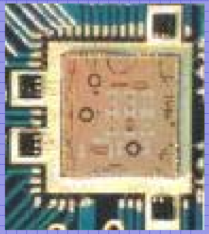
Wireless Sensor Networks

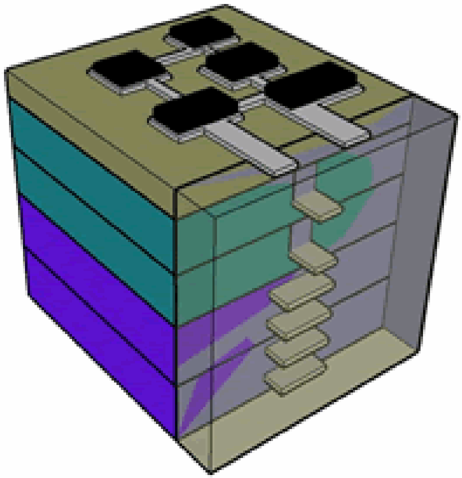
Low Power Radio



“Disappearing Computer”

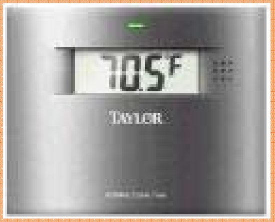
B. Gates, *Economist* (2003)

Energy Storage



“Picocube”

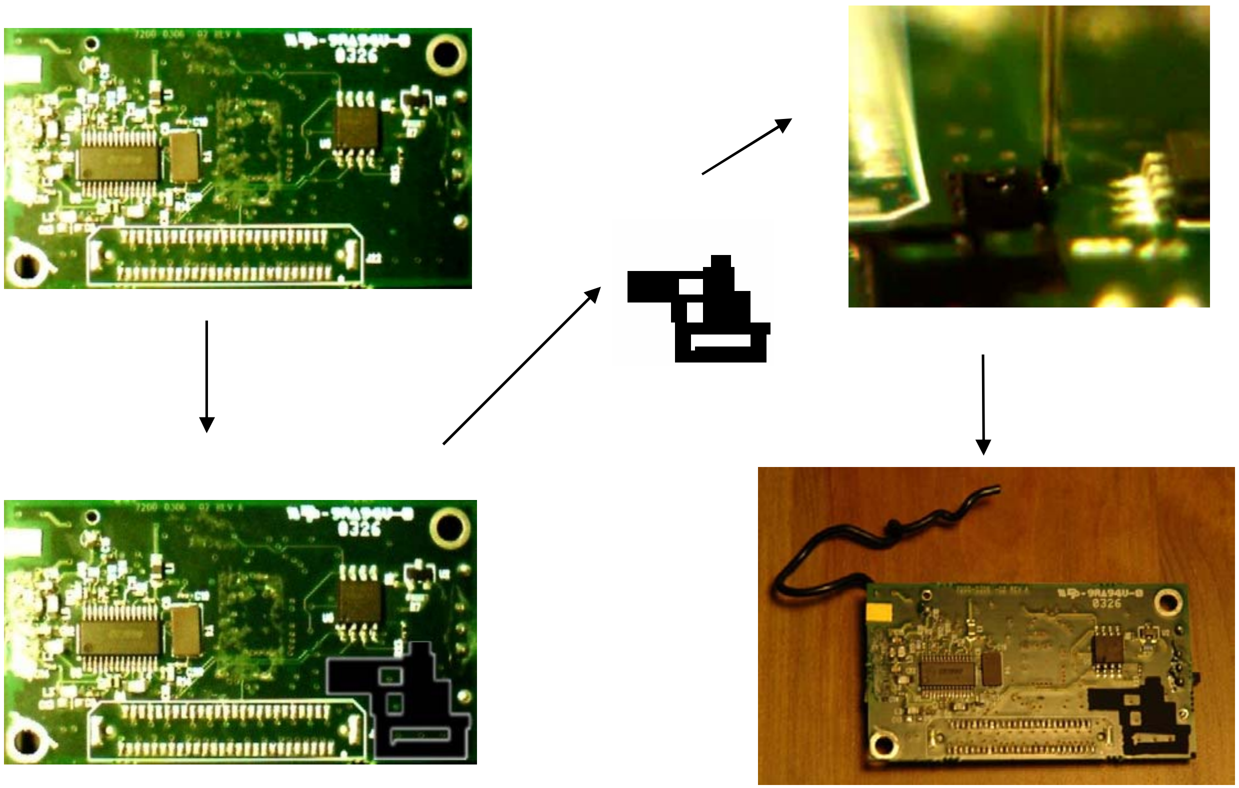
Sensor



Renewable

Dispenser Printing

Sure!

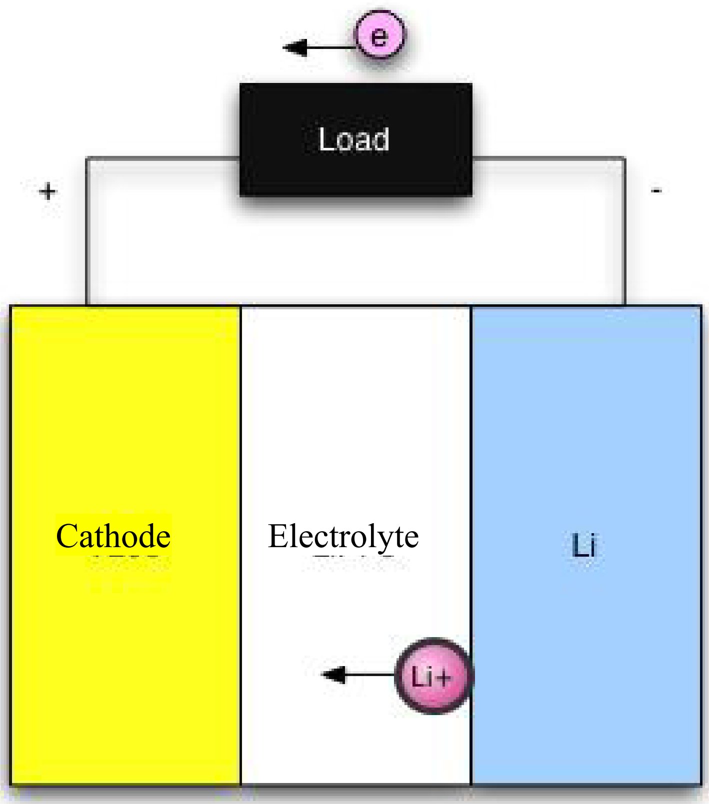


Why Print?

- **Batteries**
  - Thick films = more mass / cm^2 = more capacity / cm^2
  - Printing on device removes packaging
- **Capacitors**
  - Slurries allow for porous carbon electrodes, higher surface area

Battery Basics

- Volume of the electrodes determines capacity
- Area of interface determines power
- Chemistry determines potential



Thin film batteries are great...

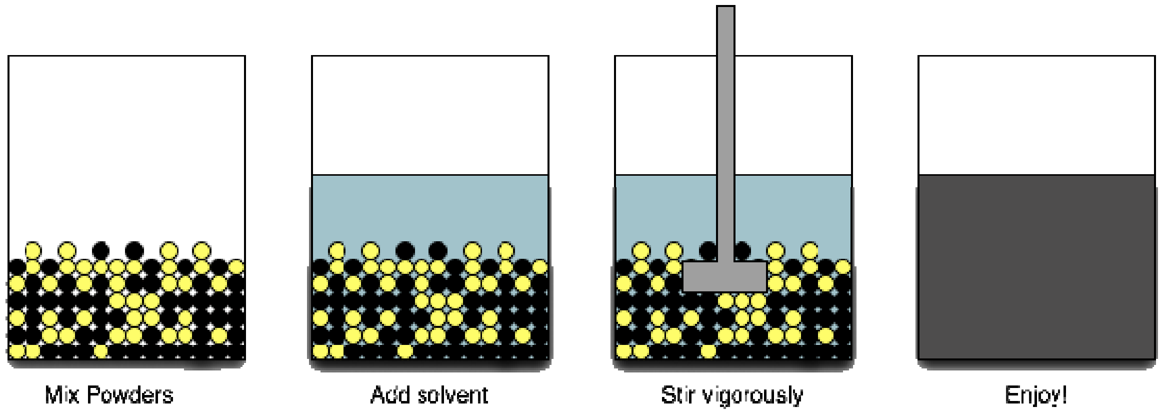
- **For high power applications with area to spare**
- **Advantages**
  - Excellent material properties
  - Lithium anodes and structured cathodes allow for high rate capability
  - Demonstrated all solid state

Thin film batteries fare poorly..

