Biologically-derived Materials for Powering Next Generation Biomedical Electronics

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Implantable biomedical devices

**Tissue stimulation**
- Stimulate deep brain for treating obesity

**Biosensor**
- Monitor pH, T, and glucose

**Controlled release**
- Deliver drugs
Challenges with implantable devices

- Infection
- Chronic inflammation
- Costly surgeries
- Replace batteries

What if we could build the devices...

- Reduce infection risk
- Temporary deployment
- Effective and efficient batteries
Why Edible Electronics?

*Most people feel comfortable with taking pills.*

- Balance of functional device lifetime with rapid deployment
- Non-invasive, high patient compliance
- Reduced sterilization burden
- Obviate issues associated with chronic implants
## Device comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>Helius (Proteus Biomedical)</th>
<th>PillCam (Given Imaging)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indication</strong></td>
<td>Monitor compliance</td>
<td>Non-invasive imaging</td>
</tr>
<tr>
<td><strong>Function</strong></td>
<td>Trigger, communication</td>
<td>Image acquisition, transfer</td>
</tr>
<tr>
<td><strong>Device lifetime</strong></td>
<td>~10 min</td>
<td>~8 hr</td>
</tr>
<tr>
<td><strong>Power source</strong></td>
<td>Mg-Cu galvanic cell</td>
<td>2 x 1.5V Ag2O batteries</td>
</tr>
<tr>
<td><strong>Logic elements</strong></td>
<td>Silicon</td>
<td>Silicon</td>
</tr>
<tr>
<td><strong>Packaging</strong></td>
<td>None</td>
<td>Polycarbonate</td>
</tr>
<tr>
<td><strong>Size (D x L)</strong></td>
<td>2 mm x 23 mm</td>
<td>11 mm x 26 mm</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>0.003 g</td>
<td>3.45 g</td>
</tr>
<tr>
<td><strong>Retention risk</strong></td>
<td>0.001%</td>
<td>1.47%</td>
</tr>
</tbody>
</table>

**Website Links:**
- [Proteus Biomedical: www.proteus.com](http://www.proteus.com)
- [Given Imaging: www.givenimaging.com](http://www.givenimaging.com)
Edible Battery

- Operated by $Na^+$ in gastric fluid
- Made of edible materials
- Temporary
- Non-invasive

Cathode: $MnO_2$

Anode: Activated carbon

Electrically-conductive elastomer
Ideal electrodes for edible electronics

Reliability
+ Long operational lifetimes
+ Robust performance
+ Manufacturing

Safety
+ Possible bioabsorption
+ Reduced risk of event
+ Materials of known risk

=
Inspired by *cuttlefish* ink
Eumelanins from cuttlefish (*sepia officinalis*)

- Homogeneous nanostructure (diameter = ~100nm)
- Stable (non-soluble) in aqueous solution
- Hydration dependent electronic-ionic hybrid conductivity
Eumelanins in multi-scale

Length scale (m)

- $10^{-6}$
- $10^{-9}$
- $10^{-12}$

Micron

Nano

Supramolecular

Molecular

Chemical structure of a molecule

Imaging scale:
- 5 µm
- 50 nm
- 5 nm
Is eumelanin a viable solution?

Activated carbon anode
MnO\textsubscript{2} cathode

Melanin anode
MnO\textsubscript{2} cathode

Specific Capacity (mAh/g):
- Activated carbon: ~10
- Melanin: ~20
Can we tune the capacity?

- **Activated carbon** anode
  - MnO$_2$ cathode
  - ~10

- **Melanin** anode
  - MnO$_2$ cathode
  - ~20

- **Synthetic Melanin Electrode**
  - ~?

Specific Capacity (mAh/g)
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Background & Motivation

Edible electronics biomedical devices

1. Controlled release Monitoring
   - Monitoring concentration
   - Patient needs to ingest physiological

2. Size-dependent gastric emptying
   - Stomach: 30 mL
   - Intestine: 1.5 L
   - stool: 150 mL
   - Intestine + stool: 200 mL

3. Monitor function of cells in GI tract
   - Helix (Novel Biomedical)
   - Helix (Novel Biomedical)
   - Helix (Novel Biomedical)

4. Relay information on biomarkers to external devices
   - Protonic device
   - Protonic device
   - Protonic device

Size-dependent gastric emptying

Edible batteries

Powered by aqueous Na+ batteries
Electrically conductive polymer:
Starch + Polycylic acid + Citric acid + Na+ nanowire
Battery electrodes:
Activated carbon anode/MnOx cathode

Results

Bio-derived materials for E-storage

- Sepia officinalis
- Adalatine

Galvanostatic Charge-Discharge

- Can we increase the capacity by controlling the topography?

Synthetic anode

Synthetic anode with peptide template

Discussion

Topography-controlled biomaterials

Melanin Synthesis using tripeptide template

- Scanning Electron Microscopy
- Raman spectroscopic characterization

Future Outlook

- Eumelanins can be used as Na+ charge storage materials within aqueous environment
- Controlling topographies using peptide template can improve the charge storage capacities of eumelanins.
Thank you