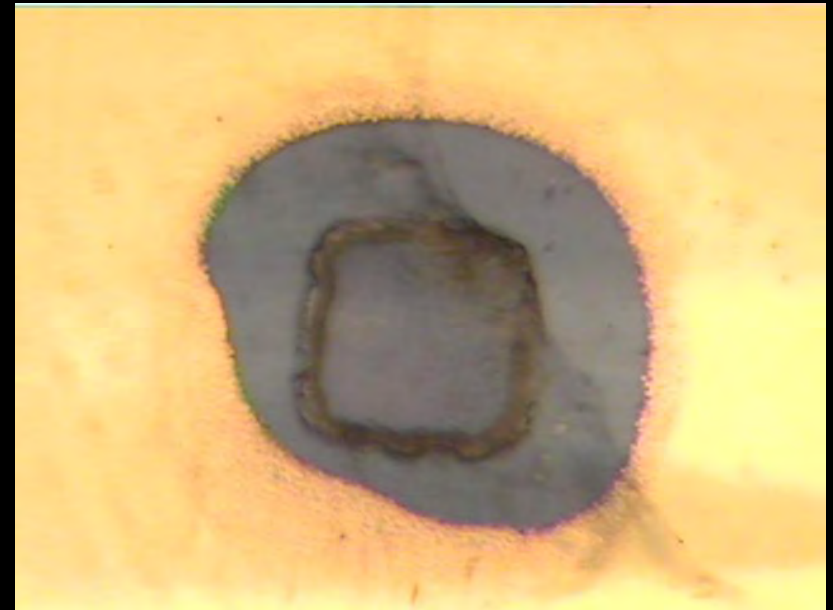
RESULTS 2: Synthesize large arrays of peptide variants on electrodes
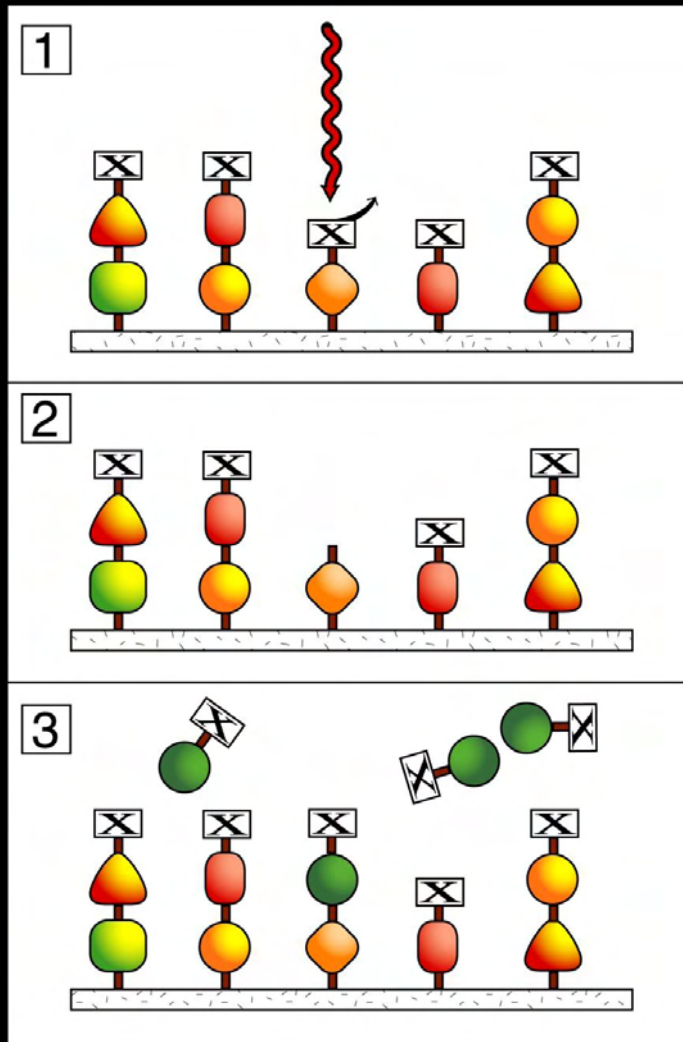
- **Use chemical concepts developed in the DNA chip industry**
- **Can synthesize 10,000 – 1,000,000 specific molecules on a slide**
- **Assay each molecule in parallel**
- **Nearly unlimited chemical options**
- **Computationally aided design of each molecule**
- **Find out both what worked and what did not, allowing intelligent creation of subsequent libraries**