- **When foot print is a concern**
  - Sputtering technologies limit overall thickness
  - ~120 μAh/cm^2 @ 3.8 (Cymbet)
  - Sure you can stack multiple cells, but then you have to bus, and....
- **Beyond thickness issues**
  - High temperature processing leads to “chicken vs. egg”
  - Materials fabrication coupled with device production

Inks

- **Binder is "optional"**
  - Without binder sinter is generally required
  - With binder sinter is optional

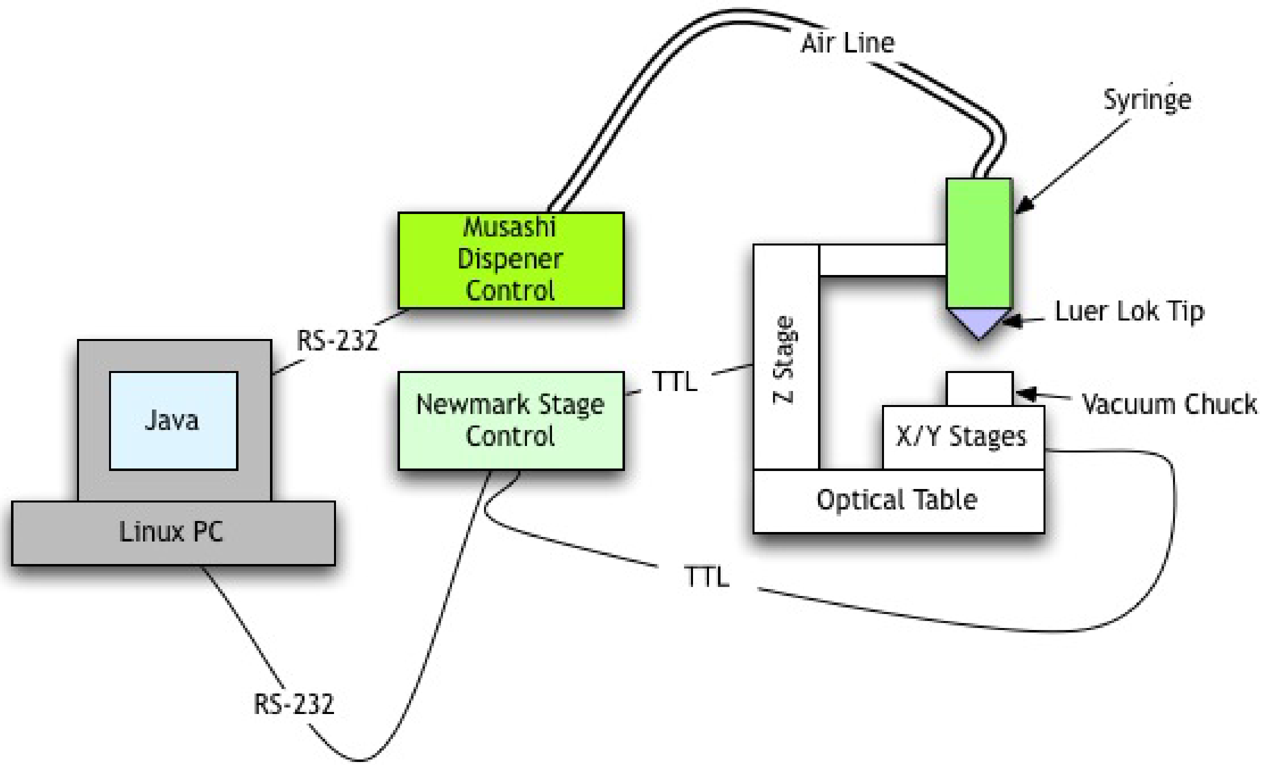


- **A note to the nano-crowd: yes you can make binder free nano-particle solutions, but....**

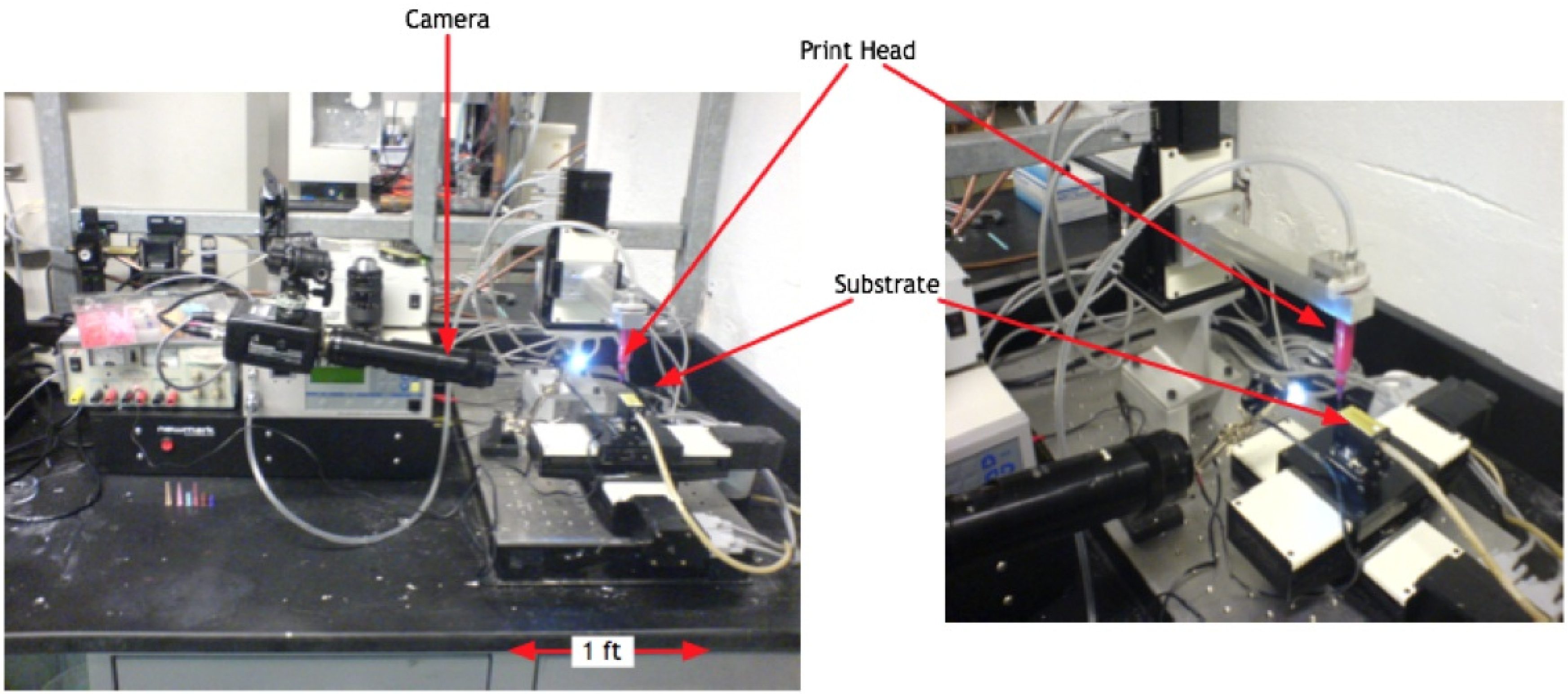
Inks

- **Binders**
  - PVDF
  - PDMS
  - PVA
- **Active**
  - Battery materials (Carbon, $LiFePO_4$, $LiCoO_2$, $Li_4Ti_5O_{12}$, PEO, Ag, ZnO, Cellulose.....)
  - Magnetics (Ferrite, Neodymium powders)
  - Thermoelectrics (unconfirmed) (Bi_2Te_3)

