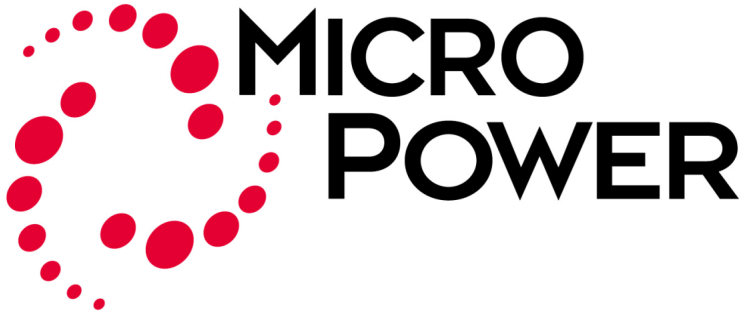


Safe Battery Design

Agenda

- About Micro Power
- Introduction
- Anatomy of a Portable Battery Pack
- Analysis of Recent Failures of Battery Packs
- Safety Aspects of Lithium Cells
- Design Considerations for Safe Battery Packs
  - Protection with Authentication
  - Electronics and Circuit Board Design
  - Pack Enclosure
  - Production and Manufacture
- Question and Answer

About Micro Power Electronics

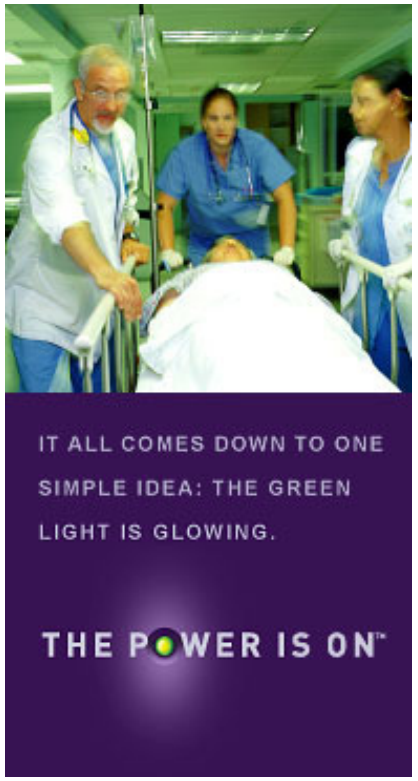
Battery packs and chargers

Exclusive OEM customers

- **Medical**
- **Military**
- **Industrial**

Twenty years experience

FDA Registered and ISO certified



Battery performance critical in our core markets

Creating strong demand for mission-critical battery systems

Portable Medical Equipment & Devices

- Defibrillators
- Patient Monitors
- Infusion Pumps
- Endoscopy

"Portable Patients"

Handheld AIDC & Rugged Computing

- Barcode Scanners
- RFID Readers
- Portable Printers
- Handheld Computing

"Portable Data Collection"

Commercial Military & Industrial GPS

- Ruggedized Radios
- Troop Location Devices
- Asset Management
- Survey & Mapping Devices

"Portable Soldiers"