Using Light Directed Synthesis to Peptide Space
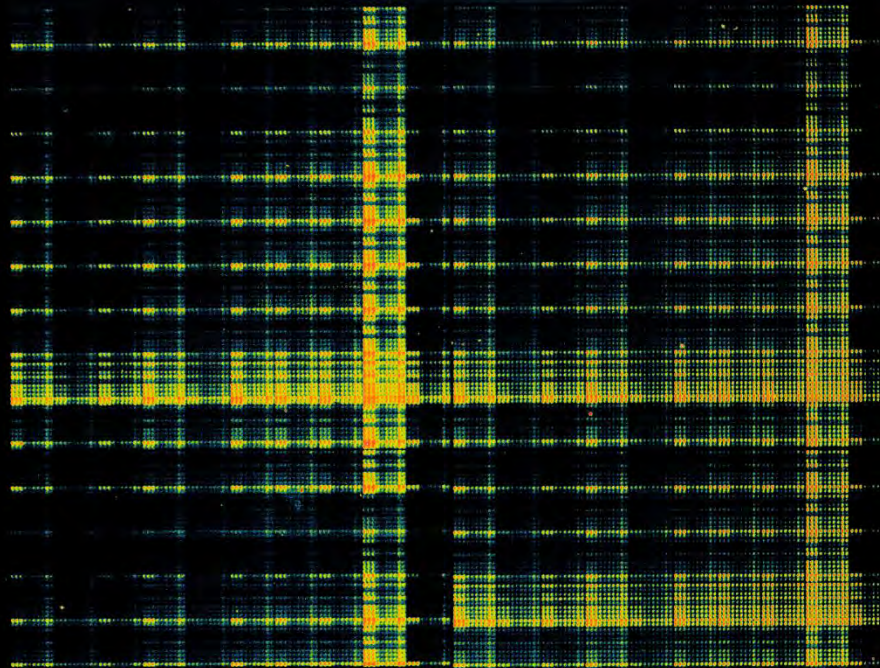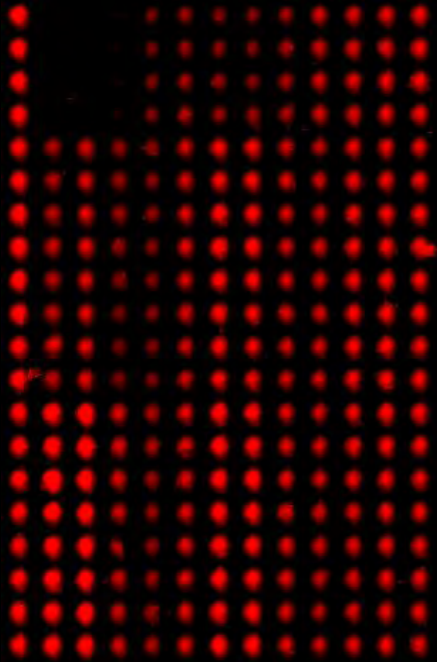
- Developed a system for generating tens of thousands of peptides on a slide