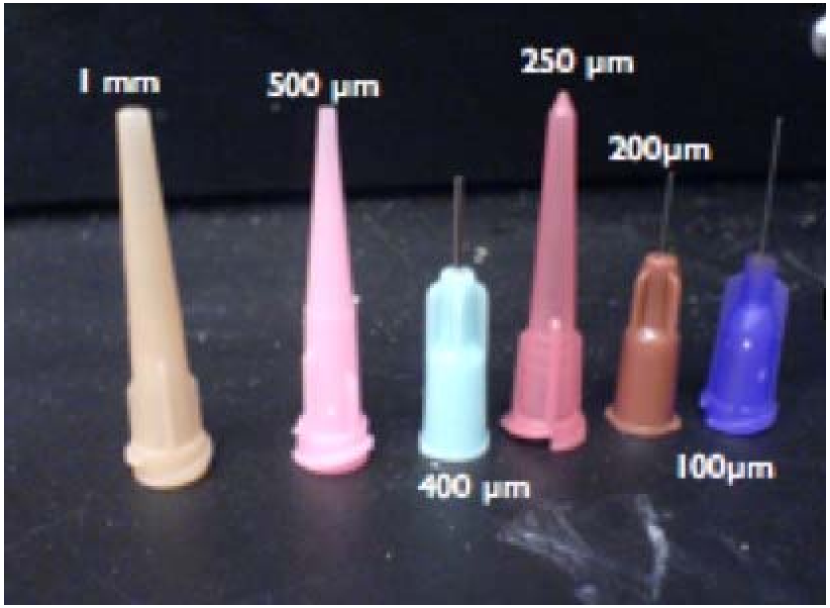
Dispenser Printing



Dispenser Printing



Dispenser Printing

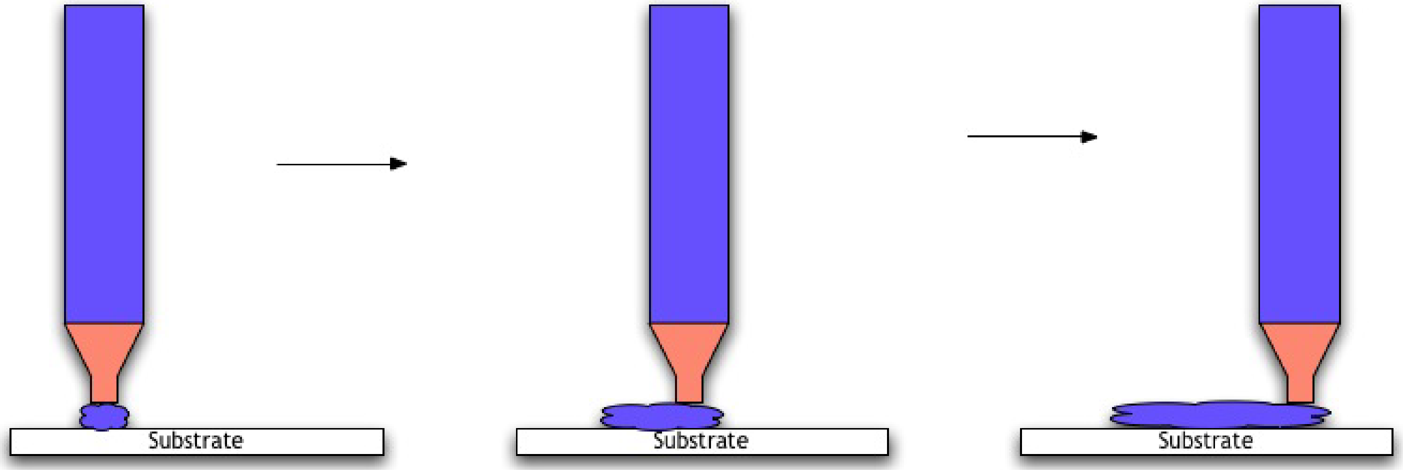


Cost < $0.50 / tip

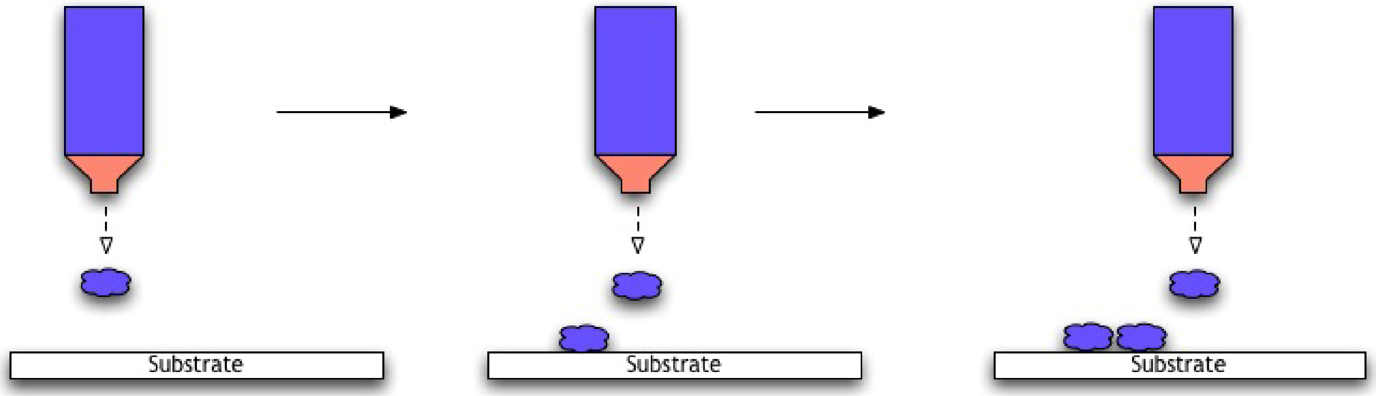
Dispenser Printing

Dispenser Printing

Dispener Printing (always in contact)

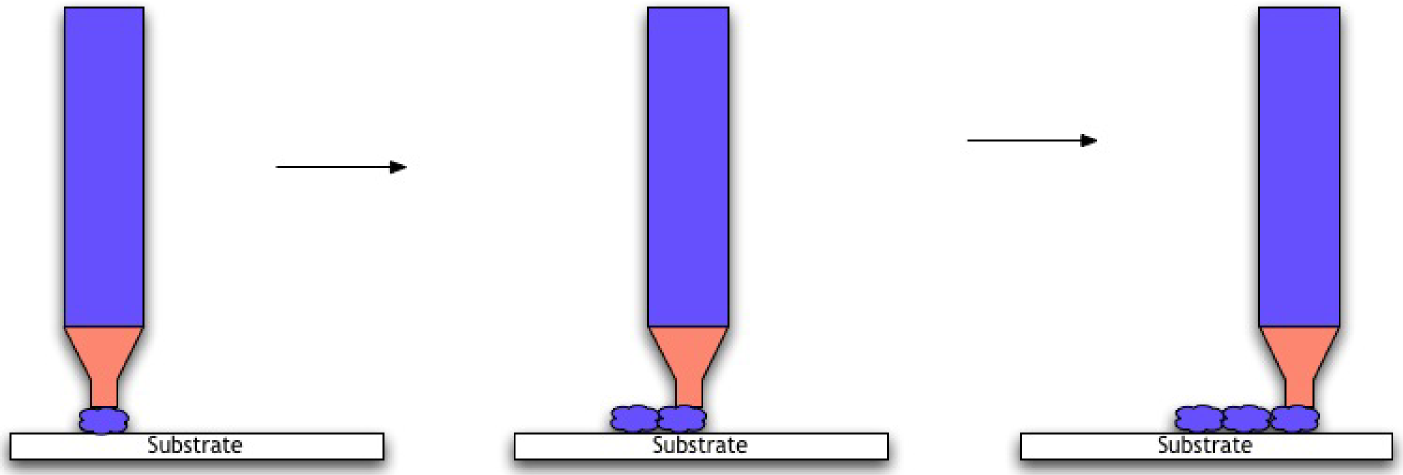


Ink Jet Printing (never in contact)

