Electrified Printmaking

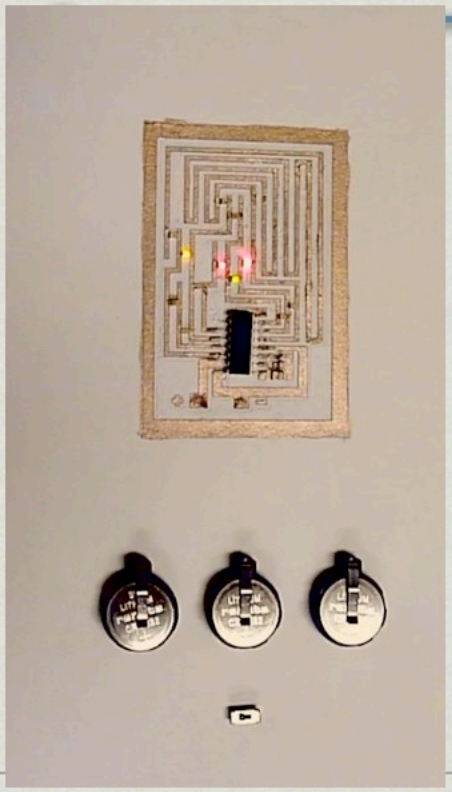
Using Conductive Ink to Create Active Images

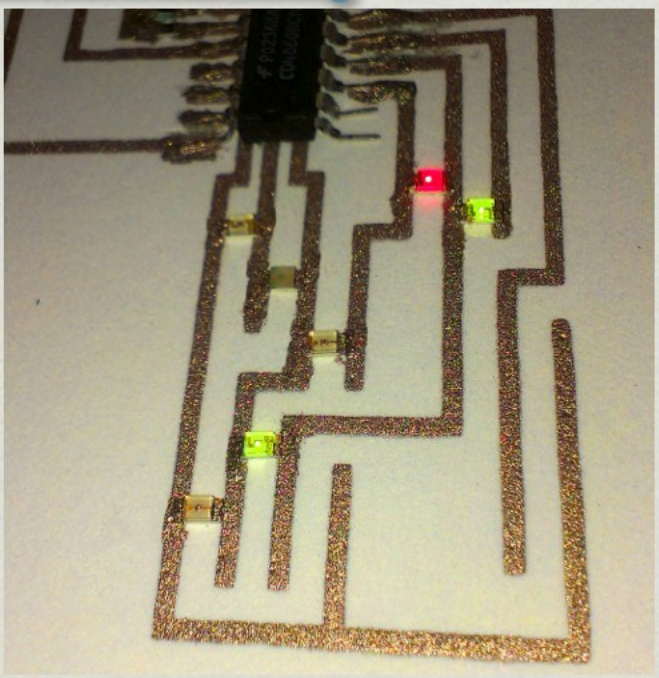
Erik Brunvand
Saltgrass Printmakers
& University of Utah

Motivation

- Printing involves transfer of ink to a substrate
  - Visual properties depend on the physical properties of the ink
- What about physical properties of the printed images?
  - What if the ink were conductive?
  - What are the possibilities of an active electronic print?
  - Extend the vocabulary of print towards digital media?

Printed "Wires"





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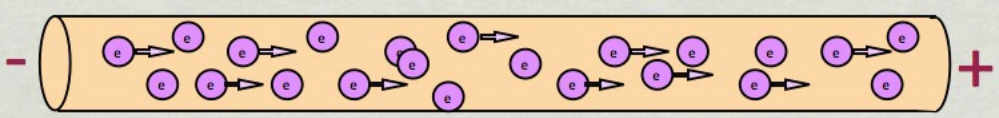
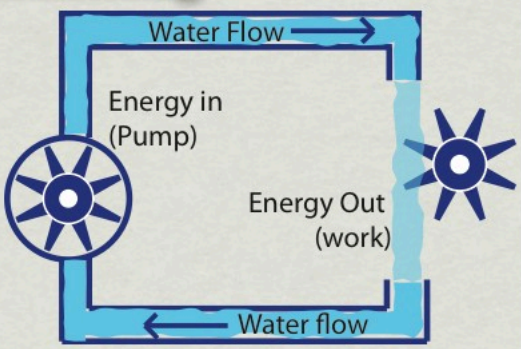
Electronics

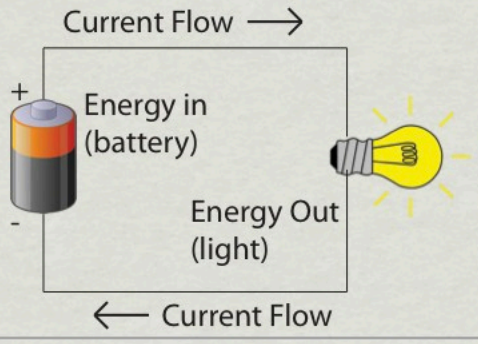
- Related to charge moving in a conductor
- Electrons moving under influence of an electronic field
  - Force is **Voltage** (volts)
  - Amount of charge moving is **Current** (amps)
  - "Friction" for current is **Resistance** (ohms)



Electronics: Water Analogy

- **Current** is like water flowing through a pipe
- **Voltage** is like water pressure
- **Resistance** is related to the diameter of the pipe
  - Water pushed through a pipe can do work (like a water wheel)
  - Electrons pushed through a wire can do work (like light a bulb)





Ohm's Law

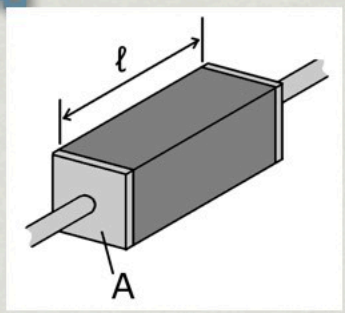
- Fundamental relationship of voltage, current, resistance

$$V = IR \qquad R = V/I \qquad I = V/R$$

- Helps put resistance / conductance in context
- Important when you start using these printed "wires"
- Important when you wire up a component like an LED

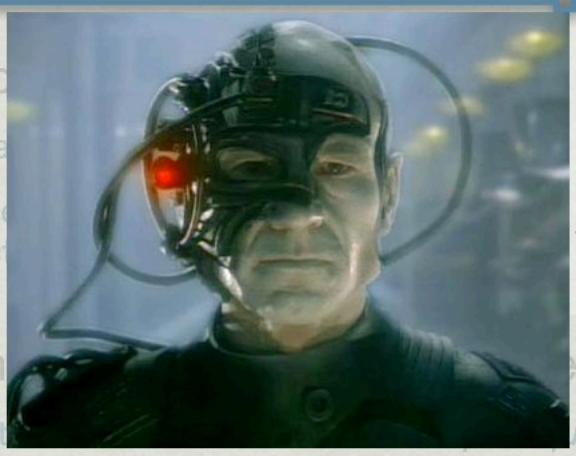
Measuring Resistance

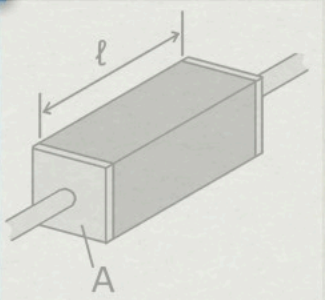
- Resistance is a function of: ρ(L/A)
  - ρ is the native resistivity of the material
  - L/A are the Length and cross-sectional Area of the material



