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A LabVIEW Based Experiment System for the Efficient Collection and Analysis of Cyclic Voltametry and Electrode Charge Capacity Measurements

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***Abstract*—Cyclic voltametry and recording of stimulation electrode voltage excursions are two critical methods of measurement for understanding the performance of implantable electrodes. Because implanted electrodes cannot easily be replaced, it is necessary to have an a-priori understanding of an electrode's implanted performance and capabilities. In-vitro exhaustive tests are often needed to quantify an electrodes performance. Using commonly available equipment, the human labor cost to conduct this work is immense. Presented is an automated experiment system that is highly configurable that can efficiently conduct a battery of repeatable CV and stimulation recording measurements. Results of preparing 96 electrodes prior to an animal implantation are also discussed.**

I. Introduction

Cyclic voltametry (CV) is commonly used to study the electrochemical reactions that takes place at electrode surfaces. Driving a voltage at a working electrode in an electrolyte solution results in current flowing to or from a counter electrode. Voltages at the working electrode are measured with respect to a known electrode potential also present in the electrode cell (often Ag/AgCl). In cyclic voltametry a triangular voltage waveform is applied to the electrode and the resulting current is measured [1].

CVs with different voltage scan rates provide different key aspects of electrode performance and physical characteristics [2]. We routinely analyze activated iridium oxide film (AIROF) electrodes in our laboratory. Slow CVs with sweep rates on the order of 50mV/Sec offer a quantitative measure of total stored charge and a qualitative understanding of physical characteristics like activation film cracks and insulation leakage. Faster CV sweep rates on the order of 50k mV/Sec provide measure of charge capacity that is closer to the stimulus pulse deliverable charge capacity. Measuring the actual deliverable charge, during a stimulation pulse, provides important data on the expected usefulness of an electrode once implanted. For AIROF electrodes it is highly informative to perform CV and pulse waveform measurements progressively as the electrode is subjected to an electrochemical activation process.

The comprehensive study of electrodes and their performance requires measurements to be taken throughout the in-vitro preparation and activation process as well as throughout the duration of their in-vivo implantation. In animal experiments that are part of a visual prosthesis research program [3] dozens of electrodes are often implanted and an efficient method for collecting, cataloging, and analyzing such a large amount of data becomes critical. The system should also store, catalogue, recall, and display the large amount of data collected in a convenient and meaningful way.

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II. Limitations of an Existing CV Measurement System

Gamry Instruments (Warminster, PA) markets and sells electrochemical measurement equipment. Modular electrochemistry software interfaces with their potentiostats to conduct experiments and gather resulting data. The Physical Electrochemistry software module provides the ability to conduct cyclic voltametry and linear sweep voltametry measurements for the purposes of biological electrochemistry.

Experiments are conducted in the native Gamry software Framework using a scripting language called "Explain". An Explain script to take a single CV measurement is provided by Gamry with the purchase of their system. The programming reach of an Explain script is limited to the potentiostat and 8 digital I/O lines. As electrode experiments increase in complexity and more instrumentation is required, a unified software platform is required to communicate to all components in a system including stimulators, oscilloscopes, switching banks, potentiostats, and others.

Experimental results can be reviewed in a Gamry software product called Echem Analyst. The standard VBA scripts provided by Gamry do not provide the ability to open more then one CV at a time. This makes the ability to compare CVs over the progress of electrode activation tedious.

III. A LabVIEW-PC Based CV/Pulse Measurement System

Using custom made LabVIEW Virtual Instruments (VIs) running on a PC, one can create and manage the instrumentation of an automated CV and stimulation pulse measurement system. Our system as shown in figure 1 is comprised of the following physical instruments:

- PC (GPIB and parallel port capabilities)
- LabVIEW (ver. 7.0)

- Gamry Potentiostat (PCI/300)
- Oscilloscope (Tektronix TDS3034B)
- Reed switches for electrode cell switching
- Stimulator IC [4] and
- Electrode cell

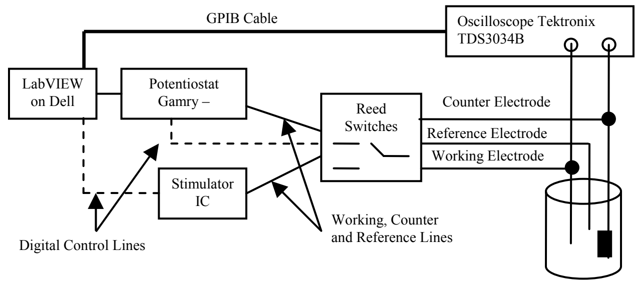

Fig. 1. Block Diagram of Proposed Electrode Electrochemical Measurement System

Both CVs and electrode activation can be achieved through a common VI controlling the potentiostat for voltage control. A user defines a voltage cycle by specifying a cathodic and anodic voltage limit, the dwell time at each voltage limit, and the sweep rate from one limit to the other.