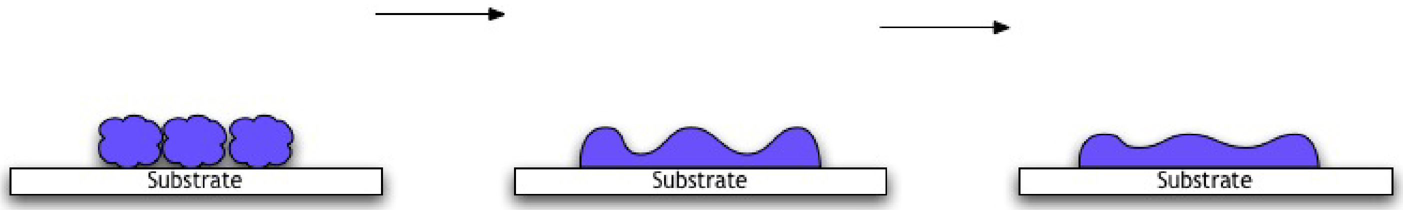


Dispenser Printing

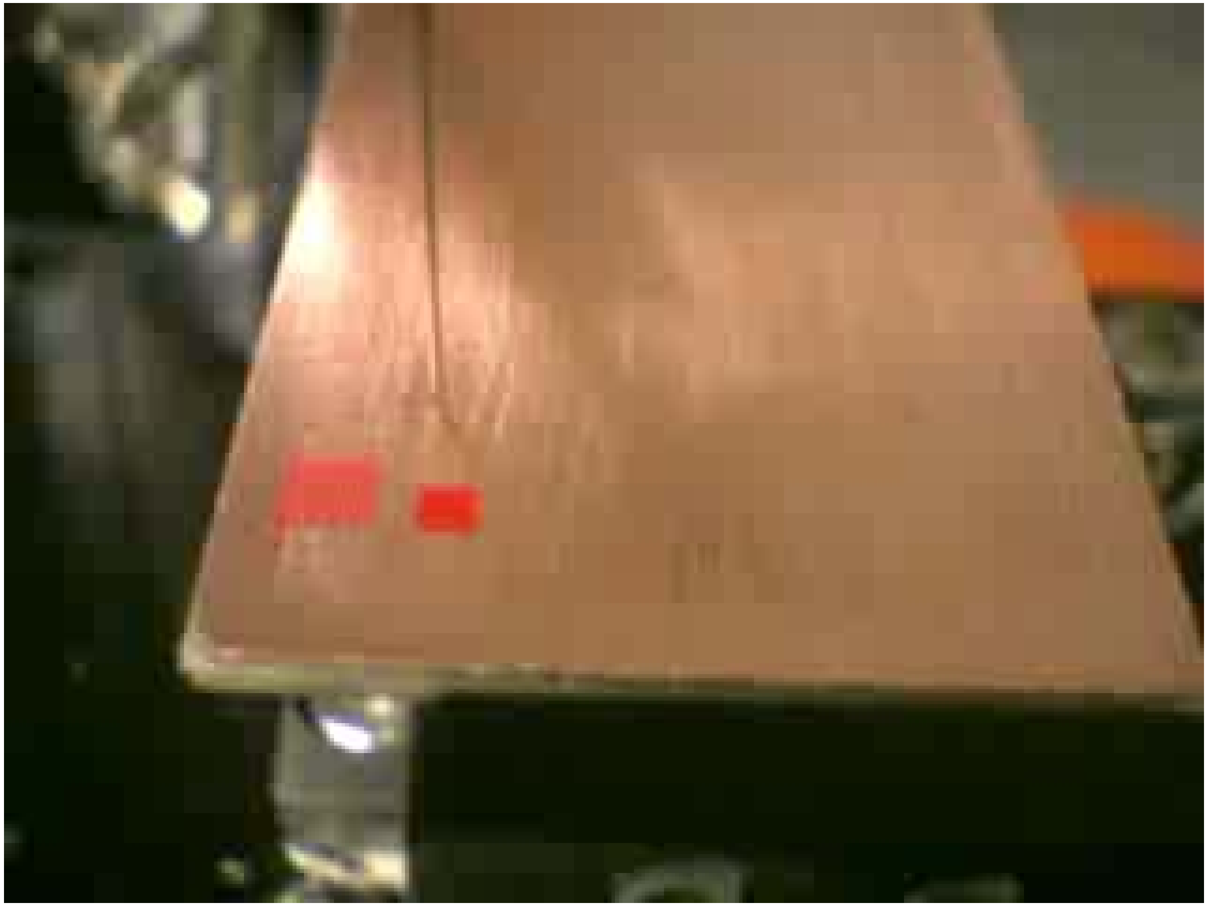
Dab Printing



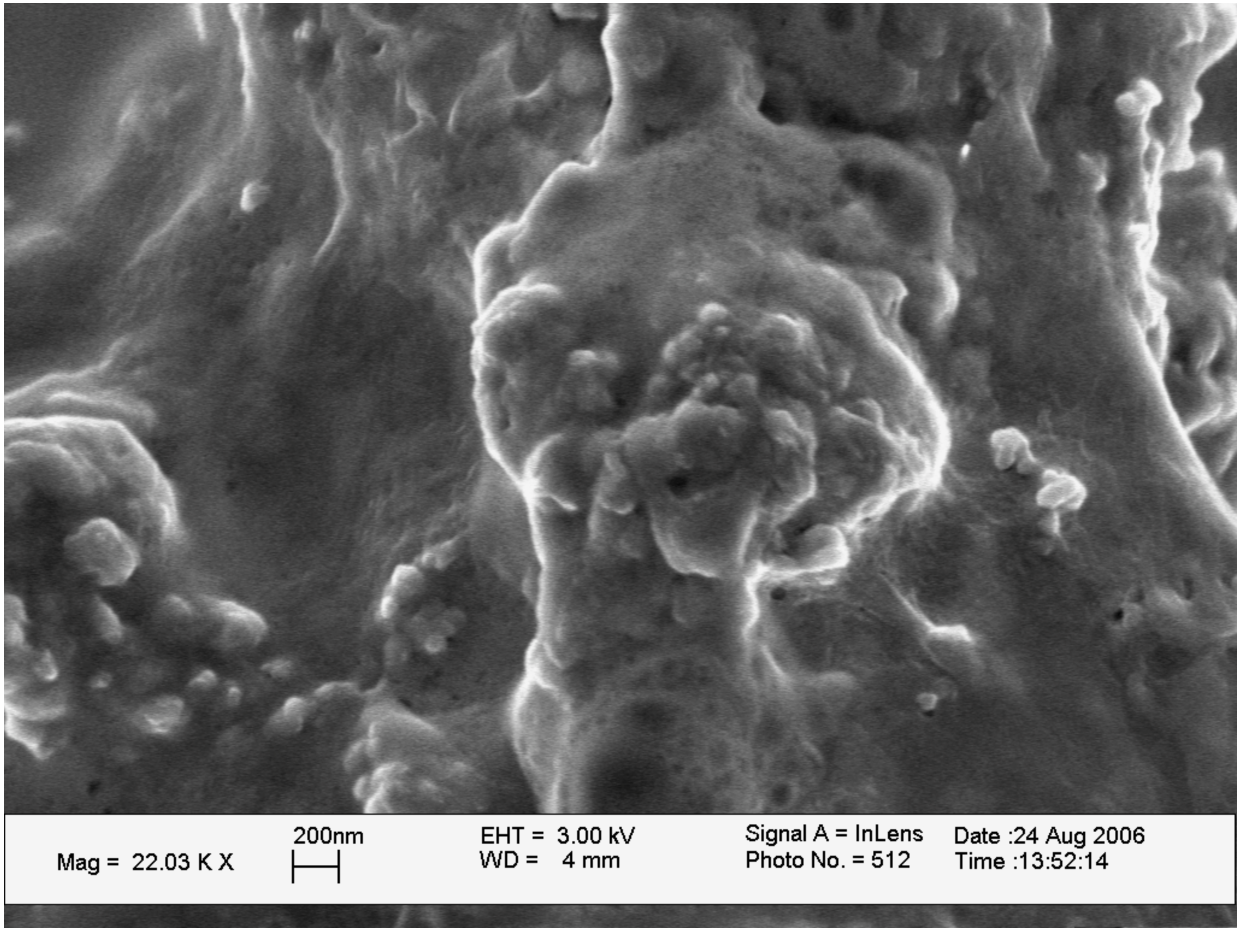
Healing



Dispenser Printing

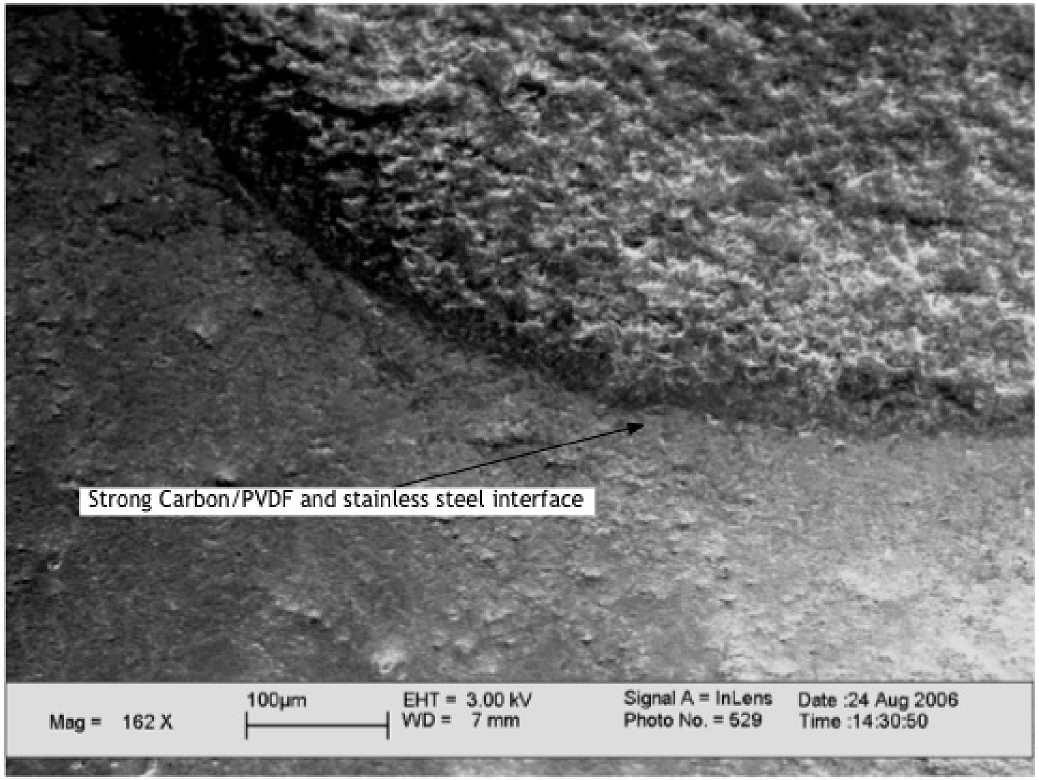


Cast Slurry