- What if the "wire" is flat and wide like a ribbon?
  - This results in a measurement of "*ohms per square*"
  - The resistance of one square unit of the material doesn't depend on how big/small the unit is!
    - OK - it does also depend on the thickness of the ribbon

Measuring Resistance

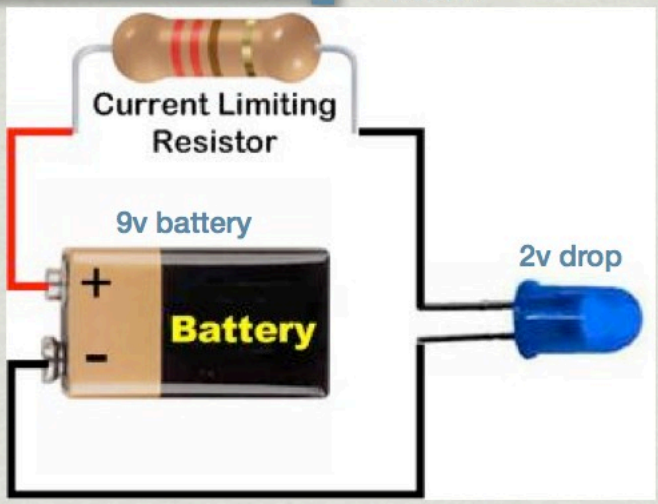




Resistance is futile!!!

LED Circuit

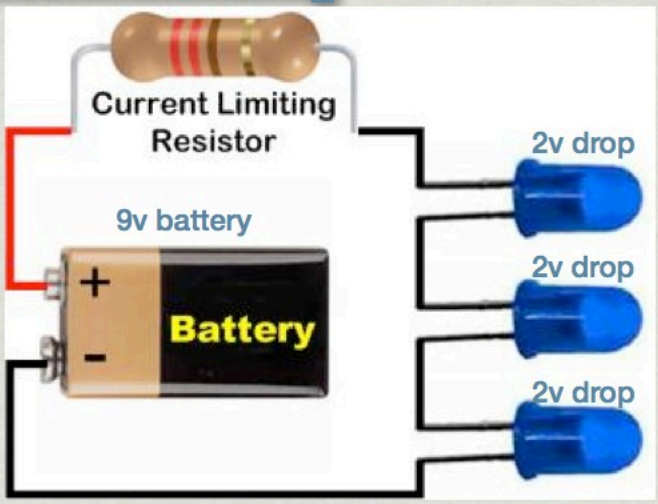
Resistor sized to drop 7v at 0.020A



- Current flowing through an LED makes it light
  - typical limit: 20mA
  - typical LED ***voltage drop***: 1.2v-3v
- $R = V/I$
  $R = (V_{bat} - V_{led})/I$
  $R = (9v - 2v)/0.020A$
  $R = 350\Omega$

LED Circuit

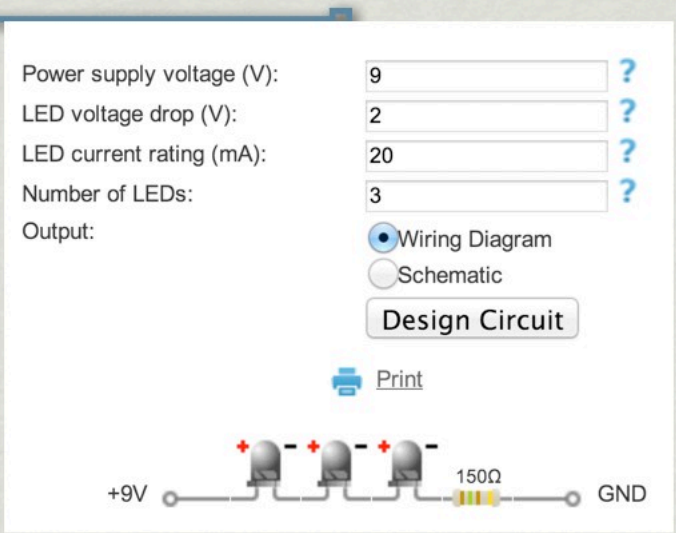
Resistor sized to drop 3v at 0.020A



- Current flowing through an LED makes it light
  - typical limit: 20mA
  - typical LED ***voltage drop***: 1.2v-3v
- $R = V/I$
  $R = (V_{bat} - V_{led})/I$
  $R = (9v - (2 + 2 + 2)v)/0.020A$
  $R = 150\Omega$

LED Circuit

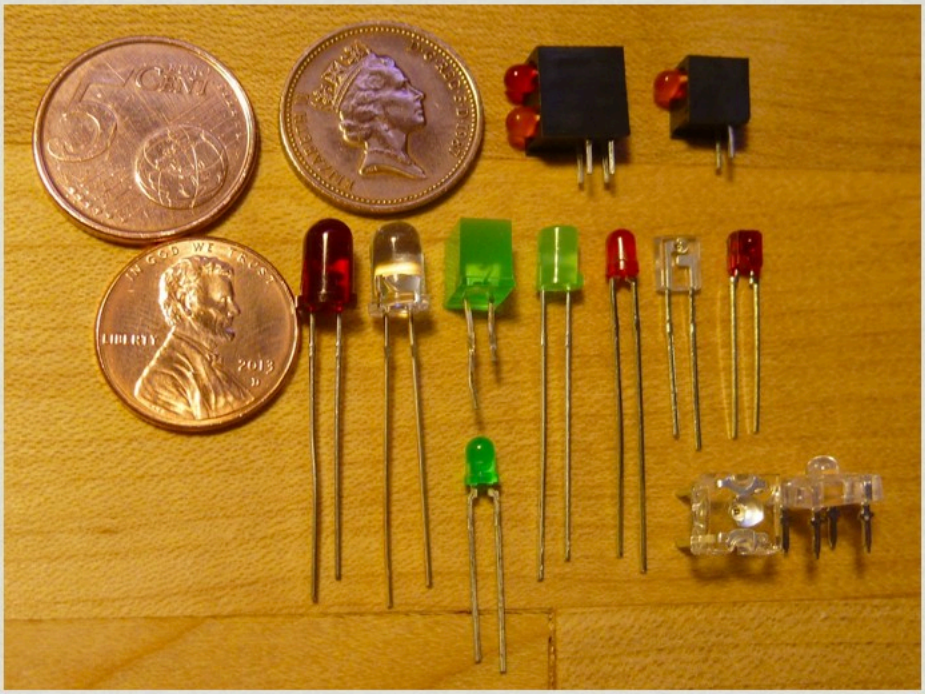
- ledCalculator.net...