- Developed addressable arrays of electrodes for light directed synthesis

Electrochemically Directed Synthesis

- **Partnering with CombiMatrix**

- **This approach allowed direct synthesis on addressable electrodes**

- **As the chemistry worked about as well as light-directed, we decided to focus on this approach**
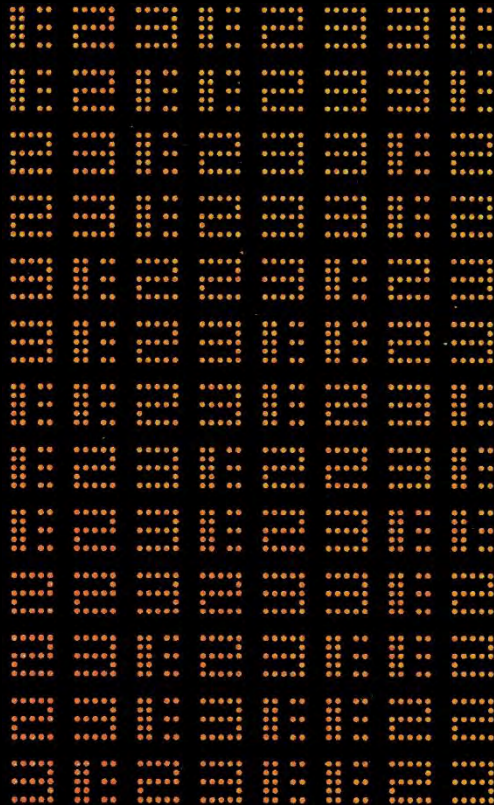
CombiMatrix Chip Configuration
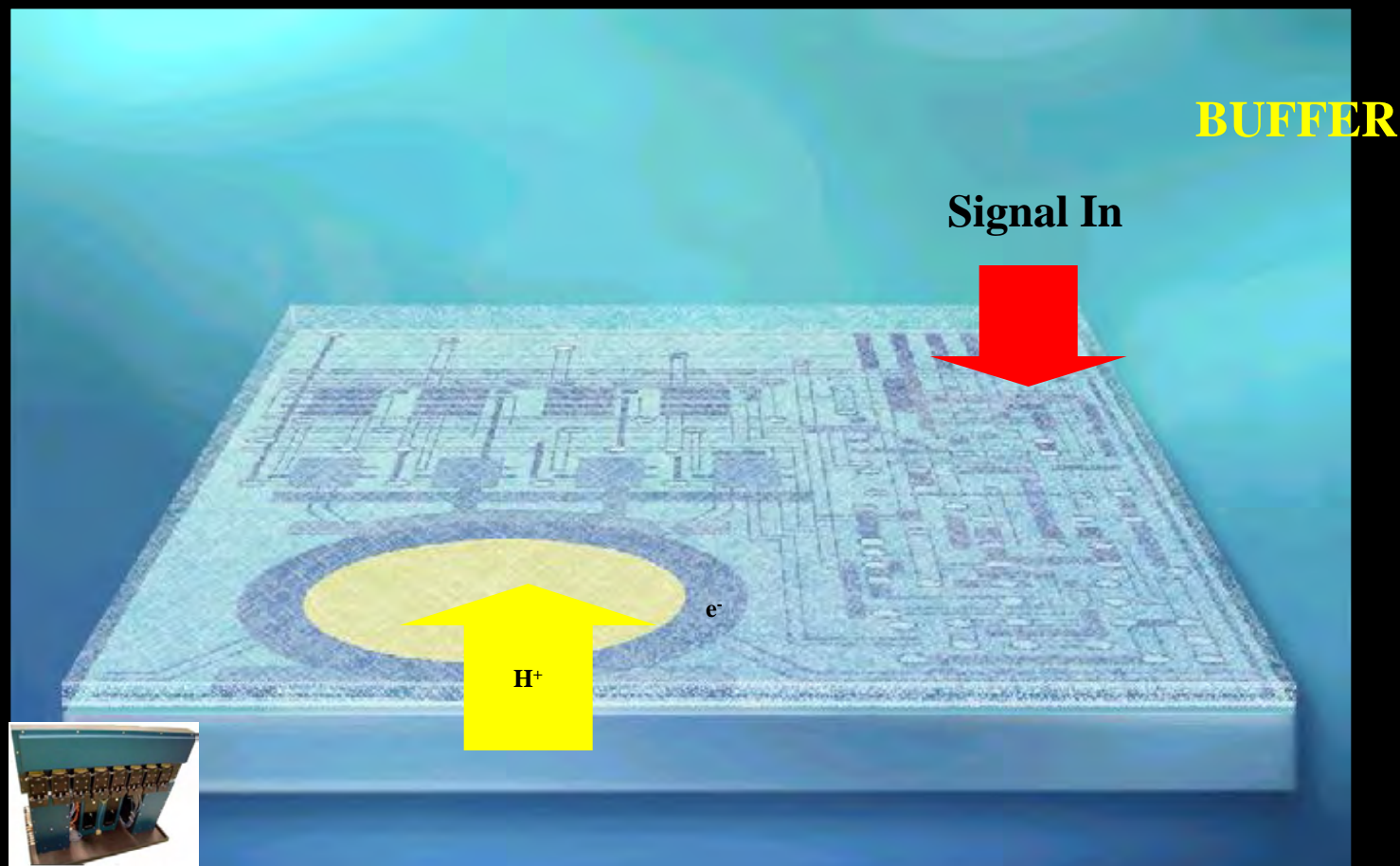
Electrochemically create an acid over a specific electrode that can be used for patterned chemistry