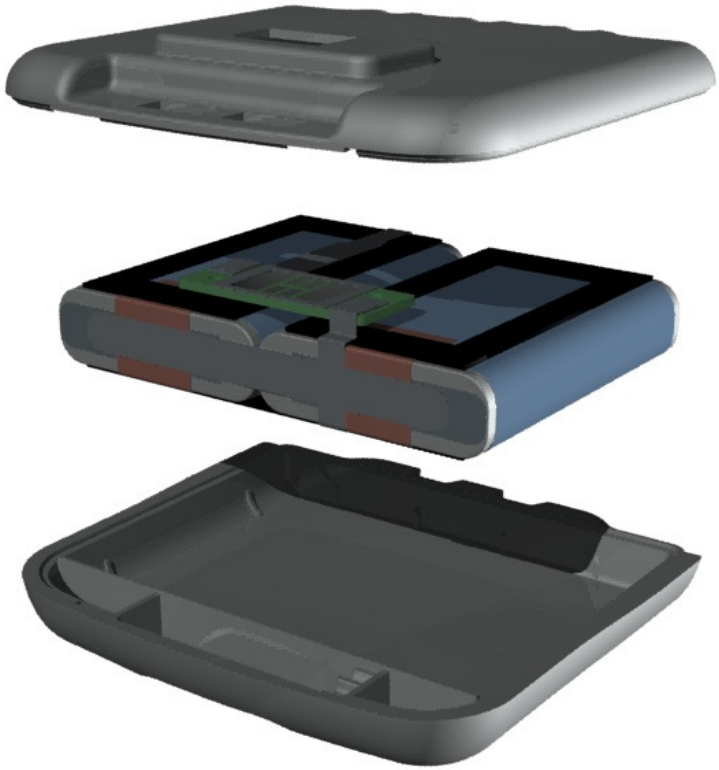
Introduction

- Battery system failures in the cell phone industry have heightened concerns about battery safety across all portable device industries
- Recalls increased from ¼ million from Oct '03-Sept '04 to almost 1½ million in the same period of the following year
- In 2004 and 2005, Apple, Dell and Hewlett Packard collectively recalled more than 300,000 laptop batteries "due to fire hazards"
- Failures result in
  - Potential for serious injuries
  - Tarnished brand name
  - Revenue loss due to returns and recalls
- Most incidents involved single cell lithium battery packs. Multi-cell lithium packs are more complex, and have more points of failure
- Safety is more a concern in industrial, military and medical equipment when reliability and safety intertwine

Anatomy of a Portable Battery System

Components of a Battery Pack

- Cells
- Circuit board supporting fue gauge, protection circuitry, thermal sensors, LEDs, and communications bus with host equipment (i.e. PCBA)
- Insulation
- External contacts
- Vent holes
- Plastic enclosure



Battery System Safety Creates Media Frenzy

Cell phone explosions become more frequent and visible

INCIDENT : August 4, 2004 - Curtis Sathre said it was like a bomb going off. His 13-year old son Michael stood stunned, his ears ringing, hand gushing blood and body covered in black ash ….. Kyocera 7135 phone short-circuited and heated up enough to trigger a built-in safety mechanism that vents super-heated gases to avoid an explosion …… Kyocera issued a recall of batteries, has doubled the number of batteries it X-rays to weed out defects…….

- **CLUES TO CAUSE**
  - Cell phone is use and in state of discharge
  - Battery pack went into thermal run-away condition
  - Cells did vent gasses, but pack exploded
  - OEM Manufacturer increases X-rays in production
- **POSSIBLE CAUSE AND SCENARIO**
  - A long conversation caused the battery cells to generate heat
  - Separator between cathode & anode material with-in cells breached, and cells internally shorted
  - Cell had safety vents and vented gasses
  - Pack had no safety vents, and pack exploded

Michael Sathre, 13, holds the remains of his cell phone. The phone's battery exploded in August of 2004.

Battery System Safety Creates Media Frenzy

Lap top explosions become more frequent and visible

INCIDENT: May 29th, 2006 - Nick Brown, 11, was playing on his Apple iBook laptop…Heat from the laptop, which was lying on the floor, had started melting the carpet. The Browns quickly carried it outside.“It was five minutes and (the computer) was in flames," Cindy Brown said. "The computer burst into flames. It doesn't seem real that you would have a fire in a computer. We all could have died, and the house could have burned down."

- **CLUES TO CAUSE**
  - Audible indication was “popping and crackling”
  - Laptop was insulated by carpeting
- **POSSIBLE CAUSE AND SCENARIO**
  - Cells overheated and shorted
  - Laptop was excessively charged and heat was trapped by carpet
  - Protection circuit failed or was never present within the battery pack, and thermal protection switch failed
  - If cell had inadequate safety vents, then cell exploded
  - If pack had inadequate safety vents, then pack exploded