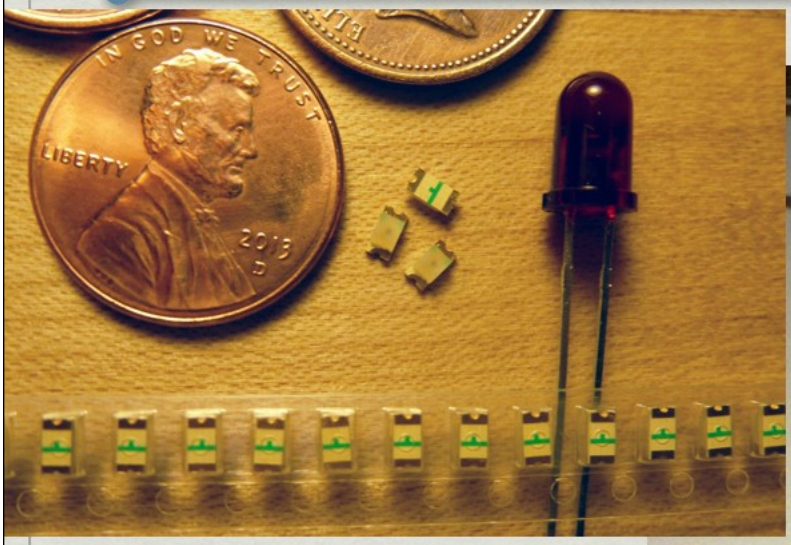
Required resistance can be in a separate resistor, or in the wires themselves!

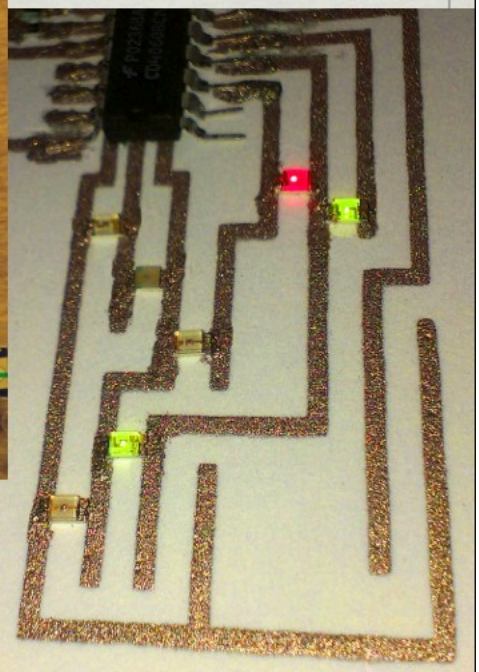
As we'll see, some printable wires have noticeable resistance...

LEDs



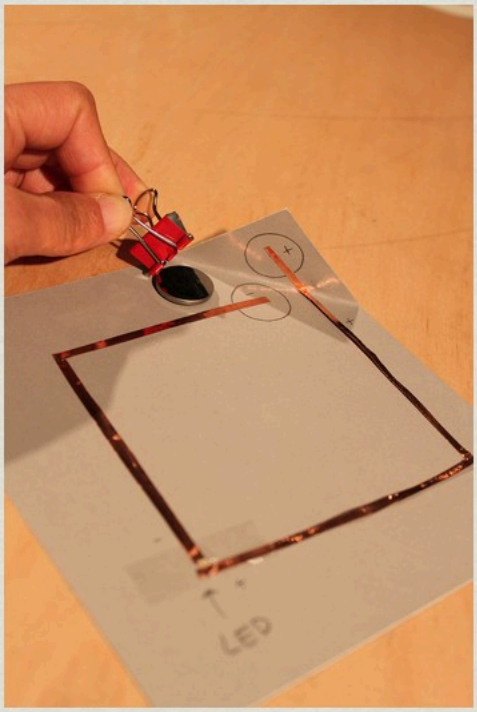
LEDs

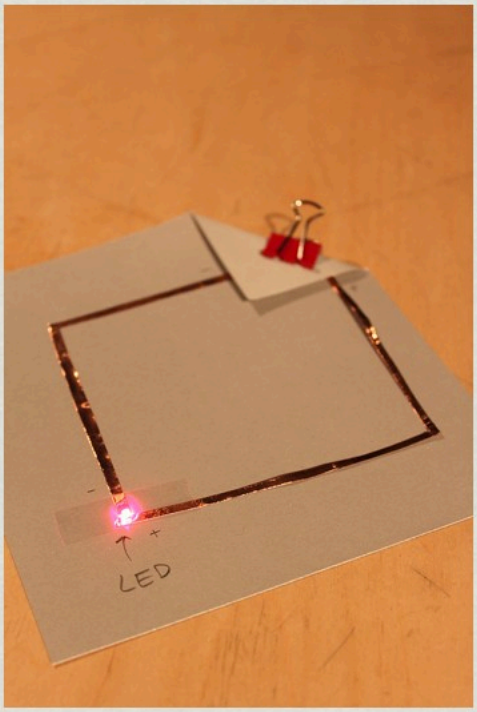




"1206" size surface-mount LED
3.2mm x 1.6mm

Paper LED Circuit





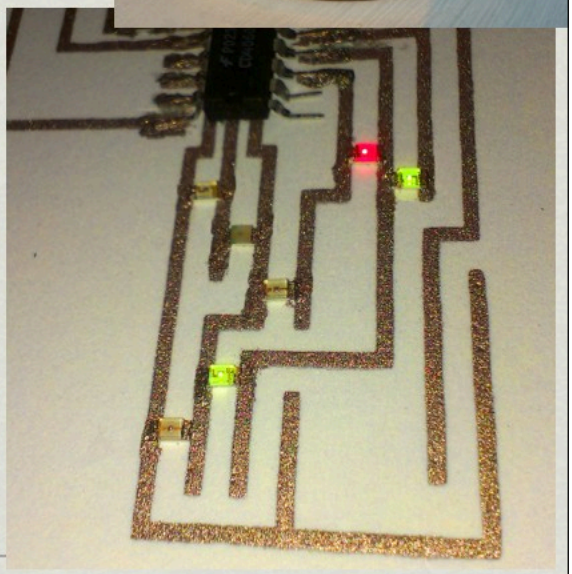
Tinkering Studio
Exploratorium, San Francisco, CA

Conductive Paint Testing

- "Metallic" paints don't work!
- Adding metal flakes to screenprint ink doesn't work
- Adding graphite to screenprint ink ***does*** work
  - Resistance is fairly high though...

