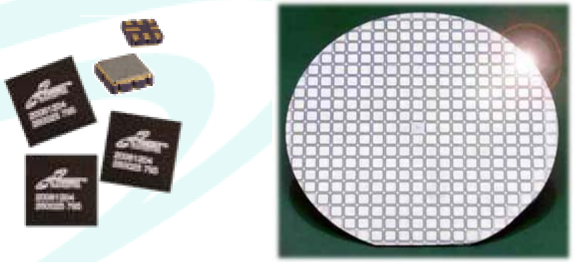
CYMBET™
CORPORATION

Small Energy Sources

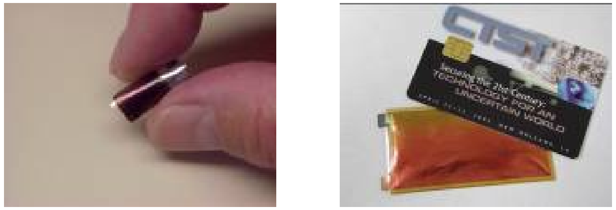
- Currently available sources
  - Scaling rules
    - Available current
    - Available power
- Other important issues
  - Internal resistance
  - Voltage selection
  - I/O, encapsulation
- Manufacturability
  - High-volume, low cost devices

Solid State Energy

- Unique energy source:
  - Scaleable - chips to flex
  - Rechargeable
  - Permanent
  - Lightweight
  - Environmentally friendly
  - Safe & flexible
- Enables unique, permanent, self-powered systems