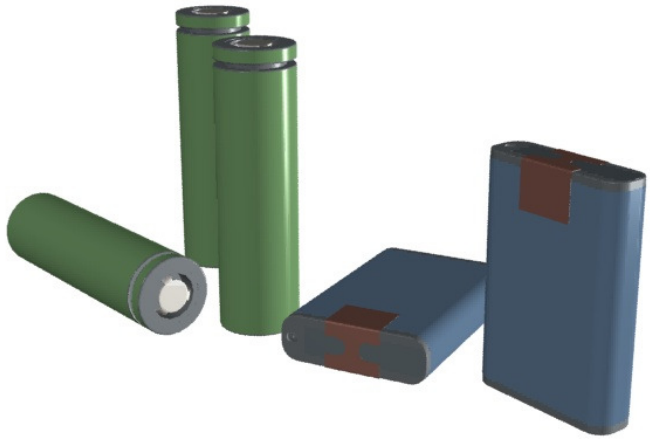
Reasons for Battery System Failures

Both OEM and aftermarket batteries share the blame

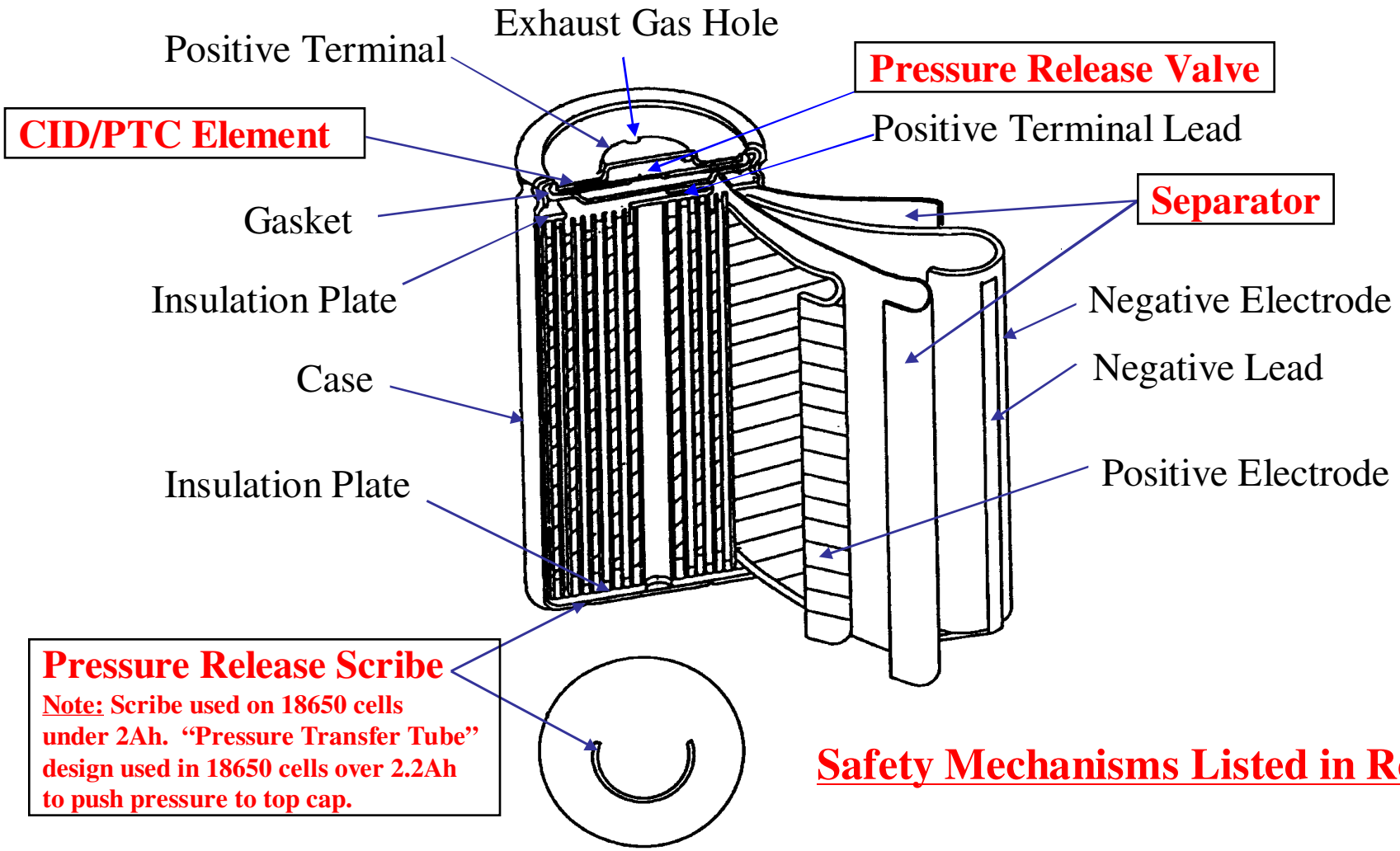
- **Use of substandard cells with single layer separators or lightly processed cathode/anode material**
- **Use of mismatched or substandard components on internal circuitry**
  - Mismatched components on circuit boards may not provide adequate performance
- **Lack of mandatory current/voltage protection circuitry**
  - Over-voltage or current leads to heating, shorting, or venting
- **Lack of mandatory thermal protection circuit**
  - Battery system overheats (without cut-off) when charging or discharging
- **Lithium cells may swell during charge and discharge cycles, especially as the cells age**
  - Swelling of cells may break circuit board and reduce protective functions
- **Nonexistent or obstructed gas vents**
  - Heated gas builds up within battery system
- **Charge/Discharge in high temperatures increase dissipation requirements**
  - Heat build-up results in system melting or explosion