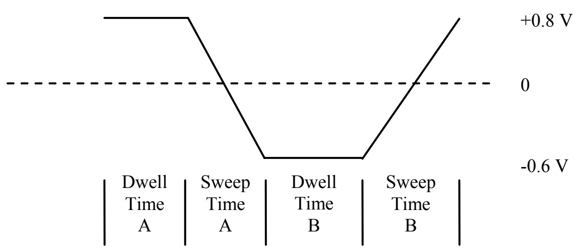

Fig. 2. Four components of a defined voltage control cycle

For a pulsed AIROF voltage activation protocol the voltage control cycle is characterized by minimal sweep times and the dwell times on the order of seconds. This produces a square wave with a definable duty cycle as can be seen in

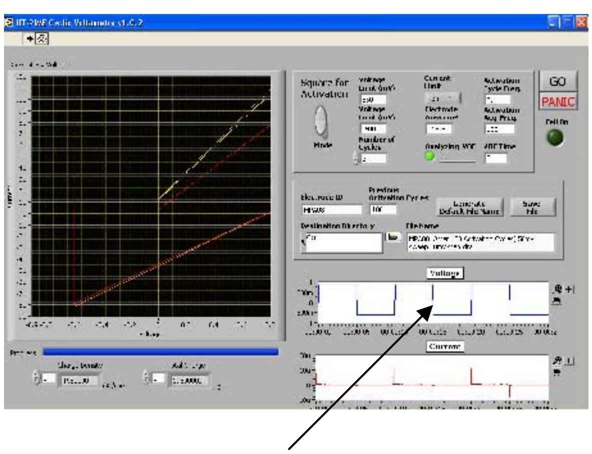

Fig. 3. A voltage control cycle achieving electrode activation.

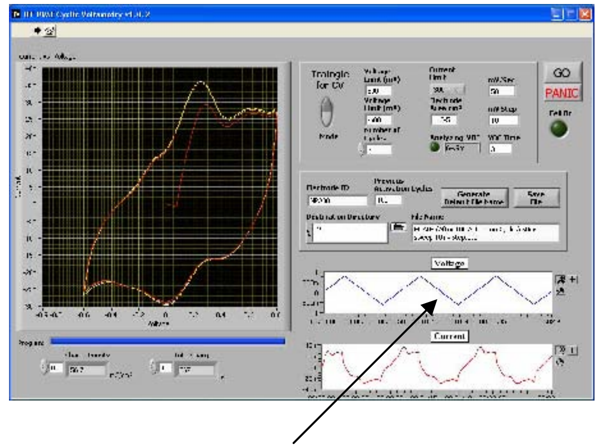

Fig. 4. A voltage control cycle achieving cyclic voltametry.

Figure 3. A CV protocol is a voltage control cycle where the dwell times are minimized and the sweep times are on the order of seconds as can be seen in Figure 4. Our system automatically calculates the sweep time based on the voltage limits and sweep rate desired. This produces definable triangle or saw-toothed waveforms.

a. Data Collection

A Comma Separated Values (CSV) file format was designed to provide backwards compatibility to Gamry's Framework software. A file naming convention was created to allow the quick sorting filtering of files. The convention is as follows: "Array Name"-"Electrode Name"-"Process Step"-"Activation Cycles"-"Sweep Rate".xls. This convention was used so that based upon a user's criteria, multiple CVs could be opened at once and overlaid on top of each other. The overlaid CVs provide a visual depiction of an electrode activation as well as a convenient way to notice non-uniformity in a collection of electrodes (such as an array). Figure 5 is a screen shot of a custom VI overlaying all CVs over the course of 100 cycles of activation, a single selected CV from the group, and the historical charge delivery at every activation cycle.