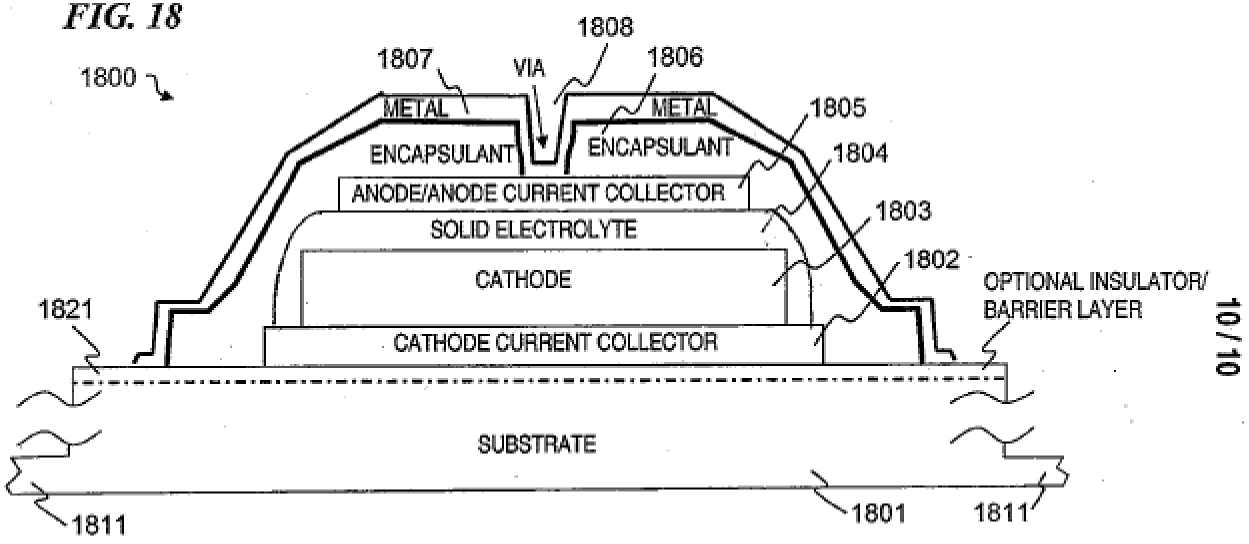
IC Packaging &
Bare Die



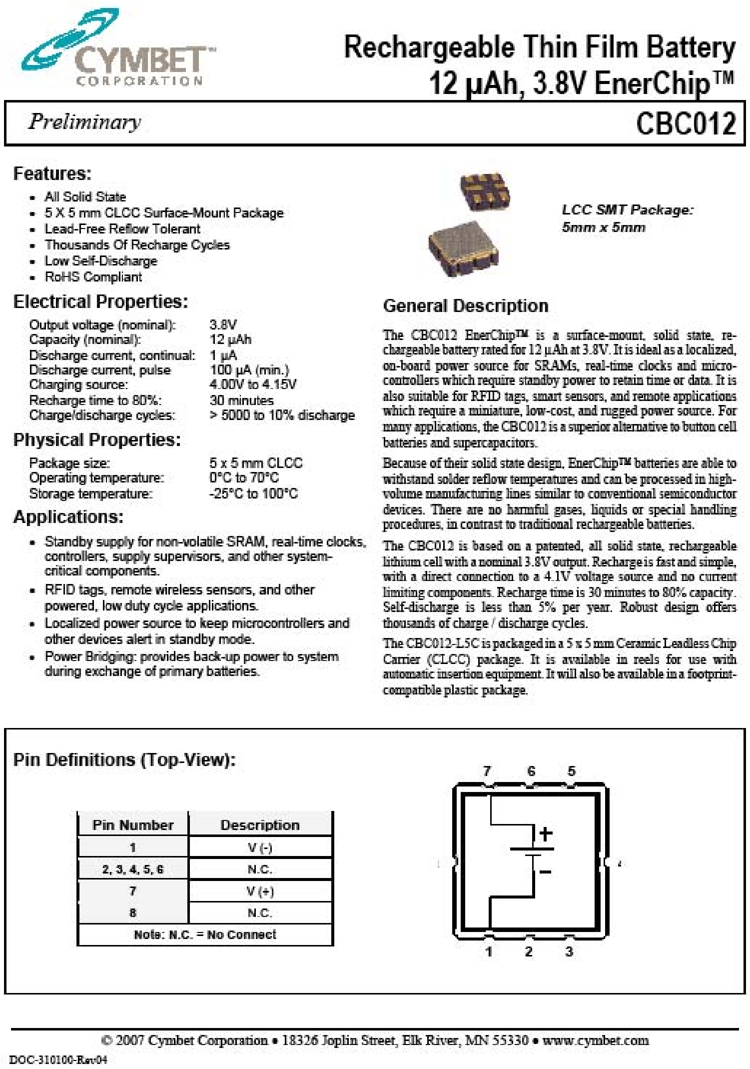
Flat/Flex

Typical Solid State Battery

FIG. 18



Small, Commercially Available Rechargeable Batteries



Rechargeable Thin Film Battery
12 µAh, 3.8V EnerChip™

Preliminary **CBC012**

Features:

- All Solid State
- 5 X 5 mm CLCC Surface-Mount Package
- Lead-Free Reflow Tolerant
- Thousands Of Recharge Cycles
- Low Self-Discharge
- RoHS Compliant

LCC SMT Package:
5mm x 5mm

Electrical Properties:

Output voltage (nominal):	3.8V
Capacity (nominal):	12 µAh
Discharge current, continual:	1 µA
Discharge current, pulse	100 µA (min.)
Charging source:	4.00V to 4.15V
Recharge time to 80%:	30 minutes
Charge/discharge cycles:	> 5000 to 10% discharge

Physical Properties:

Package size:	5 x 5 mm CLCC
Operating temperature:	0°C to 70°C
Storage temperature:	-25°C to 100°C

Applications:

- Standby supply for non-volatile SRAM, real-time clocks, controllers, supply supervisors, and other system-critical components.
- RFID tags, remote wireless sensors, and other powered, low duty cycle applications.
- Localized power source to keep microcontrollers and other devices alert in standby mode.
- Power Bridging: provides back-up power to system during exchange of primary batteries.

General Description

The CBC012 EnerChip™ is a surface-mount, solid state, rechargeable battery rated for 12 µAh at 3.8V. It is ideal as a localized, on-board power source for SRAMs, real-time clocks and microcontrollers which require standby power to retain time or data. It is also suitable for RFID tags, smart sensors, and remote applications which require a miniature, low-cost, and rugged power source. For many applications, the CBC012 is a superior alternative to button cell batteries and supercapacitors.

