Miniature power sources - emerging technologies for powering IoT and autonomous systems

Tuvia Liran
Nano Retina Ltd.
Outline

• Available miniature power sources
• Categorizing batteries
• Solid State Battery
• Super capacitors
• Nuclear batteries
The need for miniature batteries

- Wireless sensors (IoT)
- Remote controllers & RTC
- Implantable medical devices
- Watches
- Under water systems
- Active smart cards
- RFID
- Memory backup
Definition of miniature batteries

• Batteries that can be assembled with ASICs, without significant increase of package size

• Typical characteristics:
  – Area – <200mm²
  – Thickness - <<1mm
  – Weight - <100mg
  – Assembly – wirebond/bumping/soldering
  – Low loss
  – Long cycle life / many re-charging cycles
  – Compatibility – RoHS compliant, low outgassing,
Categorizing battery technologies

- Solid state
- Rechargeable
- Fuel cells
  - Non-rechargeable
- Zinc-air
  - Lithium Batteries
    - Li-ion
    - Li-polymer
- Ni-MH
- Na-MCl₂
- Lead-Acid
- Ni-Zn

Gravimetric Energy Density (Wh/kg)

Volumetric Energy Density (Wh/l)

ChipEx 2016

May 9, 2016
Energy harvesting technologies

- Energies that might be harvested

<table>
<thead>
<tr>
<th>Energy</th>
<th>Source</th>
<th>Device</th>
<th>DC/AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical/EM</td>
<td>Light, IR, EM</td>
<td>Photovoltaic, antenna</td>
<td>DC</td>
</tr>
<tr>
<td>Kinetic</td>
<td>Wind, motion, vibration, hydro</td>
<td>Turbine, piezoelectric, MEMS,</td>
<td>AC</td>
</tr>
<tr>
<td>Temperature</td>
<td>Temp gradient</td>
<td>Temp sensors</td>
<td>DC</td>
</tr>
<tr>
<td>Biochemical</td>
<td>Glucose, etc.</td>
<td></td>
<td>DC</td>
</tr>
</tbody>
</table>

- Optical energy is the most effective
- DC-DC or AC-DC converters degrades efficiency
- Energy should be stored in battery/capacitor
Power of portable applications

- WSN
- Sleep Process Transmit
- Increasing use of EH
- 100 mW
- 10 mW
- 1 mW
- 100 μW
- 10 μW
- 1 μW
- 100 nW
- 10 nW
- Standby
- RFID Tag
- Electronic watch or calculator
- 32 KHz quartz oscillator
- Battery: AA or AAA
- Large rechargeable
- μP desktop
- μP laptop
- Bicycle lighting
- GSM
- PALM, MP3
- Transceiver Bluetooth
- Miniature FM Receiver
- Hearing aid
- Standby

May 9, 2016
Comparing battery technologies

- Total power
- Specific energy (Wh/g)
- Energy density (Wh/l)
- Shelf life
- Life cycle / re-charge
- Charging rate
- Cost per Wh
- Safety
- Environmental conditions
- Operation temperature
Solid state batteries (SSB)

• Re-chargeable
• Li PON dielectric (Li ion)
• Voltage: 3-4V
• Capacity: <1mAh
• Very high charge density

• Miniature
• Safe
• Eco friendly
• Long life
• Wide temperature range
SSB packaging solutions

- Bare die + bondwire/bumps
- Packaged w RTC/PM
- Stacked
- MCM
- SMD
- Flexible (some vendors)
Examples of miniature applications