A Voltage Control graphical user interface (GUI) receives voltage cycle parameters from a user along with other experiment parameters and drives the potentiostat. This basic block of measurement functionality is shown in figures 3 and 4. To capture stimulation waveforms, a LabVIEW module communicates to a Tektronix TDS3034B digital oscilloscope over a GPIB bus. This waveform information arrives as a stream of data which is reformatted to an Excel readable format. Our most common set of measurements consist of three CVs with different sweep rates taken consecutively followed by a waveform capture of current and voltage excursion. The CV sweep rates are typically 50mV/Second, 3000mV/Second, and 50k mV/Second. Voltage limits are -0.6V and +0.8V. Stimulation pulses last 300 micro-seconds. The GUI designed for this common set of measurements is shown in Figure 6.

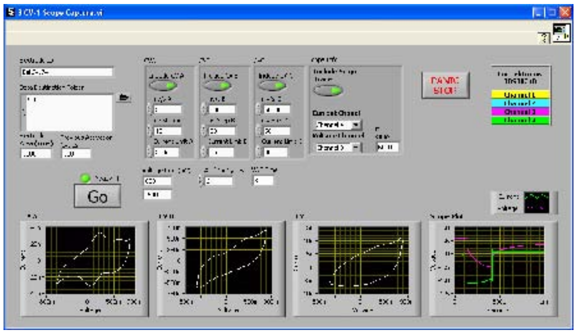

Fig. 6. Control parameters and results of an automated battery of three CVs at different sweep rates and a stimulation recording. Different electrochemical characteristics of the electrode can be seen with a single experiment set up.

Batched activation of AIROF electrodes with interspersed triple-CV and current/voltage excursion waveform captures is achieved using a top level software module. The GUI for this VI is shown in Figure 7. This software module calls the above mentioned modules as functional sub-routines to produce our most comprehensive experiment procedure.

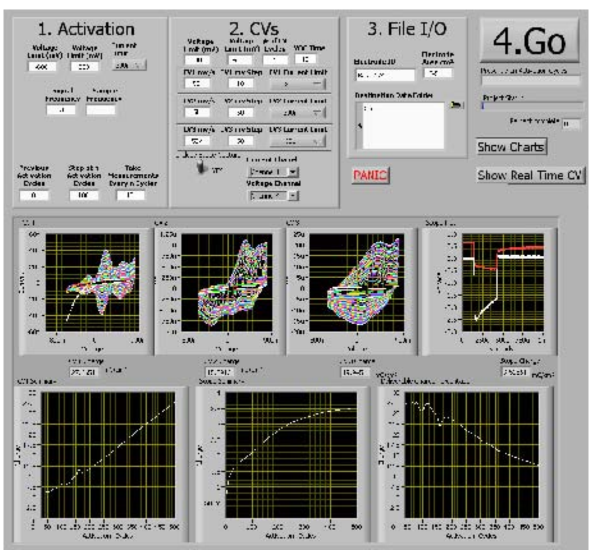

Fig. 7. Top Parameters for battery of measurements, bottom shows historical CVs and stimulation recordings throughout the activation

b. Real-time Analysis

As CV cycles complete, the quantitative value of total delivered charge is immediately computed and displayed for the user. Charge density may also be calculated if the surface area of the electrode has been provided by the user. Immediately after a pulse waveform of voltage and current excursion has been captured, the data file is analyzed to produce an estimate of access resistance, and total delivered current. In a batched activation of an electrode, the ongoing measurements of CVs and pulse waveform captures are overlaid showing the effects of ongoing activation. Charts showing CV deliverable charge vs. activation cycles and pulse waveform deliverable charge vs. activation cycles are updated and the activation process proceeds. The final chart provided in real time is the percentage of CV deliverable charge that was measured in the pulsed current excursion vs. activation cycles.

c. Post Processing and Analysis

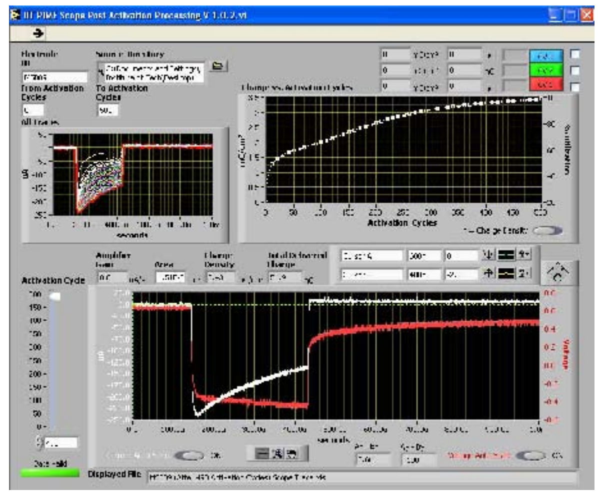

Fig. 8. Post Processing Stimulation Recording. Graphs Clockwise from upper right: Charge density versus Activation Cycles, Selected stimulation recording (red trace is voltage from working electrode to counter electrode, white trace is current through counter electrode), and overlay of all current traces during stimulations while progressively activating.