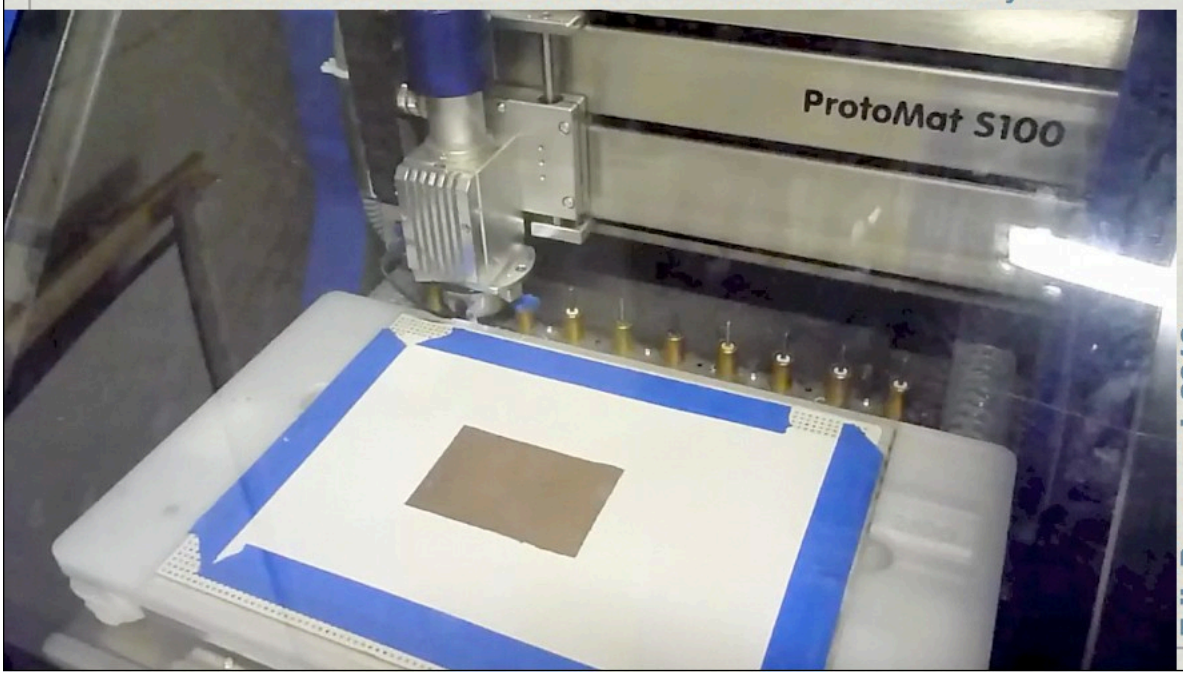
Copper-Based Paint

- CuPro Cote from LessEMF.com
- Copper-based conductive paint
  - Water-based paint - easy-ish cleanup (dries fast)
  - Low resistance: < 1Ω/sq
  - A little loose straight out of the can
  - Can be thickened a little with a little bit of screenprint medium



CNC Routing

- Start with paint applied to the paper
- Use a circuit-board CNC router to remove the surface layer



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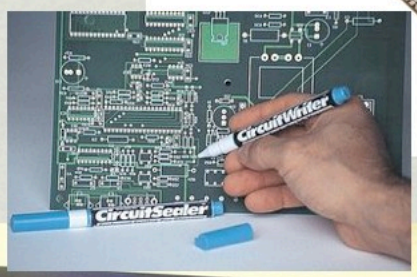
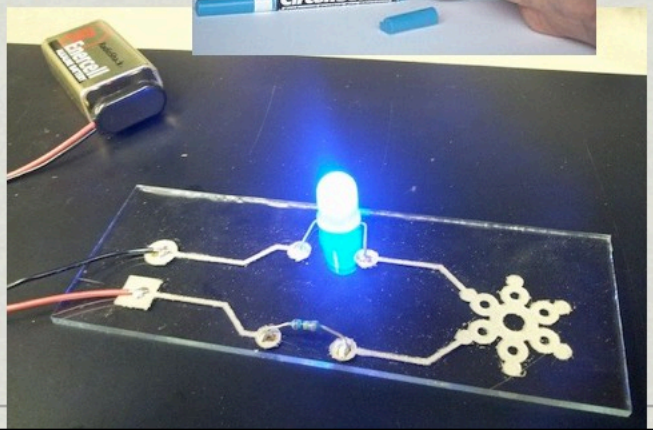
Silver Ink Pen

- CircuitWriter by Caig Labs
  - Extremely low resistance: 0.017Ω/sq
  - Designed for repairing circuit traces
  - Silver color
  - Expensive!





Conductive Ink-Jet Ink

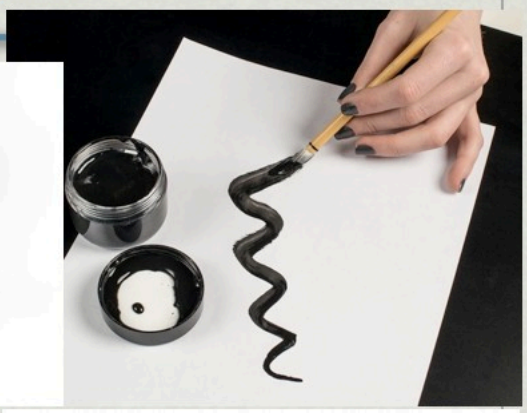
- Microsoft Research, Cambridge
- $100/100ml silver-based ink

Nickel-based paint

- MG Chemicals Super Shield
  - Nickel based coating
  - Low resistance: 0.6Ω/sq
  - Designed to be a shielding coating for electronics
  - Medium grey color
  - ***NOT water soluble! Pretty stinky stuff... Gums up screens instantly... Better used for painting than for printing...***

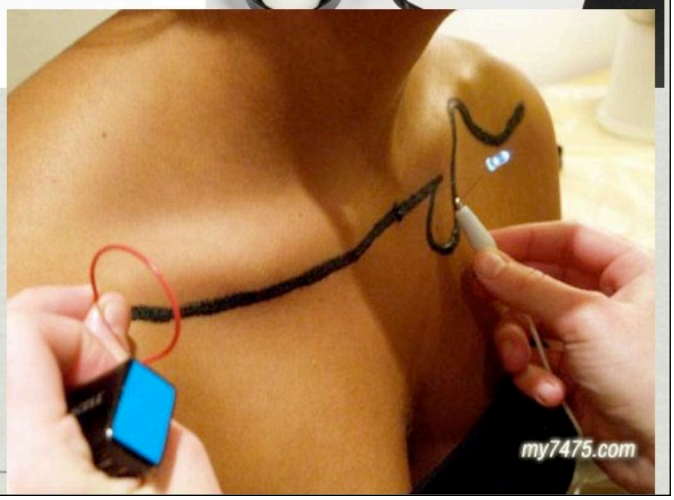
Carbon-based paint

- Bare Conductive
  - Moderate resistance: 50Ω/sq
  - Water soluble
  - Designed for painting and for printing
  - Comes in jars or pens



Carbon-based paint

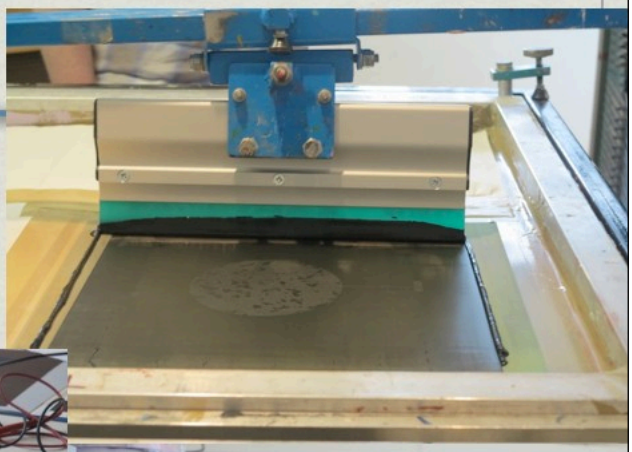
- Bare Conductive
  - Moderate resistance: 50Ω/sq
  - Water soluble
  - Designed for painting and for printing
  - Comes in jars or pens
  - Safe to paint on skin!