Use Premium, Trusted, Lithium Cells

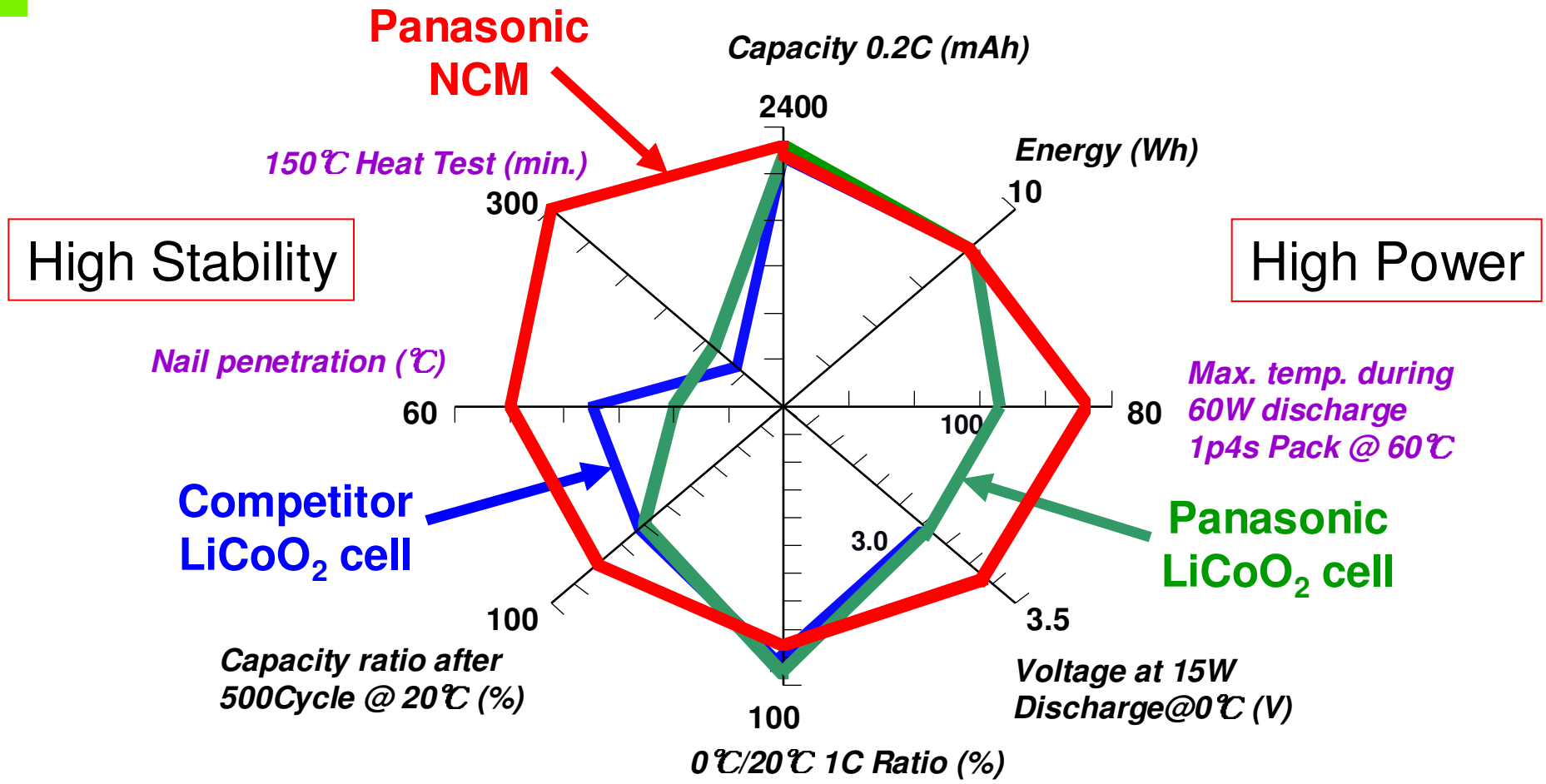
- **Use cells from branded, trusted manufacturers with demonstrated, consistent product quality over several years**
- **Use manufacturers that provide direct shipment, warranty, and indemnification**
- **Cells should be extensively profiled for performance characteristics**
- **Test a statistically significant quantity of incoming cells for each production lot of packs**
  - Open Circuit Test (OCV) is minimum test
  - Range of sample testing can be from 3% to 100% of all cells for each production lot
  - Generate a statistical analysis on the quality and capacity of the cells to be included each production lot of packs