Several other VIs were written to read in the CSV formatted files for CVs and stimulation recordings and make post measurement analysis and comparison more efficient. In addition to qualitative comparison, these post processing VIs also provide quantitative information such as the percentage utilization of charge from a stimulation recording compared to its accompanying CV. Figure 8 shows a screen capture of a GUI which opens a set of pulse measurements. Figure 9 shows a screen capture of a GUI which opens a set of CV measurements. A user enters search criteria and the VI searches an entire computer folder for all measurements fitting that criteria. This effectively eliminates the need to open multiple files individually to get a comparison between

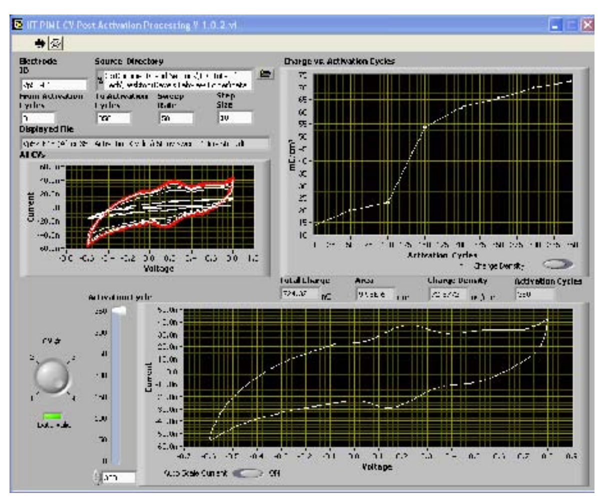

Fig. 9 Graphs clockwise from upper right: Charge Density versus Cycles of Activation, Selected Single CV, All CVs during Progressive Activation

multiple measurements. Both of these post processing GUIs display a collective overlay, a selectable single measurement and a historical delivered charge vs. activation cycle histogram.

RESULTS

This system was used to capture, analyze, and display data for 96 electrodes used in-vivo and in-vitro for a visual prosthesis animal model. CV's and pulse waveform captures were captured at the following stages of electrode preparation and experiment duration:

- Pre cleaning
- Post cleaning
- Post activation
- Post construction
- In modified PBS
- Immediately after implantation
- One-year after implantation
- Two-years after implantation

In total 2592 CVs have been captured for these electrodes. The total disk space for these measurements is approximately 800Mb. A comprehensive discussion of this data was presented in [2].

The duration for a multi-measurement experiment is constrained by the time required for the physical measurement. The time spent configuring and operating the system in minimal. The total time to capture three CVs at 50mV/Sec, 5000mV/Sec, and 50k mV/sec for an entire 16 electrode array is approximately 50 minutes of which 45 minutes are spent acquiring only the 50 mV/Sec CVs.

CONCLUSION

The required amount of information pertaining to electrode characterization is increasing as more electrodes are included in implantable prosthesis. Understanding in vitro and in vivo performance is also critical to a successful implant. The different types of measurements required to gain a complete understanding of electrode performance extends beyond the limits of a single instrument. The system described facilitates the acquisition of multiple CVs with different sweep rates, activation procedures, as well as single stimulation recordings. The flexibility of the system allows a user to set up a batch experiment of activation, CV measurements, and stimulation recordings requiring no ongoing operator oversight. This experiment system also collects information in a manner conducive to efficient analysis at a later time. By far the most beneficial aspect of this system is its ability to free up a researcher to attend to other activites. Once an experiment is set up and underway an operator can continue to collect a tremendous amount of important data and not have to wait and initiate single measurements one at a time.

FUTURE WORK

Aspects of this system can be improved by consolidating instrumentation into fewer components as well as developing increasingly comprehensive and flexible software modules. It is envisioned that the Gamry potentiostat will be replaced entirely by the capabilities of an enhanced IC Stimulator. If the stimulator IC's voltage steps are small enough to prevent transients, the continuous sweeping voltage necessary for CVs along with the stimulation pulsing may be provided by a single thumb sized instrument. As more experiments are conducted new needs will become self-evident and become specifications for future software development work.

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