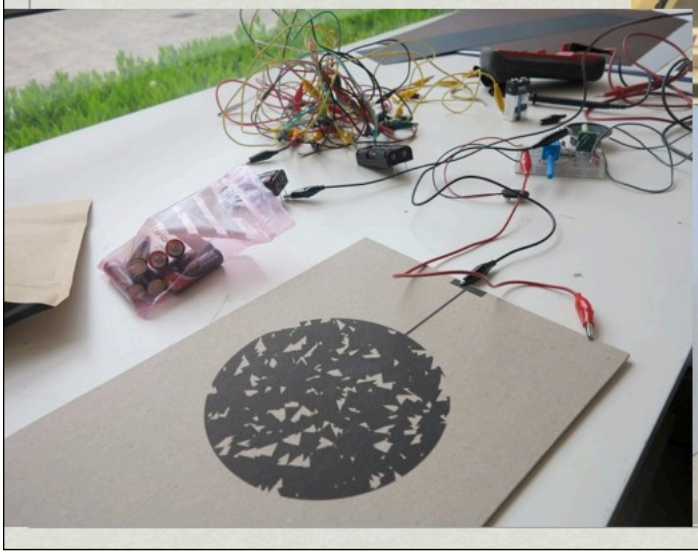


Luma Studios

(London)

Screenprinting with Bare Conductive carbon-based ink





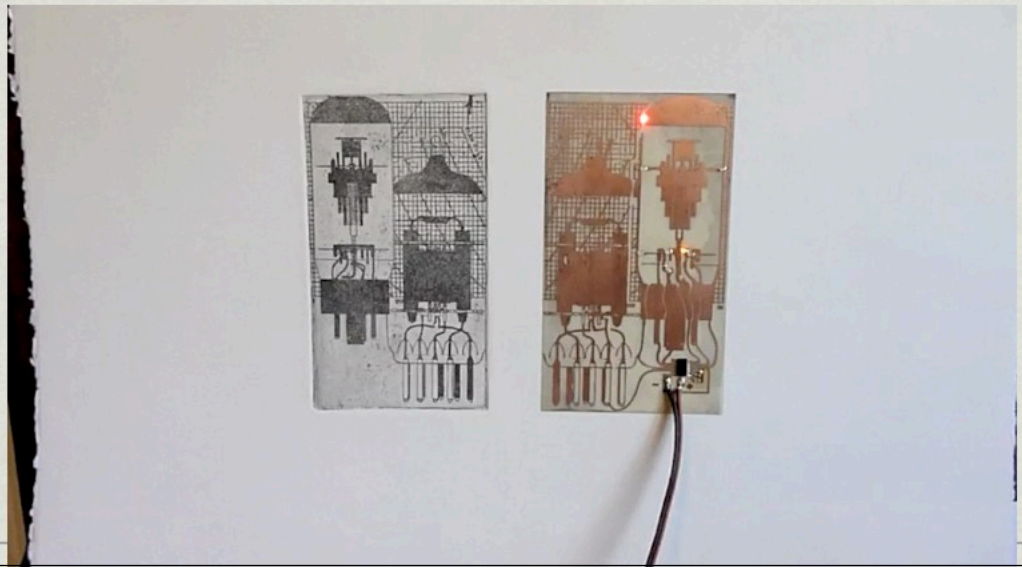
Commercial conductive inks

- e.g. Vorbeck Materials
  - $100/500g sample
  - Not water-based...

Etched Copper

Homespun Technology
portfolio
Crawford Bldg
Rm 212, JDCAD

- Copper-plated fiberglass
  - Used for electronic circuits
  - Etched in Ferric Chloride, just like copper etching plates



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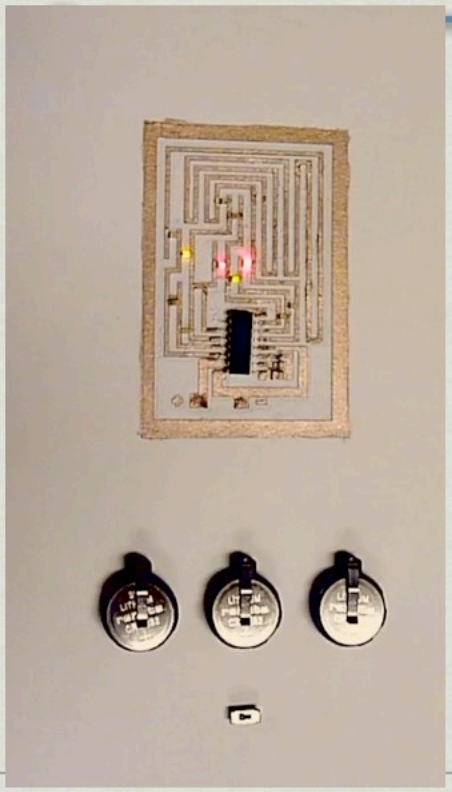
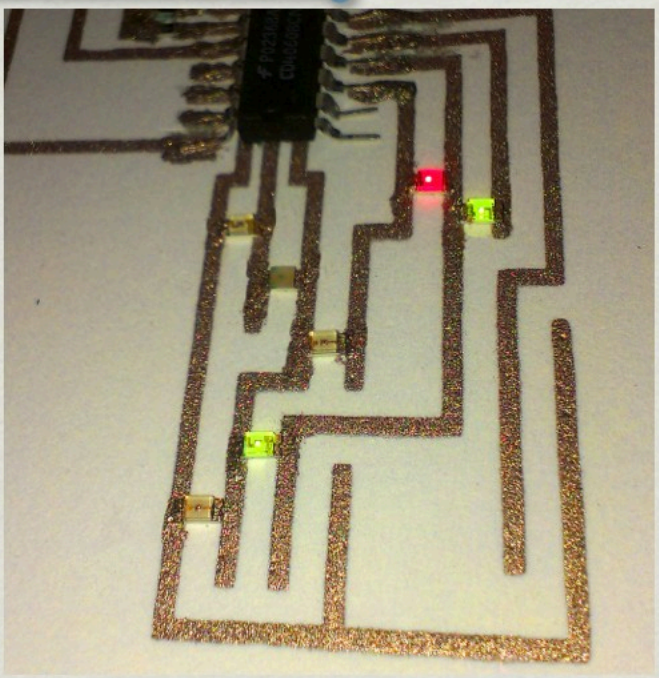
Gallery