Internal Structure of an 18650 Lithium-Ion Cell



New Lithium-Ion Formulations Can Enhance Safety without Compromising Power



NCM = LiCoMnNiO2

Design of the Battery Pack

- Major requirements of IEEE Standard 1625-2004 on Rechargeable Batteries for Portable Computers
  - One Positive Temperature Coefficient (PTC) per pack to protect over-current discharge
  - One Thermal Protection Circuit (TPC) per pack to prevent over-heating
  - One over-voltage protection circuit per pack to prevent overcharging
  - Mechanical isolation of the printed circuit board from the cells
  - Support for the release of vented gasses
  - Additional testing
- Details for the design of a safe battery pack on following slides include
  - Authentication
  - High temperature operation
  - Safety circuits
  - Mechanics

The Problem: Aftermarket & Counterfeit Batteries

- More than 5 million phony cell phone batteries and accessories were destroyed by law enforcement authorities in 2003
  - Verizon Wireless recalled 50,000 counterfeit LG phone batteries last June

- An increasing number of counterfeit batteries and unauthorized accessories are being sold as legitimate replacements for portable products. As a result;
  - Brand names are compromised with unauthorized replacements
  - Public safety compromised as counterfeits often lack sufficient protection features
  - Product returns increase, customer satisfaction decreases
  - Legitimate manufacturers face potential revenue loss

What is authentication?

- **In General:**

  A simple and cost effective method to identify and validate identity

- **Specific to Peripherals:**

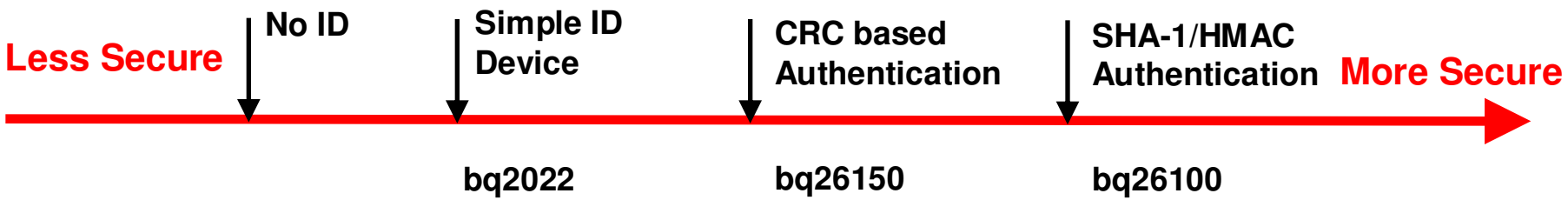
  A simple and cost effective method to ensure peripherals come from authorized sources