Medical patches

1mm³ Intraocular Pressure Monitor
Cymbet/enerchip

- Silicon substrate
- Die/package
- Bondable

**Operating Characteristics - CBC005**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITION</th>
<th>MIN</th>
<th>TYPICAL</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge Cutoff Voltage</td>
<td>25 °C</td>
<td>3.0(1)</td>
<td>-</td>
<td>-</td>
<td>V</td>
</tr>
<tr>
<td>Charge Voltage</td>
<td>25 °C</td>
<td>4.0(2)</td>
<td>4.1</td>
<td>4.3</td>
<td>V</td>
</tr>
<tr>
<td>Pulse Discharge Current</td>
<td>25 °C</td>
<td>Variable - see App. Note 1025</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-Discharge (5-yr. average; 25 °C)</td>
<td>Non-recoverable</td>
<td>-</td>
<td>2.5</td>
<td>-</td>
<td>% per year</td>
</tr>
<tr>
<td></td>
<td>Recoverable</td>
<td>-</td>
<td>1.5(3)</td>
<td>-</td>
<td>% per year</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-</td>
<td>-40</td>
<td>25</td>
<td>+70</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>-</td>
<td>-40</td>
<td>-</td>
<td>+125(4)</td>
<td>°C</td>
</tr>
<tr>
<td>Cell Resistance (25 °C)</td>
<td>Charge cycle 2</td>
<td>-</td>
<td>7</td>
<td>11</td>
<td>kΩ</td>
</tr>
<tr>
<td></td>
<td>Charge cycle 1000</td>
<td>-</td>
<td>30</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Recharge Cycles (to 80% of rated capacity; 4.1V charge voltage)</td>
<td>25 °C</td>
<td>10% depth-of-discharge</td>
<td>5000</td>
<td>-</td>
<td>cycles</td>
</tr>
<tr>
<td></td>
<td>50% depth-of-discharge</td>
<td>-</td>
<td>1000</td>
<td>-</td>
<td>cycles</td>
</tr>
<tr>
<td></td>
<td>40 °C</td>
<td>10% depth-of-discharge</td>
<td>2500</td>
<td>-</td>
<td>cycles</td>
</tr>
<tr>
<td></td>
<td>50% depth-of-discharge</td>
<td>-</td>
<td>500</td>
<td>-</td>
<td>cycles</td>
</tr>
<tr>
<td>Recharge Time (to 80% of rated capacity; 4.1V charge voltage; 25 °C)</td>
<td>Charge cycle 2</td>
<td>-</td>
<td>11</td>
<td>22</td>
<td>minutes</td>
</tr>
<tr>
<td></td>
<td>Charge cycle 1000</td>
<td>-</td>
<td>45</td>
<td>70</td>
<td>minutes</td>
</tr>
<tr>
<td>Capacity</td>
<td>40nA discharge; 25 °C</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>μAh</td>
</tr>
</tbody>
</table>

Silicon die

Packaged with power management die
Front edge technology/NanoEnergy®

- Ultra thin
- Safe & environmentally friendly
- Long cycle life
- High current charge
- Flexible form factor
- Low self-discharge
- Bendable

- 50u thick
- Stackable
- Flexible

As thin as 0.05 mm (0.002 inch) including package.
All solid-state, using ceramic electrolyte LiPON developed by Oak Ridge National Laboratories. Contains no liquid or environmental hazardous material.
More than 1,000 cycles at 100% depth discharge.
Can be charged to 70% of rated capacity in 2 minutes.
Can be discharged at rates of more than 10 C.
Can be made into different shapes and sizes.
Less than 5% per year.
Can be bent and twisted without damage.
Other SSB vendors

- Johnson Battery Technology
- Excellatron Solid state
- Bellcore
- Infinite Power Solutions
- Planar Energy
- Honeycomb Battery (Israel)
- .....
Power management for SSB

- Charger/DC-DC converter for charging
- LDO/DC-DC converter for discharge
- Over-voltage protection during charging
- Under-voltage protection during discharging
- Charge monitor

Power management devices are available
Super capacitor

• **Key advantages WRT SSB**
  – Virtually unlimited cycle life
  – Fast charging
  – Simple charging to any voltage
  – Safe - forgiving if abused

• **Key limitations WRT SSB**
  – Limited capacity
  – Linear discharge voltage
  – High self-discharge
  – Higher cost per watt
Nuclear batteries

- Concept – photovoltaic that is stimulated by nuclear sources:
  - Alphavoltaics
  - Betavoltaics
  - Gamavoltavics
Betavoltaics Tritium battery

- Tritium = $^3$H (isotope of Helium)
- Available from nuclear waste
- Radioactive – half life is 12.3 years
- Decay equation: $(e^- = 18.6\text{KeV}) \quad ^3_1T \to ^3_2\text{He}^{1+} + e^-$
- $e^-$ converted to energy by photovoltaic
- Compounded in tritides (titanium, scandium)
- Power - $<<1\mu W$
- Lifetime – 10÷20 years
- Safety – considerable for medical
- Prices – hundreds of USD
Applications of Tritium batteries

- Environmental pressure/temperature sensors
- Intelligence sensors
- Medical implants
- Semi-passive and active RFID
- Silicon clocks
- SRAM memory backup
- Deep-sea oil well sensors
- ...

May 9, 2016
Summary

• Miniature batteries are available
• Implementing autonomous systems is doable
• High improvement rate in all types of battery technologies
• Optimal implementation includes:
  – Efficient battery
  – Ultra low power system
  – Battery management