Peptide Array Synthesis

- **Top shows peptides of up to 10 amino acids synthesized on the CombiMatrix array**
- **Side show yield experiment giving stepwise yields of 94% using just glycine monomers**

More Complex Peptides: 70% Stepwise Yield and MALDI-Based Detection
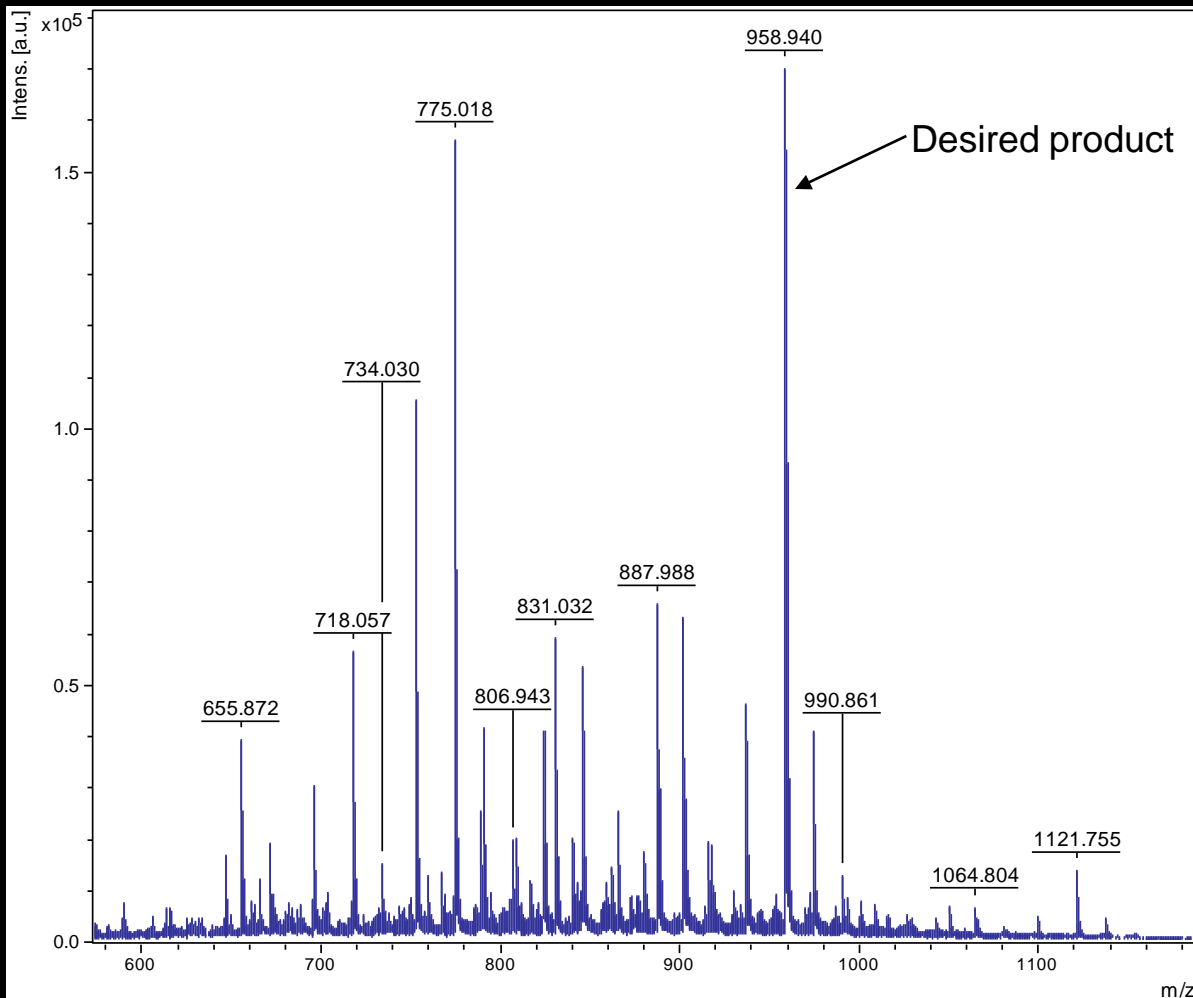
As we moved to more complex peptide synthesis, we needed a more chemically informative analysis approach. We developed MALDI methods for direct detection, position sensitive from the chip surface.