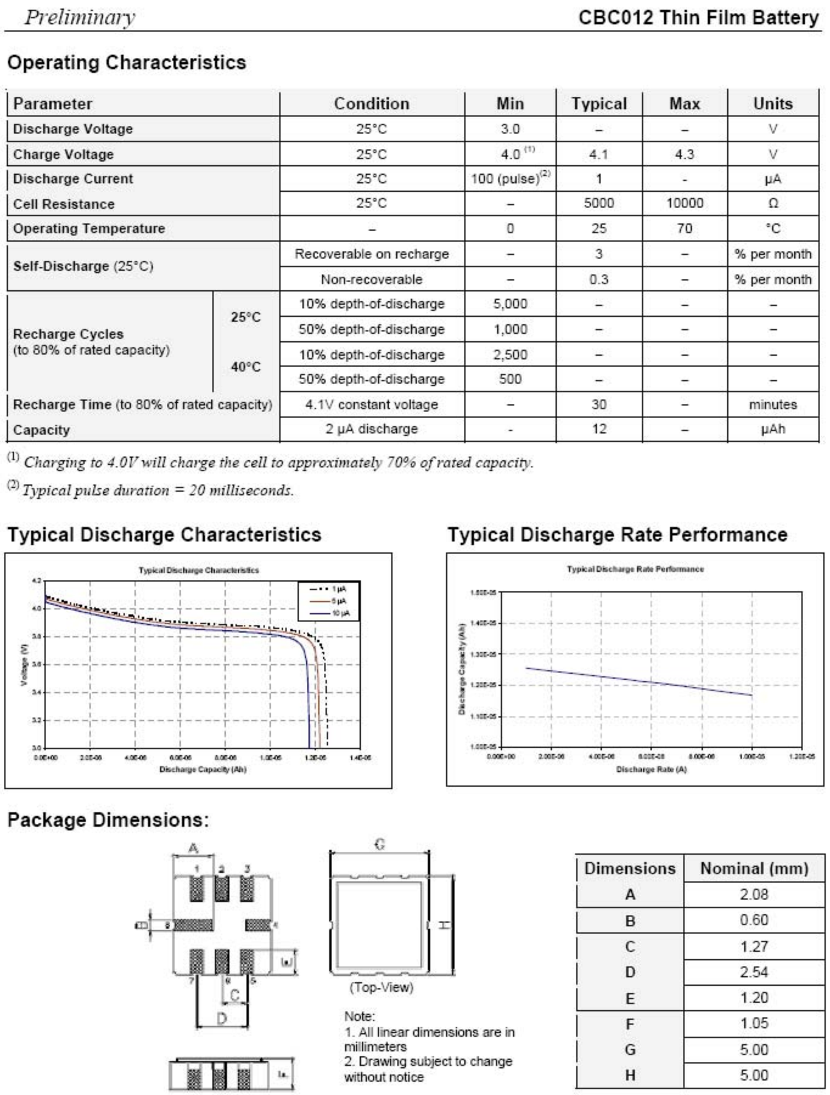
Because of their solid state design, EnerChip™ batteries are able to withstand solder reflow temperatures and can be processed in high-volume manufacturing lines similar to conventional semiconductor devices. There are no harmful gases, liquids or special handling procedures, in contrast to traditional rechargeable batteries.

The CBC012 is based on a patented, all solid state, rechargeable lithium cell with a nominal 3.8V output. Recharge is fast and simple, with a direct connection to a 4.1V voltage source and no current limiting components. Recharge time is 30 minutes to 80% capacity. Self-discharge is less than 5% per year. Robust design offers thousands of charge / discharge cycles.

The CBC012-L5C is packaged in a 5 x 5 mm Ceramic Leadless Chip Carrier (CLCC) package. It is available in reels for use with automatic insertion equipment. It will also be available in a footprint-compatible plastic package.