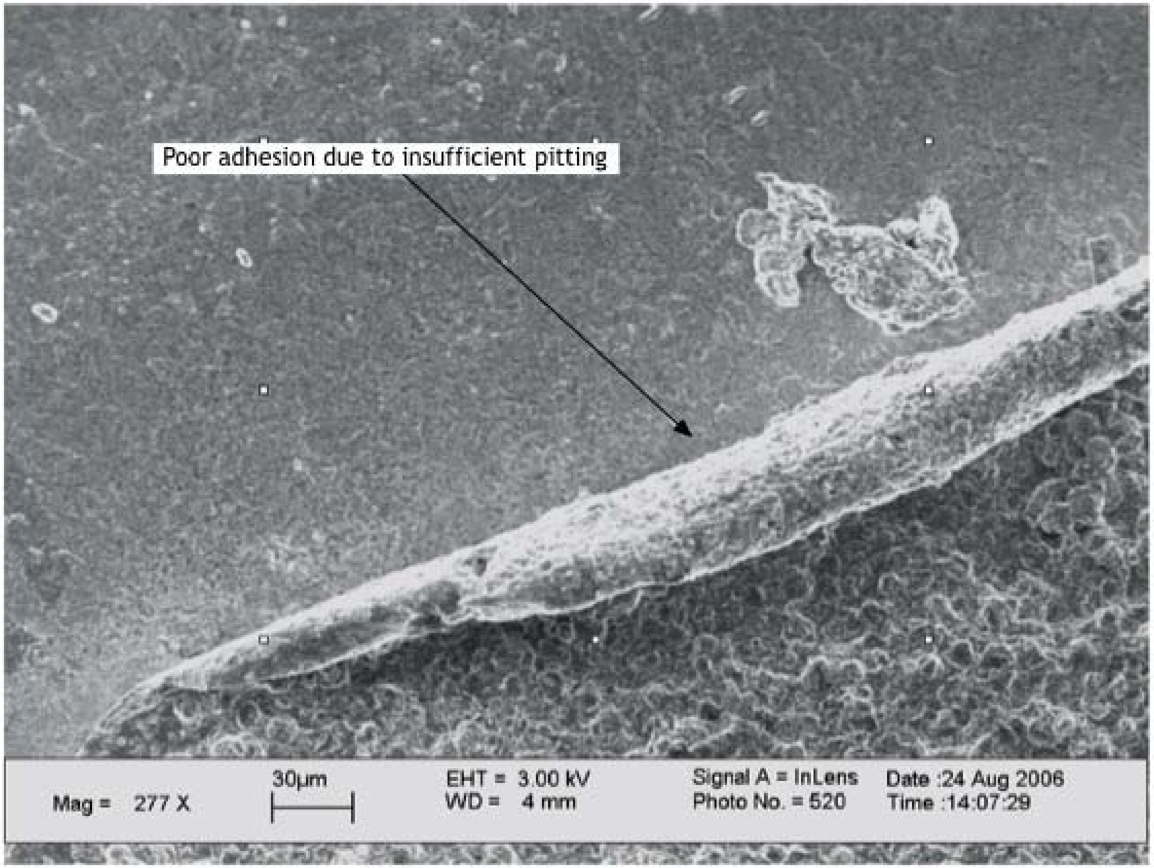


Mag = 22.03 K X
200nm
EHT = 3.00 kV
WD = 4 mm
Signal A = InLens
Photo No. = 512
Date :24 Aug 2006
Time :13:52:14

Film Adhesion is good

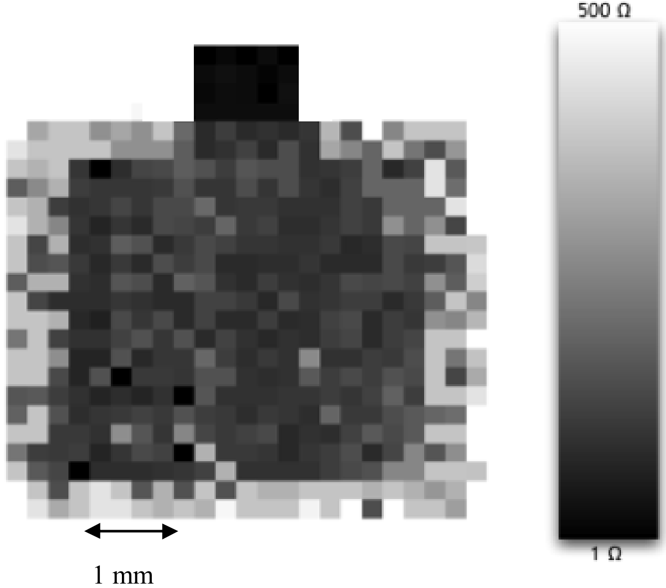


Care must be taken.....