Erik Brunvand





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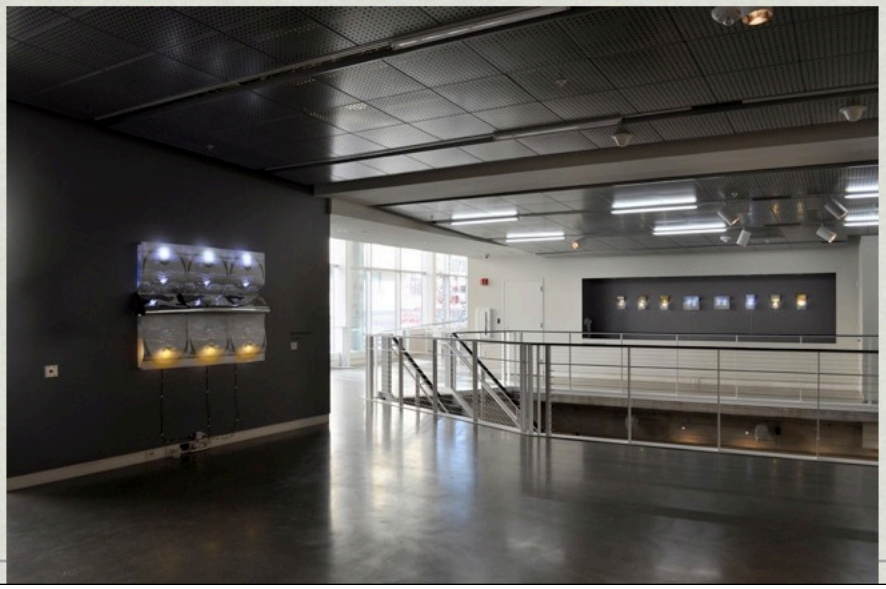
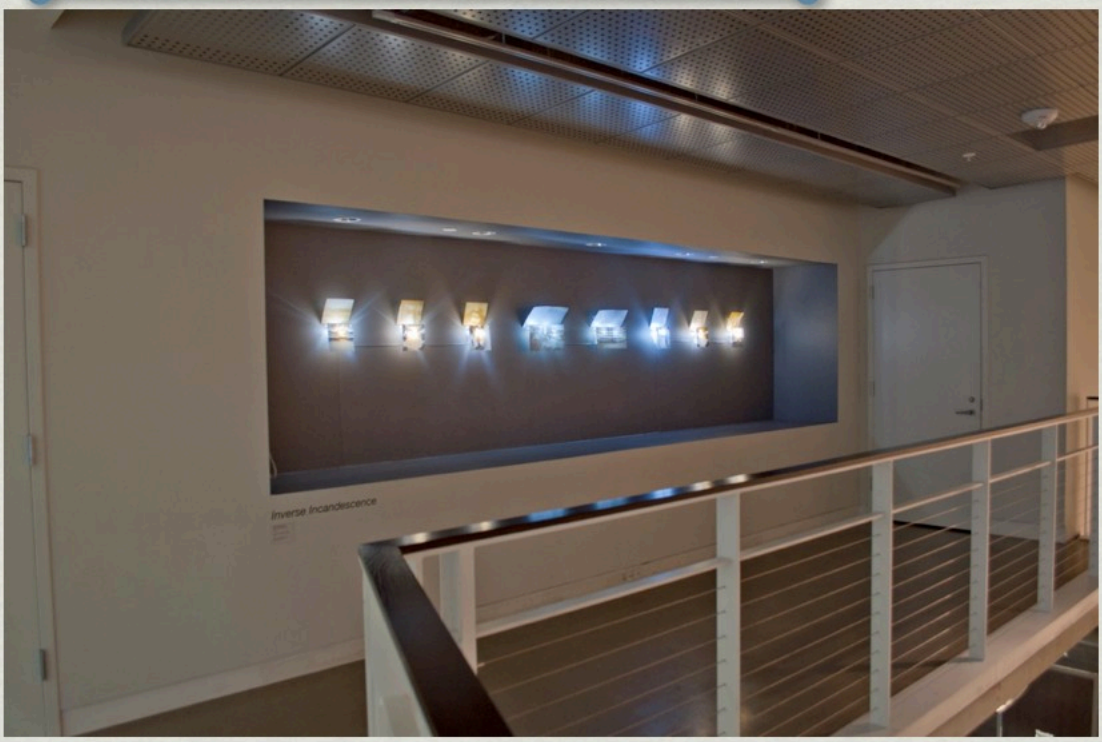
Erik Waterkotte

- Chimera and Inverse Incandescence
  - Exhibited at Utopia/Dystopia at the Urban Institute of the Contemporary Arts, Grand Rapids, MI, 2013



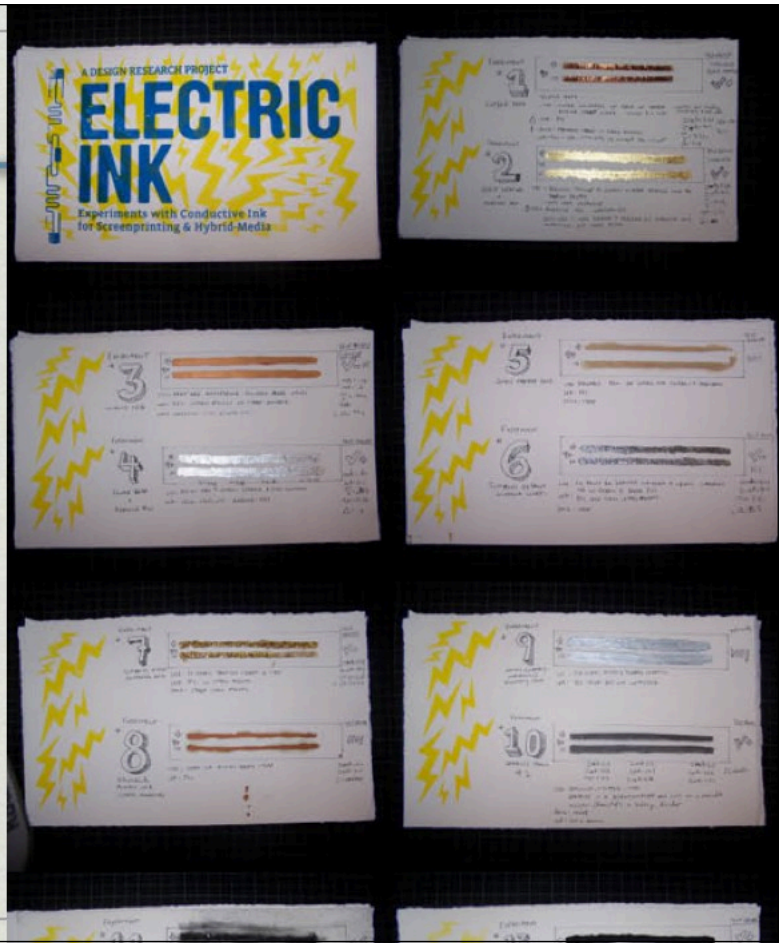
Erik Waterkotte



Erik Waterkotte

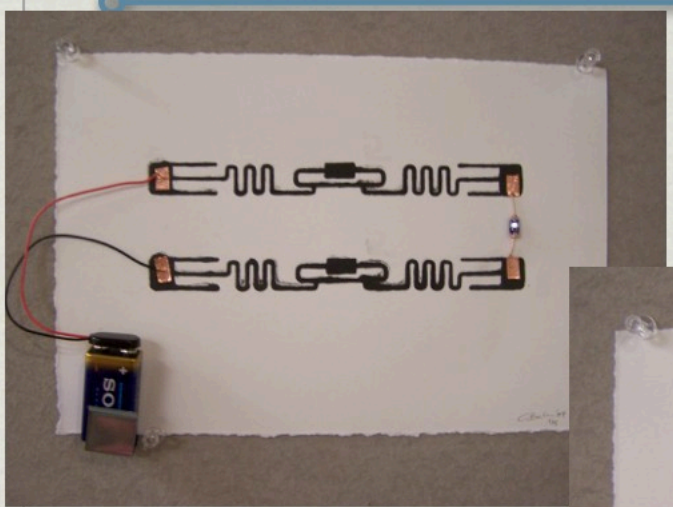
Chris R. Becker

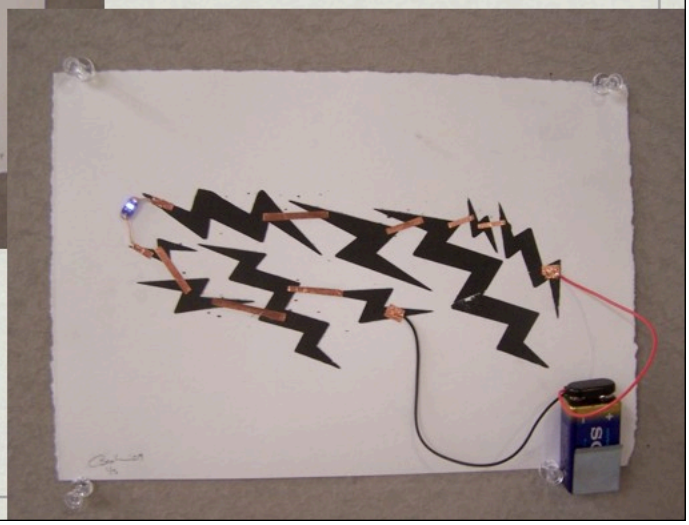
- UX designer
  - Huntington Beach, California
- Experiments with conductive ink
  - From student days at Art Center College of Design in Pasadena, CA (2009)