Pin Definitions (Top-View):

Pin Number	Description
1	V (-)
2, 3, 4, 5, 6	N.C.
7	V (+)
8	N.C.
Note: N.C. = No Connect	



Operating Characteristics

Parameter		Condition	Min	Typical	Max	Units
Discharge Voltage		25°C	3.0	–	–	V
Charge Voltage		25°C	4.0 (1)	4.1	4.3	V
Discharge Current		25°C	100 (pulse)(2)	1	-	µA
Cell Resistance		25°C	–	5000	10000	Ω
Operating Temperature		–	0	25	70	°C
Self-Discharge (25°C)		Recoverable on recharge	–	3	–	% per month
		Non-recoverable	–	0.3	–	% per month
Recharge Cycles (to 80% of rated capacity)	25°C	10% depth-of-discharge	5,000	–	–	–
		50% depth-of-discharge	1,000	–	–	–
	40°C	10% depth-of-discharge	2,500	–	–	–
		50% depth-of-discharge	500	–	–	–
Recharge Time (to 80% of rated capacity)		4.1V constant voltage	–	30	–	minutes
Capacity		2 µA discharge	-	12	–	µAh

(1) *Charging to 4.0V will charge the cell to approximately 70% of rated capacity.*

(2) *Typical pulse duration = 20 milliseconds.*

Typical Discharge Characteristics

Typical Discharge Rate Performance

Package Dimensions:

(Top-View)

Note:
1. All linear dimensions are in millimeters
2. Drawing subject to change without notice

Dimensions	Nominal (mm)
A	2.08
B	0.60
C	1.27
D	2.54
E	1.20
F	1.05
G	5.00
H	5.00

Battery Metrics

- Specific Energy
  - W·hr/kg (W·hr = V·Ahr)
    - Larger values = lighter batteries
    - A measure of how much energy is stored
- Energy Density
  - W·hr/L
    - Larger values = smaller batteries
- Power Density (Specific Power)
  - W/kg
    - How much energy can be delivered

Other Energy Devices

- Not Covered Here
- To be covered tomorrow
  - Fuel Cells
    - MeOH, H_2
    - Reaction with O_2 to produce *e*-
    - Very stable, long term operation with sufficient fuel
    - Miniaturization?
- *In vivo* sources
- Chemical Fuel (gasoline)
  - 45 mJ/μg
  - 8.76 pW·hr/μm^3 – 31.5 nW·s/μm^3

Scaling

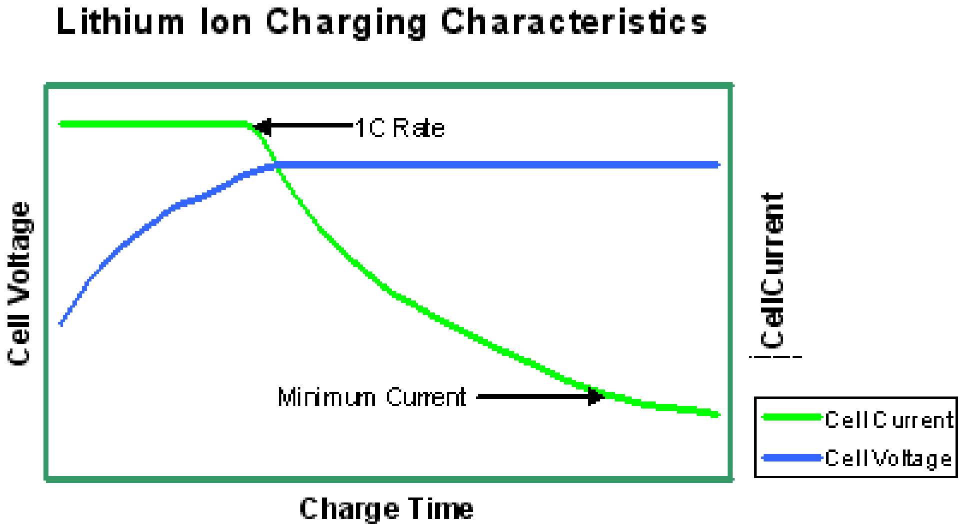
- Most solids are ~ 5×10^{22} atoms/cm^3
  - 5×10^{10} atoms/μm^3
- If all are ions (e.g. Li^+)
  - 10 nC/μm^3
  - Gravimetric (based on density) 7.4 nC/μm^3
- $LiCoO_2$ (common battery material)
  - 69 μA·hr/cm^{2}μm
  - If device (cathode) is 10μm x 10μm x 1μm
    - 69 pA·hr = 248 nA·s (250 nC)
- Increasing the valence change (more e^- transfer per atom) helps
  - Copper oxide has $2e^-$ transfer, 15 nC/μm^3 (6X that of $LiCoO_2$)