Current Status

- **The synthesis yields are good enough to make small arrays (hundreds) by combining a small number of electrochemical (variable amino acid) steps with standard Fmoc synthesis for the bulk of the peptide.**

- **The biggest synthesis problem we have is that the electrochemistry is not 100% orthoganal to the side chain protection chemistry. This results in side products when side-chain protected amino acids are present.**

- **We are exploring and comparing different conditions and different protection chemistries.**

RESULTS 3: Characterize the activity of each of the metal binding peptides

- **Each of the 12,000 elements in the array can be individually probed for electrochemical activity**
- **Current voltage measurements can be performed**
- **This allows electrochemical assays in array format**
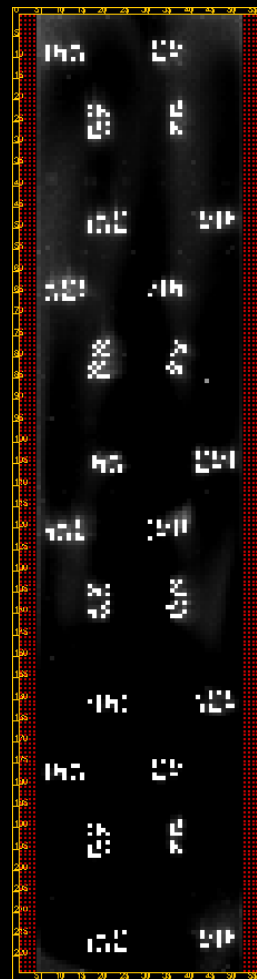
Initial work showing that the instrumentation was functional using electrocatalysis by horse radish peroxidase

Create and Measure an Array of Control and Test Peptides

- A large number of control and test peptides were placed in a checkerboard pattern
- Careful comparison of I/V curves from each peptide were performed
- Net result was no difference between control and test peptides +/- Mn

Future Work

- **Check directly for metal binding on the chip**
- **Create an array of variants using electrochemical synthesis**
- **Vary a small number of positions in the amino acid sequence**
- **Minimize the effects of side chain protecting groups on the synthesis**
- **Repeat current measurements using the multi-Mn peptides**
- **New electrode surface preparation?**

Summary

- *Have designed metal binding peptides to use as starting sequences*
- *Have demonstrated the utility of light directed synthesis methods for creating libraries of peptides*
- *Have developed electrochemically directed synthesis of peptides with a limited number of side chains*
- *Have shown the ability to perform I/V measurements on the 12,000 CombiMatrix electrode chips*
- *Now trying to create arrays of variants and show optimization of electrocatalysis*