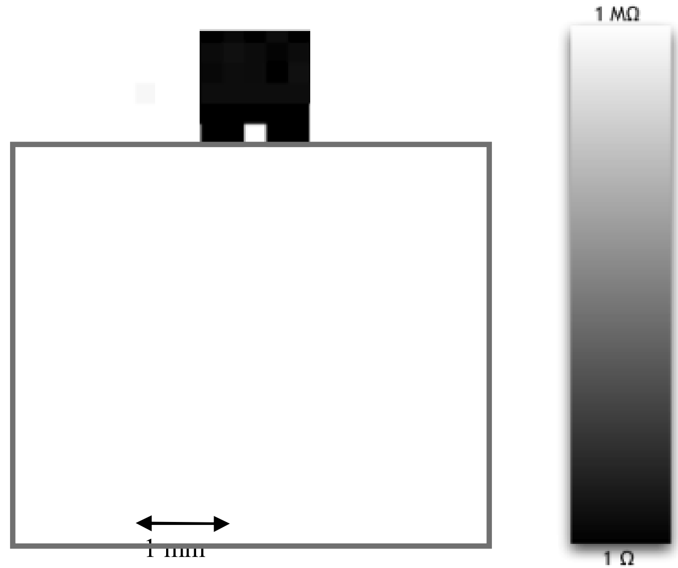


Dielectric Layers

Before PVDF

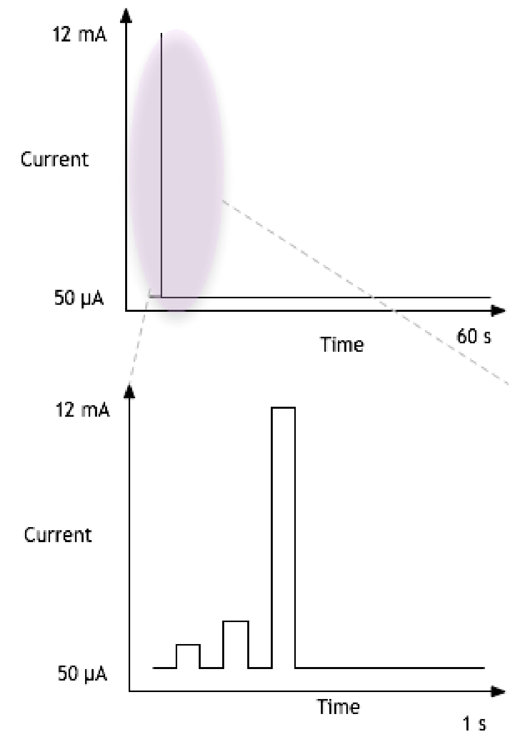


After PVDF



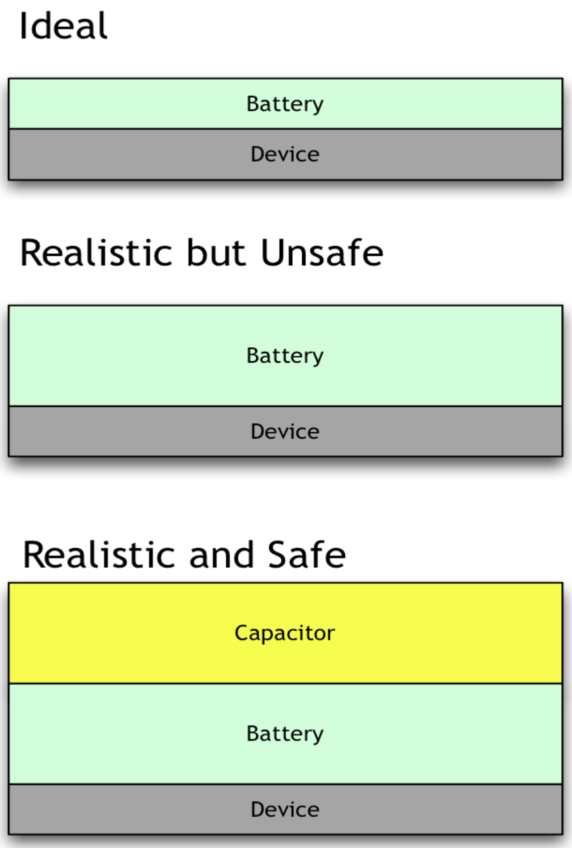
Application

- **"Smart Dust"**
  - Small volume (< 1 cm^3)
  - Small footprint (< 1 cm^2)
  - Low duty cycle
    - < 1% active time
  - Huge spikes
    - 50 µA - 100 µA sleep
    - 12 mA transmit
  - A practical battery should last overnight, thus a capacity of > 800 $\mu Ah/cm^2$ is required



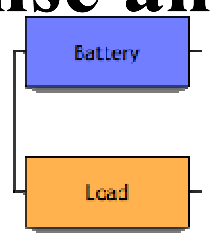
Batteries

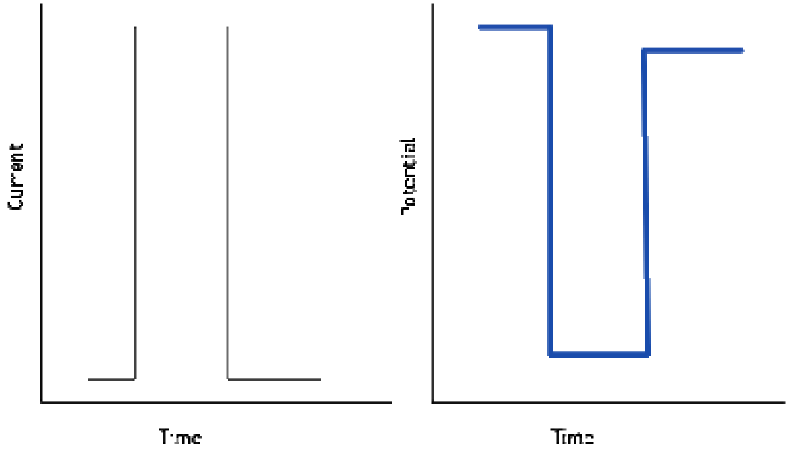
- 1000 µAh ideally could be a achieved in a space of 100 µm thick by 1 cm by 1 cm
- Realistically > 200 µm thick by 1 cm by 1 cm
- Better yet, 400 µm by 1 cm by 1 cm (hybrid supercapacitor setup)



Low Duty Cycle Example

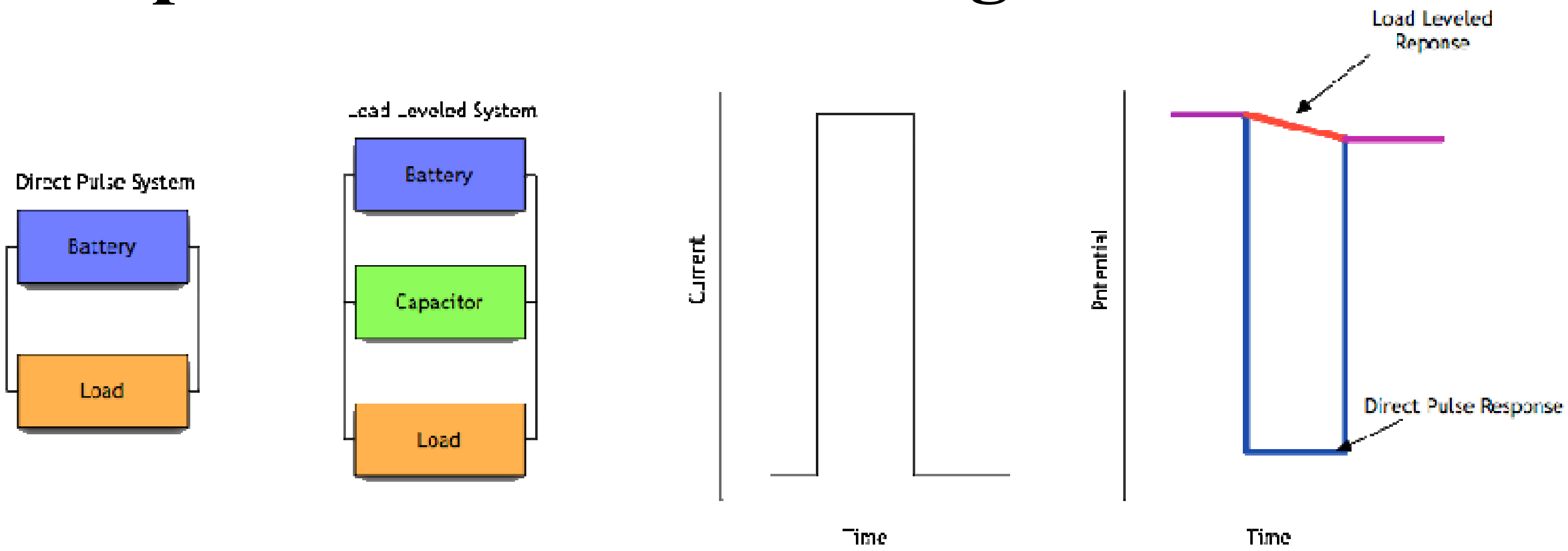
- Directly apply the load to the battery
- Change the sense and send rate