Resistance

- Internal resistance of battery limits current
  - Small objects have high resistance
- R = ρL/A
  - For the 10μm x 10μm x 1μm device
    - $R = 10^4 \rho$
  - Typical resistance could be 1 - 10MΩ
    - Current limiting: 3V, 3MΩ = 1μA
    - If 250 nC, then 0.25 μA for 1 s
      - Theoretical limit is 4X higher
    - 3 μW for 1s (Probably lower power for longer time)
  - Resistance is also a function of discharge rate
    - Temperature also affects capacity
    - The higher the discharge rate, the lower the capacity

Battery Charging

- Charging and discharging limited by ion diffusion
  - More complicated than RC time constant



Select Operating Voltage with Materials

Need to select voltage to avoid costly V_{dc} - V_{dc} conversion

Materials	$LiCoO_2/ Li_4Ti_5O_{12}$	$LiFePO_4/ Li_4Ti_5O_{12}$
Voltage	2.3 V	1.9 V
Energy Density	60-80 W·hr/kg 0.22 – 0.29 mW·s/μg	40-60 W·hr/kg 0.14 – 0.29 mW·s/μg
Volumetric Energy Density	150 W·hr/L 0.54 mW·s/μL	100 W·hr/L 0.36 mW·s/μL

More Scaling issues

- A 10 x 10 x 10 μm device is 1000μm^3.
  - Average densities are between 2 and 10g/cm^3.
    - Entire device might weigh 10 ng
    - 10 mg contains 10^6 devices!
      - A reasonable "dose"?
    - Redundancy, statistics and bioinformatics
  - 200 mm dia. Substrate = $\pi \times 10^{10}\ \mu m^2$
    - More than 10^6 devices could be made simultaneously

Other Battery Issues

- Focused on cathode materials
  - For Li^+, it is the source of energy
- Need anode
  - Intercalating materials often used
    - Reduces physical strain in the battery
    - Typically same thickness as cathode
- Need electrolyte and/or separator
  - Smallest device probably would use solid electrolyte
- Encapsulation may be the most important issue
  - Battery materials typically not compatible with water
  - Could be the largest component of the device

Energy Harvesting for Recharging

- Will devices be used more than once?
  - If so – must recharge battery
- Photovoltaic, Thermoelectric, Piezoelectric
  - Current uses
    - Remote sensing
    - RFID tag
    - Temporary back-up
  - Added components needed
- *In vivo* energy sources?
- Wireless inputs?

In Body Wireless*

- MICS band
  - 402 – 405 MHz, 300kHz bandwidth
    - Needs a very large antennae
  - 10 cm communication distance
  - 25 mW maximum power output
- Conventional devices
  - “ultra-low power” 500nA sleep
  - Much less than 1 μA leakage needed, preferably <1nA
  - Transmit – 1 mA
- Non rechargeable
  - Pacemakers
- Rechargeable
  - Cochlear implants
- Take home number – 1mA for 1s

*embedded.com

Conclusions

- Target cathode size – 10 x 10 x 1 μm
  - Best aspect ratio for known mfg. techniques
  - Total size - 10 x 10 x 10 μm
- Upper limit – 10 μW for 1s (100 nW for 100s)
  - Cannot predict charge and discharge rate for such small devices
  - May need additional capacitor if higher current is required
  - Rechargeable (Energy harvesting)
    - 10 – 1000 recharge cycles
    - Requires additional circuitry
- Need to select operating voltage
  - 1.5 – 4 V
  - Avoid costly conversion
- May only be enough energy to store information, not transmit