Current Options

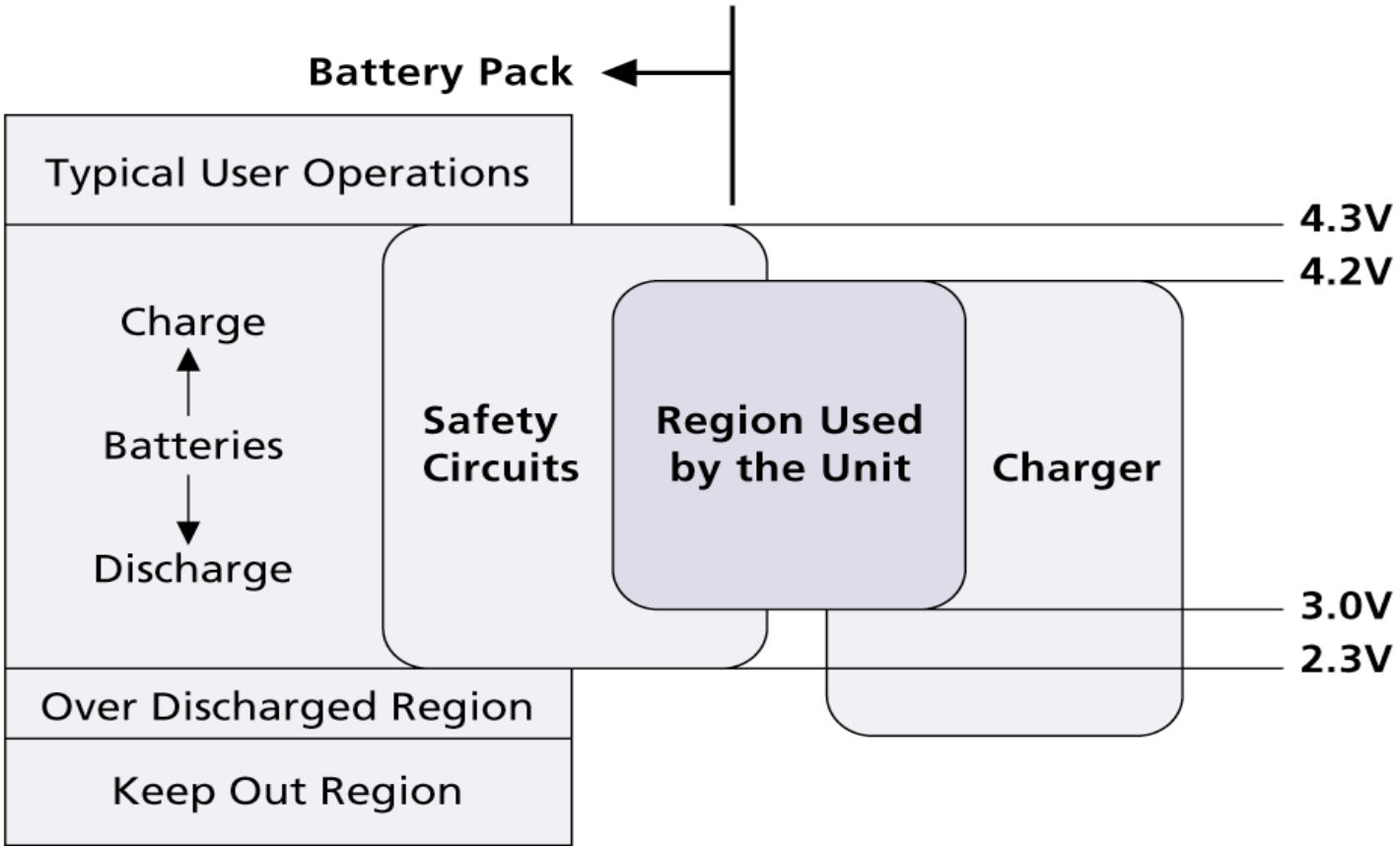
- **Form factors**
  - Strength: Economies of scale
  - Weakness: Hard to revise
- **Labeling**
  - Strength: Cheap
  - Weakness: Easily copied & moved around
- **User Intervention**
  - Strength: Informed consent
  - Weakness: Requires user motivation, difficult to enforce