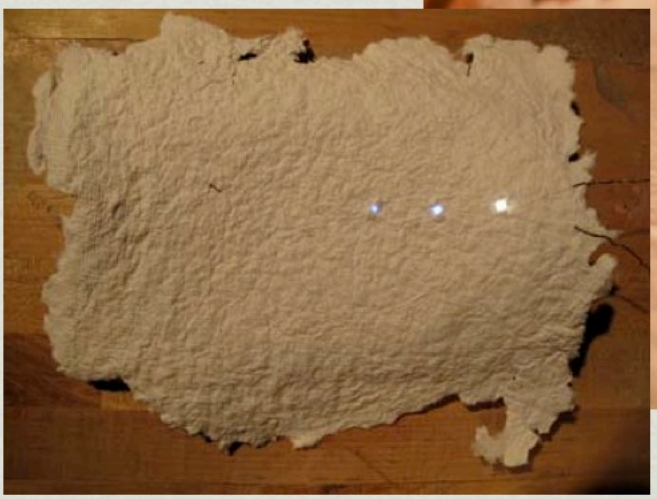
Chris Becker

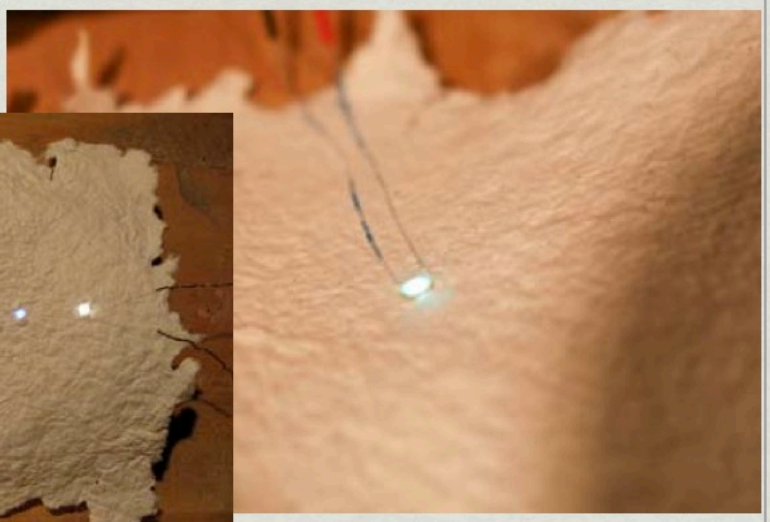
2009





Caroline Brown

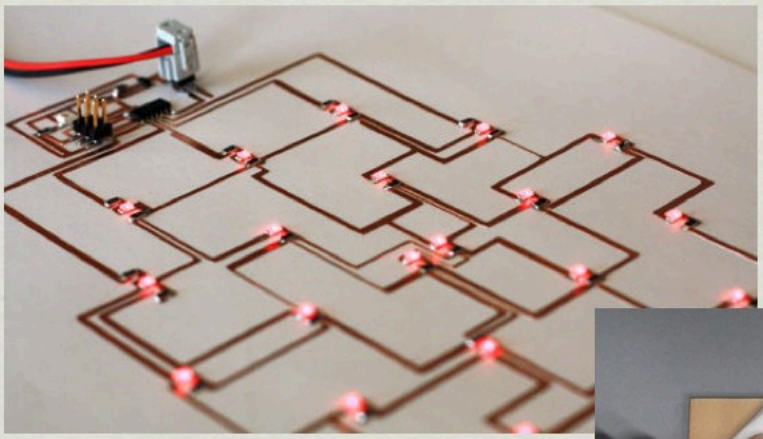


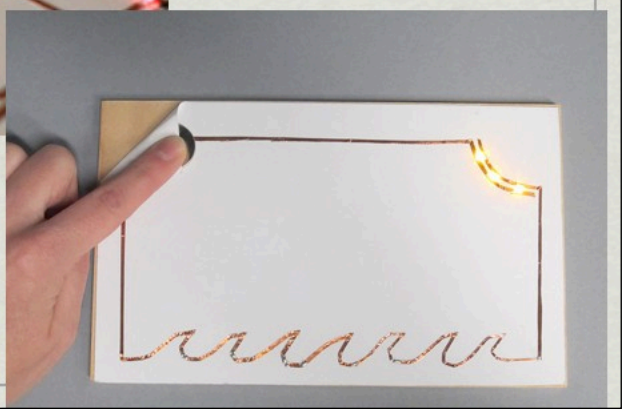


Student at ITP program at NYU

Tinkering Studio

Exploratorium, San Francisco, CA





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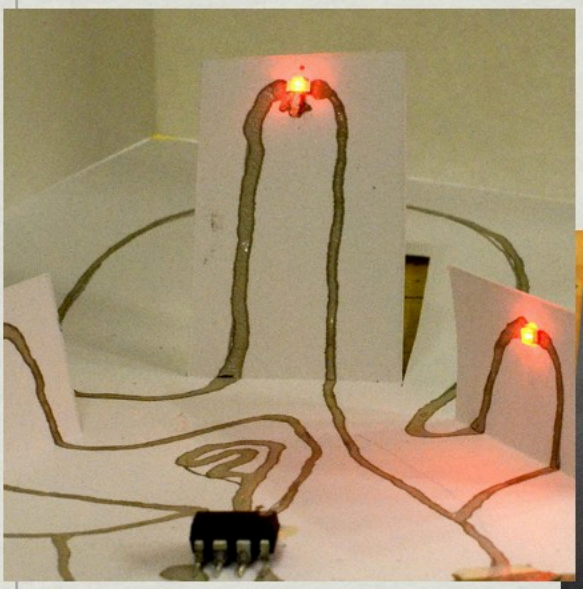

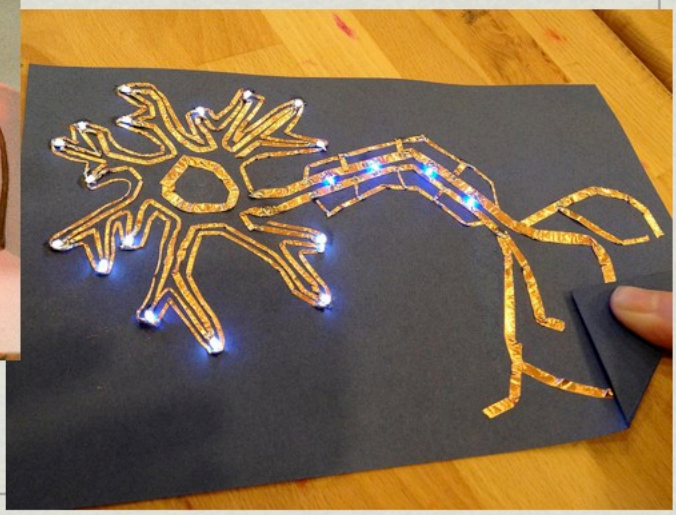

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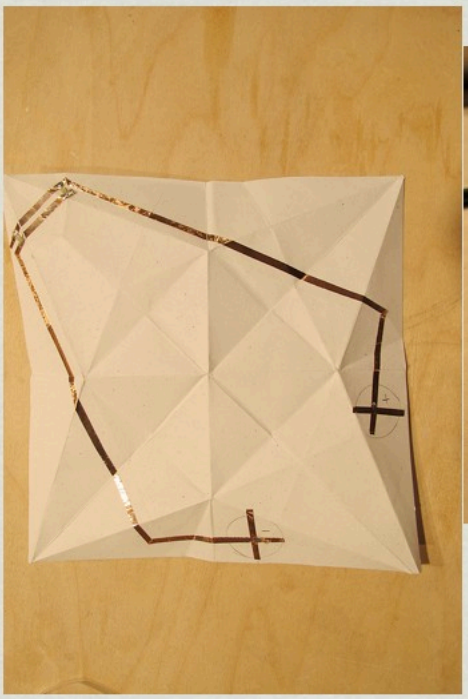
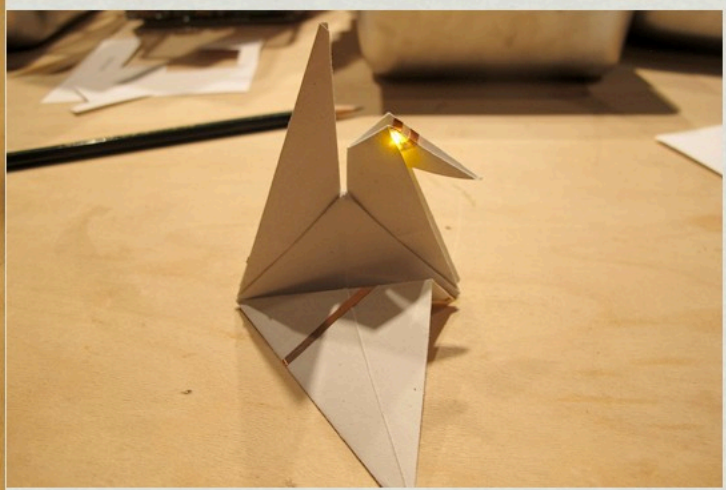
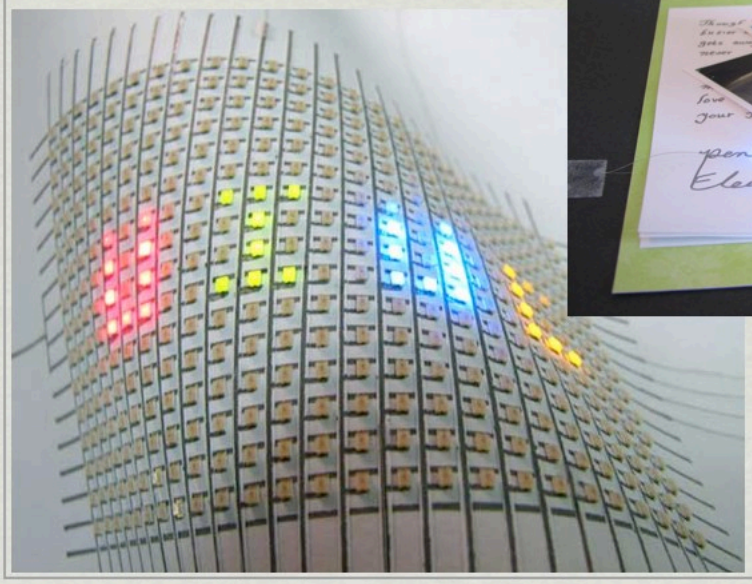




Jennifer Lewis (UIUC)



Silver-based ink
Made to go in a standard rollerball pen

Jennifer Lewis (UIUC)

Michael Shorter - DJCAD

- Printed electronics
  - Makes a "Theramin-like" musical instrument
- Workshop at Impact 8!
  - Saturday, 11:30, DJCAD
  - Conductive Ink Workshop: Making Paper Work

Conclusions

- Fascinating possibilities!
- Don't be intimidated!
  - Ink/Paint is a little expensive, but not terrible
  - Electronics can be very simple and effective
  - Electronic components (LEDs, resistors) are cheap
- Add some bling to your prints!

Erik Brunvand, elb@cs.utah.edu, www.cs.utah.edu/~elb

Materials Summary ($)

- Copper-based paint: CuCote
  - <1Ω/sq, copper metallic, **$30/4oz(118ml), $160/qt(946ml)**
    $0.25/ml in small can, $0.17/ml in qts
- Carbon-based paint: Bare Conductive
  - 50Ω/sq, black, **$30/50ml, or 10ml pen for $10**
    $0.72/ml in jar, $2/ml in pen
- Silver-Based Pen: CircuitWriter
  - 0.017Ω/sq, silver colored, **$20/5g** roughly $4/ml
- Nickel-based paint: SuperShield
  - 0.6Ω/sq, silver metallic, **$94/900ml** $0.10/ml

Materials Summary (£)

- Copper-based paint: CuCote
  - <1Ω/sq, copper metalic, **£20/4oz(118ml), £105/qt(946ml)**
    £0.16/ml in small can, £0.11/ml in qts
- Carbon-based paint: Bare Conductive
  - 50Ω/sq, black, **£18/50ml, or 10ml pen for £6**
    £0.47/ml in jar, £1.29/ml in pen
- Silver-Based Pen: CircuitWriter
  - 0.017Ω/sq, silver colored, **£13/5g** roughly £2.6/ml
- Nickel-based paint: SuperShield
  - 0.6Ω/sq, silver metalic, **£61/900ml** £0.06/ml

Information Sources

low-tech circuit DIY...

- *Erik Brunvand,*
  University of Utah and Saltgrass Printmakers
  - *elb@cs.utah.edu,* *www.cs.utah.edu/~elb*
- Kinetic Art and Embedded Systems class at Utah
  - www.eng.utah.edu/~cs5789/
- MIT Media Lab
  - High Low Tech: hlt.media.mit.edu/
  - Kit of No Parts: web.media.mit.edu/~plusea/
- ITP program at NYU Tutorials
  - itp.nyu.edu/physcomp/Tutorials/Tutorials

Information Sources

Electronic Components..

- *Erik Brunvand,*
  University of Utah and Saltgrass Printmakers
  - *elb@cs.utah.edu,* *www.cs.utah.edu/~elb*
- Sparkfun Electronics
  - www.sparkfun.com
- Adafruit Industries
  - www.adafruit.com
- Oomlout
  - oomlout.co.uk

Information Sources

Conductive Ink...

- *Erik Brunvand,*
  University of Utah and Saltgrass Printmakers
  - *elb@cs.utah.edu,* *www.cs.utah.edu/~elb*
- CuPro Cote - copper-based paint
  - www.lessemf.com/paint.html
- Bare Conductive - carbon-based paint
  - www.bareconductive.com
- Super Shield - nickel-based paint
  - www.mgchemicals.com
- CircuitWriter - silver-based pen
  - store.caig.com/s.nl/sc.2/category.174/.f