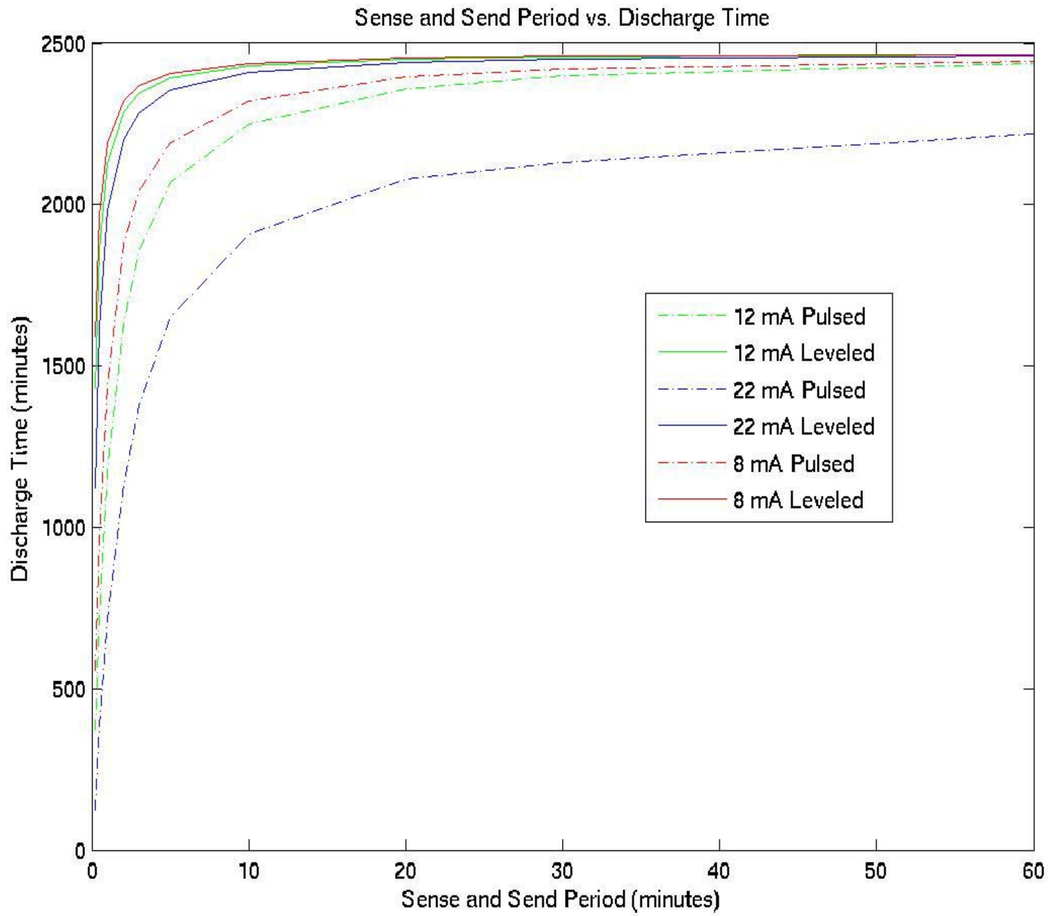


Low Duty Cycle Example

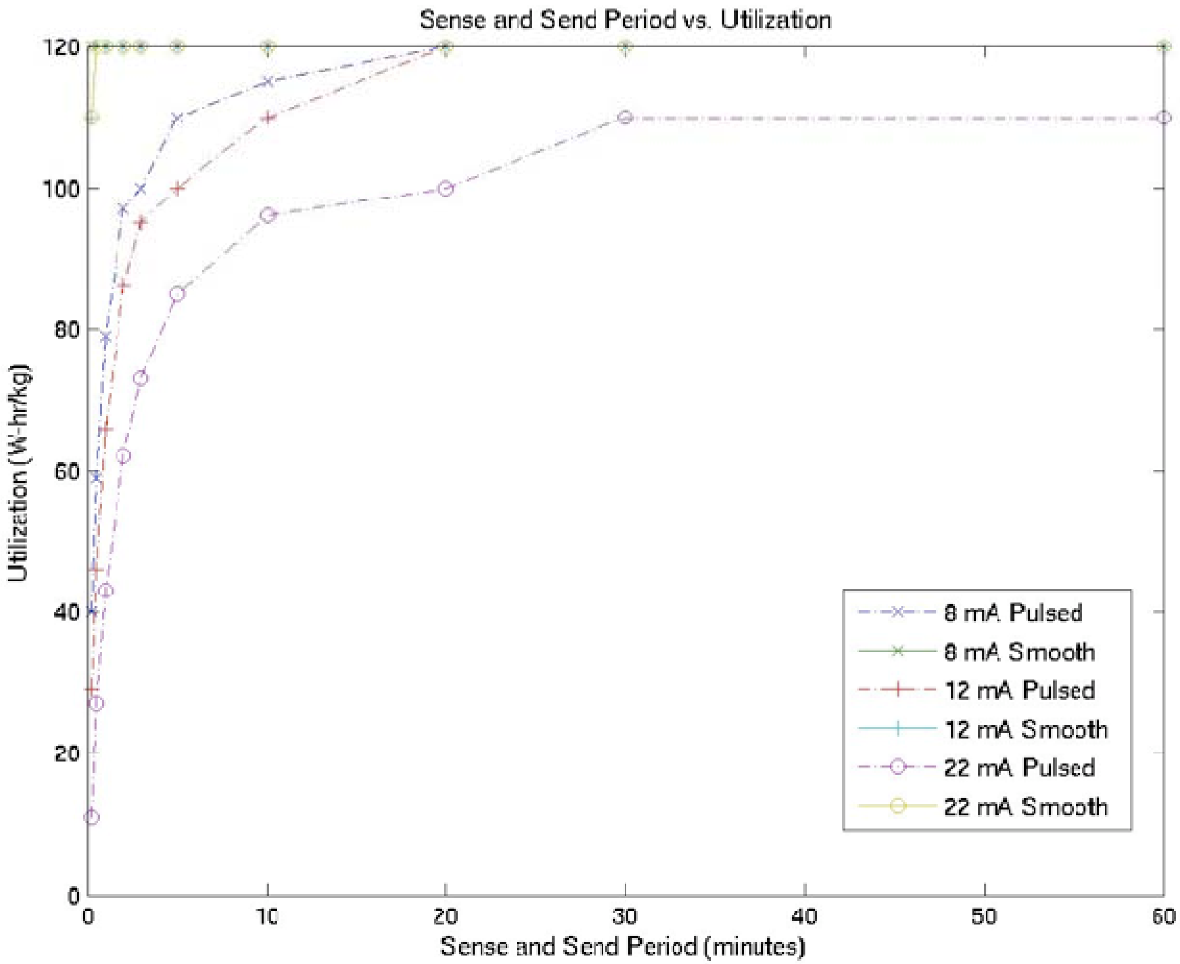
- Take a super capacitor, place in parallel with load and device, such that the capacitor is “trickle charged”



