So, here might be a short outline to begin.  
Something like: Anodization and characterization of titanium electrodes for electrolytic capacitors  
  
I. Introduction.  Refer to both of the above papers but concentrate on titanium anodization and the potential of titanium capacitors for energy applications.

1. **Titanium Printed Capacitors for microminiturization**
   1. “By an appropiate cleaning and forming procedur, titanium metal can be anodically oxidized to a low leakage current, which makes it possible to use this material for capacitor fabrication.”
   2. leakage currents as low as 1uA/cm^2 can be reached
   3. A clean surface of Titanium is essential for proper anodizaiton
   4. It is possible to use an etching solution to clean off layers of oxide on the Titanium
   5. The thickness of the oxide layer is dependent on the forming voltage
2. **Hagiwara and Yamashita, Characteristics of Titanium Electrolytic Capacitors**
   1. Titanium electrolytic have slightly larger leakage current then tantulum
      1. but tantalum is much more expensive then titanium
   2. Table 1: Comparing some film forming metals
      1. comparing Ta,Nb,Al,&Ti
      2. Ti has a much higher dielectric constant
      3. Ti has a high overall capacitive density
      4. This will allow me to put some numbers to how good of a capacitor Ti can be
3. <http://electrochem.cwru.edu/ed/dict.htm#a06>
   1. Anodization is the process of forming an oxide layer on a metal.
   2. You anodize the anode, positive, electrode
4. <http://electrochem.cwru.edu/encycl/art-a02-anodizing.htm>
   1. anodization involves immersing two electrodes in a solution and hooking up a voltage/current source
   2. the current that flows is ionic
   3. The overall reaction that takes place during [anodization](http://electrochem.cwru.edu/ed/dict.htm#a06) is:
      1. 2Al + 3H2O ==> Al2O3 + 3H2
      2. We are growing an oxide over the
5. <http://pdn.sciencedirect.com/science?_ob=MiamiImageURL&_cid=271639&_user=6325866&_pii=S0010938X06001089&_check=y&_origin=article&_zone=toolbar&_coverDate=28-Feb-2007&view=c&originContentFamily=serial&wchp=dGLzVlB-zSkWz&md5=151991a882cdc8575a1aaf73763d9d06/1-s2.0-S0010938X06001089-main.pdf>
   1. The oxide is formed as Ti02.
6. <http://www.electronics.ca/presscenter/articles/1609/1/Global-Aluminum-Electrolytic-Capacitors-Market-to-Reach-US104-Billion-by-2017/Page1.html>
   1. The aluminum electrolytic capacitor market is projected to reach $10.4 billion by 2017
7. <http://www.aluminum.org/AM/Template.cfm?Section=Home&TEMPLATE=/CM/ContentDisplay.cfm&CONTENTID=28233>
   1. The aluminum electrolytic capacitor market is projected to reach $4.2 billion by 2015
8. <http://www.electrochem.org/dl/ma/201/pdfs/0241.pdf>
   1. Welsch and Don
   2. Titanium sponge can have a dielectric energy density of over 2000J/cm^3
9. **Review Anodic oxidation of Titanium and its alloys**
   1. Titanium dielectric may contain:
      1. Ti0
      2. Ti2O3
      3. Ti02
10. Steve’s thesis
    1. dielectric strength and dielectric constant values for a range of materials
       1. air->titanium

II. Description of the anodization process and the basic circuitry to control/monitor the anodization process and the leakage current.  This can include any calibration results.  
  
(ref 10) - “The rate at which the oxide grows is proportional to the amount of current flowing into the sample.” Therefore, we can control the oxide growth by creating a current source for the DUT. As seen in fig #, as the oxide grows on the sample, its resistance will increase, resulting in a higher voltage. This voltage rises approximately linear with time until it hits the voltage compliance limit of the source.  
  
Anodization requirements  
  
1-30V  
1-100mA  
speed: ------What is the slew rate that we expect?  
  
Basic circuitry:  
  
The basic circuitry has two main parts, sourcing and measurement. The current source has the ability to supply 1-100mA of current at a voltage of 1-30V. The actual safe operating region is depicted in the following graph.  
  
**Insert safe operating parameters graph**  
  
Portions of the desired operating area are curtailed in order to stay within the safe power limits of the pass transistors. Further development is planned to increase the operating range, by actively calculating the power dissipation in the pass transistors. The current calculations are done based upon worse case, open loop, scenarios.  
  
The current source is made up if an op-amp controlled current mirror.  
  
**Insert picture of control circuitry**  
  
  
The left leg of the mirror is controlled by a DAC set by a microcontroller. It is mirrored at a x10 rate on the right side. The current source can provide current up until the voltage of the DUT reaches the compliance voltage, which is defined as the voltage at the top of the current mirror minus several small voltage drops.  
  
  
The second part of the circuitry is measurement side. The voltage is measured by a differential amplifier chip across the DUT, while the current is measured by a transimpedance amplifier.  
  
**Insert picture of the measurement circuitry**  
  
Since it is desirable the measure both the anodization current and the leakage current afterwards, a basic transimpedance amplifier design was modified to include 3 switched feedback paths. This allows the current measurement to measure currents over 8 orders of magnitude. The circuitry can handle currents from 10nA to 100mA.  
  
In this way, the circuitry can measure both the current and voltage of the DUT in real time. Both the voltage and current are filtered by Butterworth filters in the Sallen-Key topology. After filtering, the signals are fed into ADCs on the microcontroller and digitized. The microcontroller is an Atmel ATxMega64a3, with 12 bit ADCs, giving a resolution of:

|  |  |  |
| --- | --- | --- |
| Resolution | Full scale measurement | Comment |
| 7.32mA | 30V |  |
| .098mA | 100mA | Hi current measurement |
| .98uA | 1ma | Med current measurement |
| .98nA | 1uA | Lo current measurement.\* |

\*This measurement is before calculations of external noise and temperature variations.  
  
Once the data is collected onto the microcontroller, it is sent to a PC via USB for further analysis. The data is sampled by the ADCs at a rate of #baud and transferred to the PC at a rate of 2Mbaud. This allows for maximum flexibility on the PC side, where any data coming in at a rate greater than what is desired can simply be discarded.  
  
**III. Experimental procedures.  Describe the open beaker anodization.**  
  
The experimental setup to anodize the anode of a titanium capacitor with the aforementioned circuitry is as follows. The anode sample is prepared by cleaning the surface oxide off with a chemical bath. It is then transported into a beaker of anodizing solution. The current source is connected to the DUT and acts as both a current source and data logger until the test is over.ent through the DUT has dropped to the leakage current  
  
  
**IV. Experimental results.  This can be a selection of the materials Don and Laurie have anodized.  To date I am not sure if we really have any from Don.**  
  
To date this method has anodized a number of different materials, including the following list: