Micro/Nano Mechanical Systems
Lab – Class#8

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Outline

◆ Micro/nano technologies for energy storage
  • Lithium ion battery
  • Supercapacitor
    – Nanostructures for supercapacitors
      • Carbon nanotubes
      • Graphene
    – Design of working supercapacitors

◆ Lab #3 (Supercapacitors based on Laser Induced Graphene)
Super capacitor (I)

- Working principle
  - Electrochemical double-layer effect

Electrochemical Double Layer

Typical Electrode: Porous Carbon, Carbon nanotube, Graphene…

\[ C \approx \frac{A_{\text{interface}} \epsilon \epsilon_0}{d} \]

http://en.wikipedia.org/wiki/Supercapacitor
Supercapacitor (II)

- Working principle
  - Pseudo capacitive effect

Typical Electrode: **Metal Oxide, Conducting Polymer**…

\[
C(V) = \frac{dQ}{dV}
\]

http://en.wikipedia.org/wiki/Supercapacitor
Nanostructures for Supercapacitors

◆ Design of nanostructures for supercapacitors


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Carbon nanotubes & Graphene

Carbon nanotubes

Graphene

http://wiki.seg.org/wiki/Carbon
Carbon nanotubes (I)

- For supercapacitors electrodes
  - Reasonable surface area (100-500 m²/g)
  - High electrical conductivity
  - High mechanical and electrochemical stability – perfect scaffold
Vertically aligned carbon nanotubes (VACNT) for hybrid supercapacitor applications

- Grown on silicon and Fe/Al/Mo stacking layer
- Electrodeposition of nickel nanoparticles
- Specific capacitance of 1.26 F/cm³, 5.7 X higher than pure CNT

Carbon nanotubes (III)

- VACNT + ALD RuO$_2$

- Atomic layer deposition (ALD) of ruthenium oxide
- Specific capacitance of 644 F/g
- 170 X higher than pure CNT

Carbon nanotubes (IV)

- VACNT + ALD TiS$_2$

- Atomic layer deposition (ALD) of titanium disulfide
- Specific capacitance of 195 F/g, 3V in aqueous electrolyte
- 60.9 Wh/kg

Graphene properties

- **Charge carrier mobility**: ~200,000 cm²/V s
- **Thermal conductivity**: ~5000 W/m K
- **Transparency**: ~97.4%
- **Specific surface area**: ~2630 m²/g
- **Young’s modulus**: ~1 TPa
- **Tensile strength**: ~1100 GPa
Graphene production

- Mechanical exfoliation from graphite
- Chemical vapor deposition
- Reduction from graphite oxide
- Produced from polymer

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Graphene production

◆ Reduction from graphite oxide

- Graphite oxide: compound of carbon, oxygen, and hydrogen in variable ratios
- 0.7~1.1 nm between layers (0.335 nm for graphite)
- Weak van der Waals bonds
- Hydrophilic


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Graphene production

- Reduction from graphite oxide by laser


- High conductivity: 1700 S/m,
- High surface area: 1500 m²/g
  (2600 m²/g for ideal graphene)

Graphene production

♦ Reduction from polymer by laser

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Design of working supercapacitors

- Electrode configurations for supercapacitors
  - In-plane vs. sandwich

Design of working supercapacitors

- On-chip micro supercapacitors
Design of working supercapacitors

- Electrode configurations for supercapacitors
  - Coaxial fiber

Design of working supercapacitors

- Electrode configurations for supercapacitors
  - Woven fabrics

Design of working supercapacitors

◆ Electrode configurations for supercapacitors
  • Woven fabrics

Lab #3

◆ Supercapacitors based on laser induced graphene
  • Design your own electrode pattern (before the lab!)
  • Discuss with GSI to verify the pattern
  • Scribe out the pattern on polymer using laser
  • Apply polymer based electrolyte
  • Make electrical connection, charge and light up a LED

◆ In your reports
  • Introduction
  • Electrode pattern design
  • Results (photo of the device, charging process, powering a LED for how long)
  • Discussion (Capacitance, voltage, how to optimize)
Lab #3 – Instruction (I)

◆ Instructions to pattern design

1. Draw your pattern using PPT (recommended), and save the pattern as .jpg file

2. Use black blocks to build the pattern, check the size, limit all patterns within a 2” x 2” or 5cm x 5cm square, the smallest feature size should be >0.02” or 0.5mm
Lab #3 – Instruction (II)

◆ Instructions to pattern design

3. Copy your pattern, then
   – Use a semi-transparent color to indicate areas to be covered with electrolyte
   – Use another color to indicate areas used for electrical contact
   – Use dashed lines to indicate lines to be cut
Lab #3 – Instruction (III)

◆ Instructions to pattern design

4. Send the original design pattern and colored pattern to GSI before the lab through the email: shencw10@berkeley.edu

5. GSI will comment on the designs before printing them out using laser