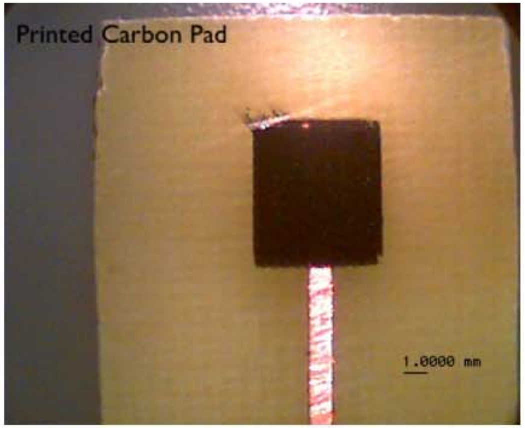
Power and Energy

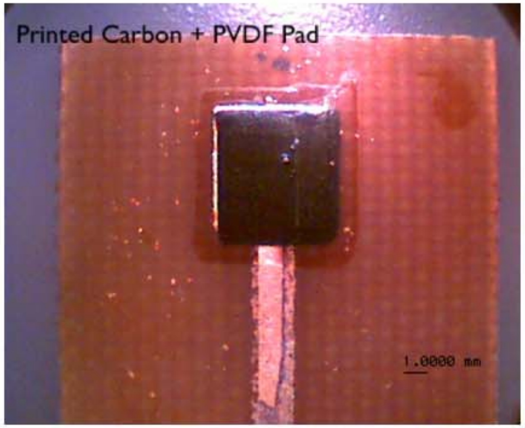


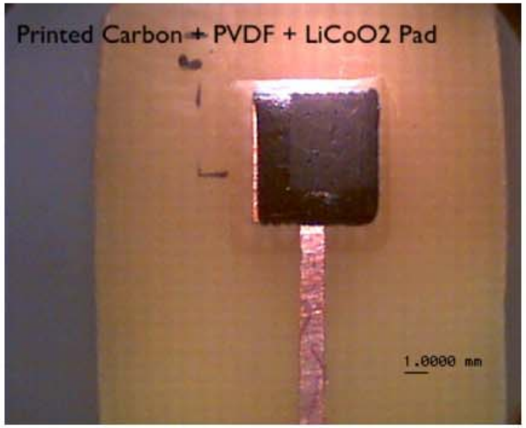
Power and Energy



Fully Printed Cells

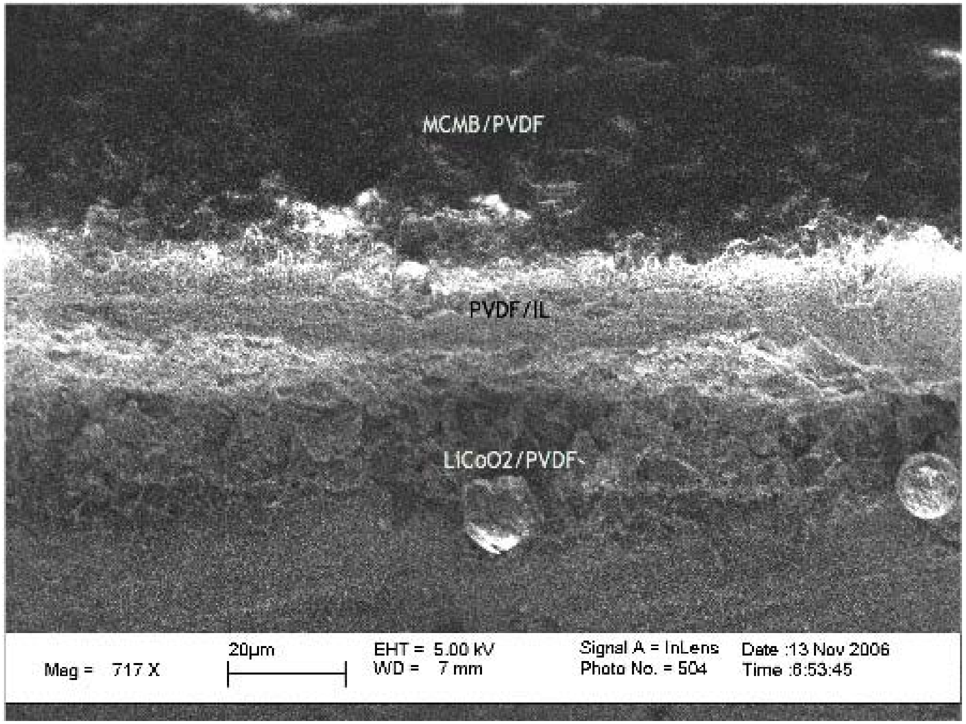




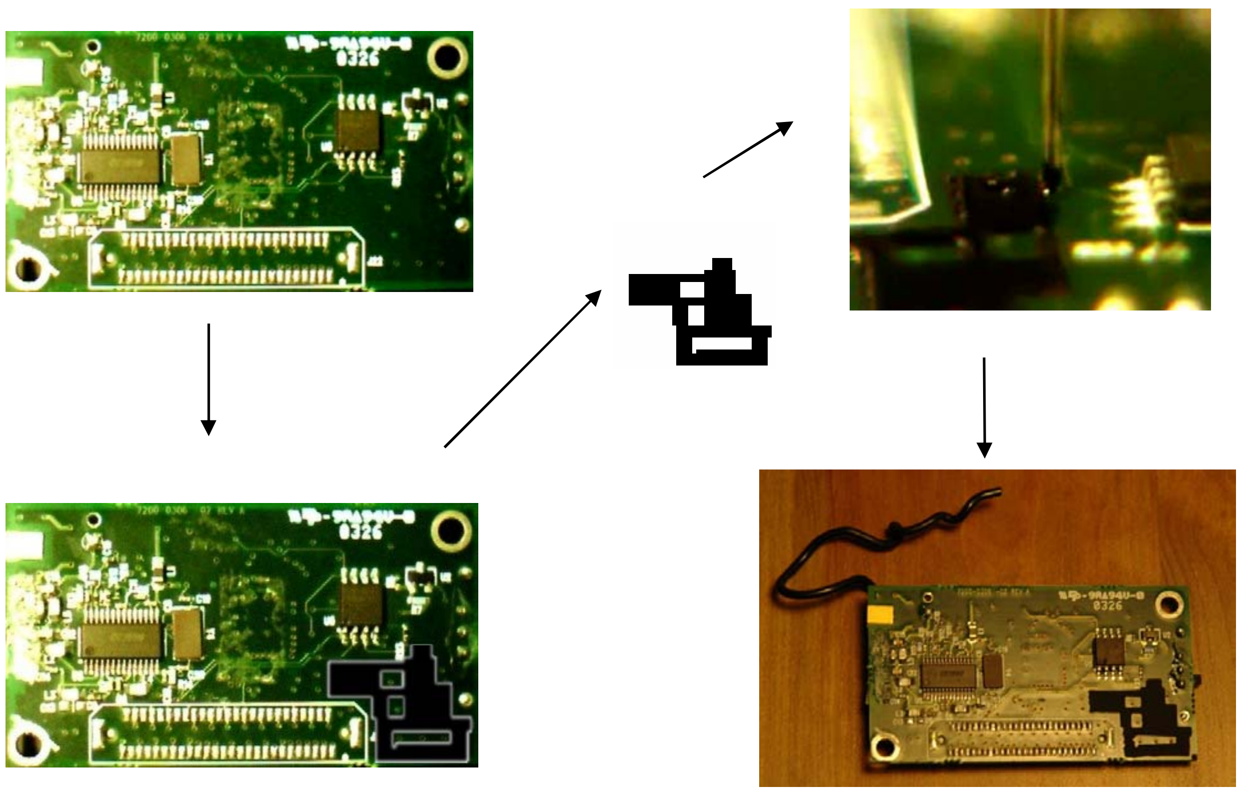


Fully Printed Cells

- **Look great, test poorly**
  - Too much water

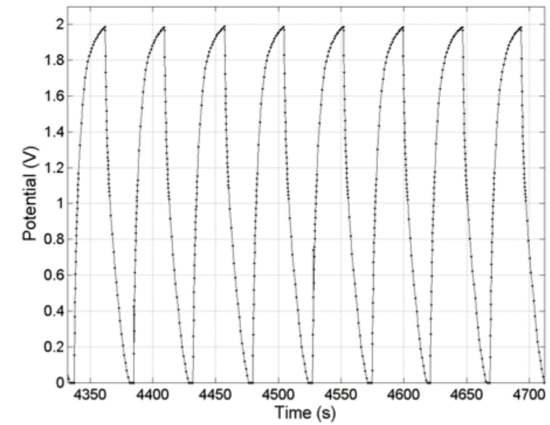


But it allows us to dream



Printed Capacitors

- 5 mm by 5 mm by 100 µm
- Capacity of 3 F/g
- Materials limited (currently)



Galvanostatic Cycling at 30 µA