Summary of Authentication Schemes

Authentication Transform	Advantages	Disadvantages
ID (bq2022)	Simplest solution, very small footprint, cheap	Fixed inputs and fixed outputs
CRC Approach (bq26150)	Simple solution, small footprint, adds some burden to crack	Not a cryptographic function
SHA-1/HMAC (bq26100)	More complicated algorithm that significantly increases the burden to crack	Proven cryptographically

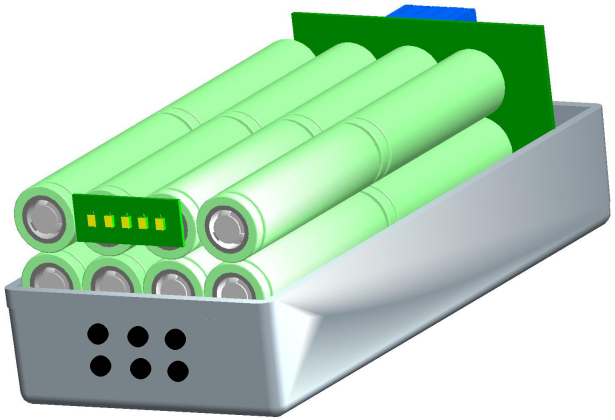


Safety Circuits for Lithium-Ion Batteries



Safe Operation at High Temperatures

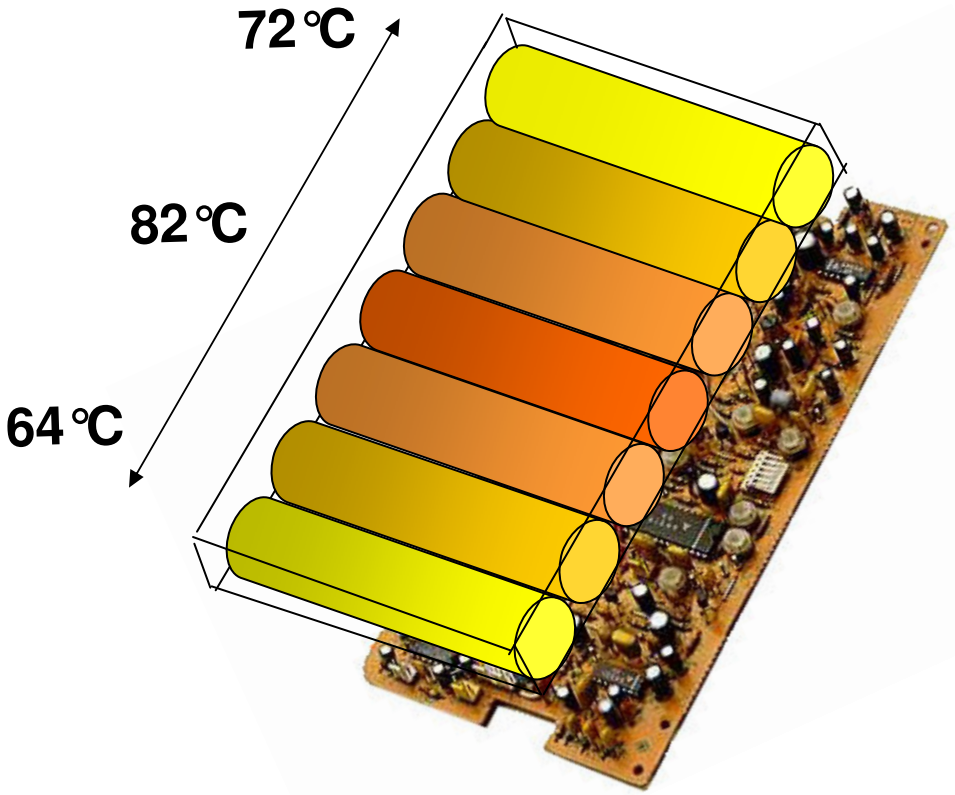
- Certain applications require extended operating temperatures of - 40 to + 80 C
  - Rechargeable lithium operates well at - 20 to + 60 C
- Solutions for high temperature environments;
  - Strategic placement of vent holes enables convection cooling
  - Strategic placement of heat generating components (i.e. MOSFETs on the PCBA) with respect to the cells
  - Strategic placement of battery pack with respect to host device electronics
  - Utilize esoteric, bulky cells designed for high temperature operation
  - Utilize primary (disposable) lithium cells – operational range is -40 to +80 C with low self-discharge



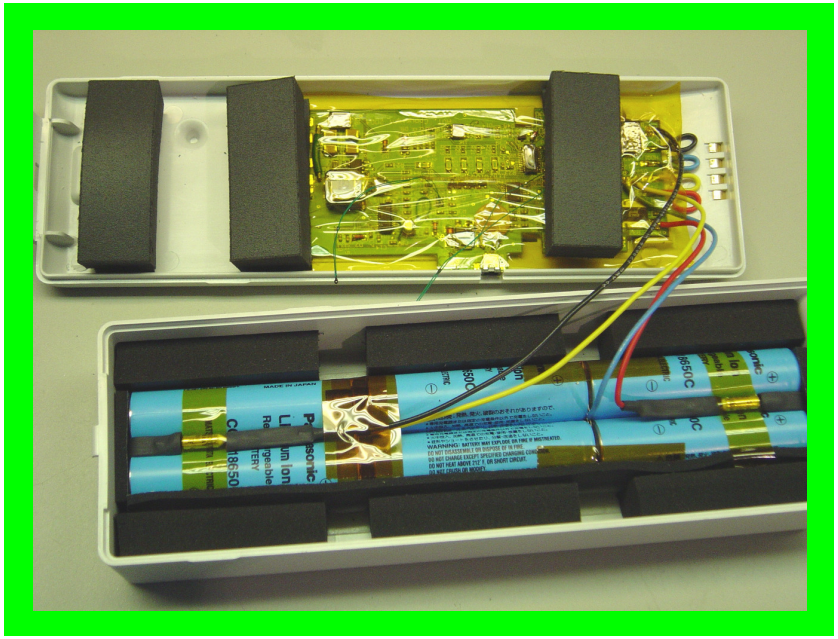
Vent holes for exhaust and cooling

Component Position Affects Thermal Performance

- Heat from a “hot” PCBA component can erode performance of cells above
  - May create imbalances in cells that are connected in series
  - All cells in string will operate to the level of the lowest performing cell



Withstanding Shock and Vibration



- Quality resistance welds that meet IPC 610 soldering standards
  - Repeated pull tests throughout manufacturing process
- Adequate qauge for nickel strips welded to battery terminals
- Strategic placement of PCBA within the battery pack – fixed mounts & clearance
- Composite material and wall thickness of battery pack enclosure
  - PolyCarbonate (PC), Acrylonitrile Butadiene Styrene (ABS), PC/ABS blends, plus Fire Resistant (FR) additives
- Insulation to absorb shock and vibration for PCBA and cells
  - Puncture resistant, withstand temperature changes without shrinkage & deformation, and adequate thickness
  - Vulcanized rubber, polyaramid paper, or polyimide film

Insulating Material within the Pack

- **Unlike this example, insulating material should be used in select locations**

- **Excess insulation;**
  a) impedes heat dissipation,
  b) may block exhaust holes,
  c) adds extra weight

Excessive silicon insulation

Insulate between Cells

Unsafe packs may have no insulation between cells.

No protection between cells causes possible shorting hazard between cells.

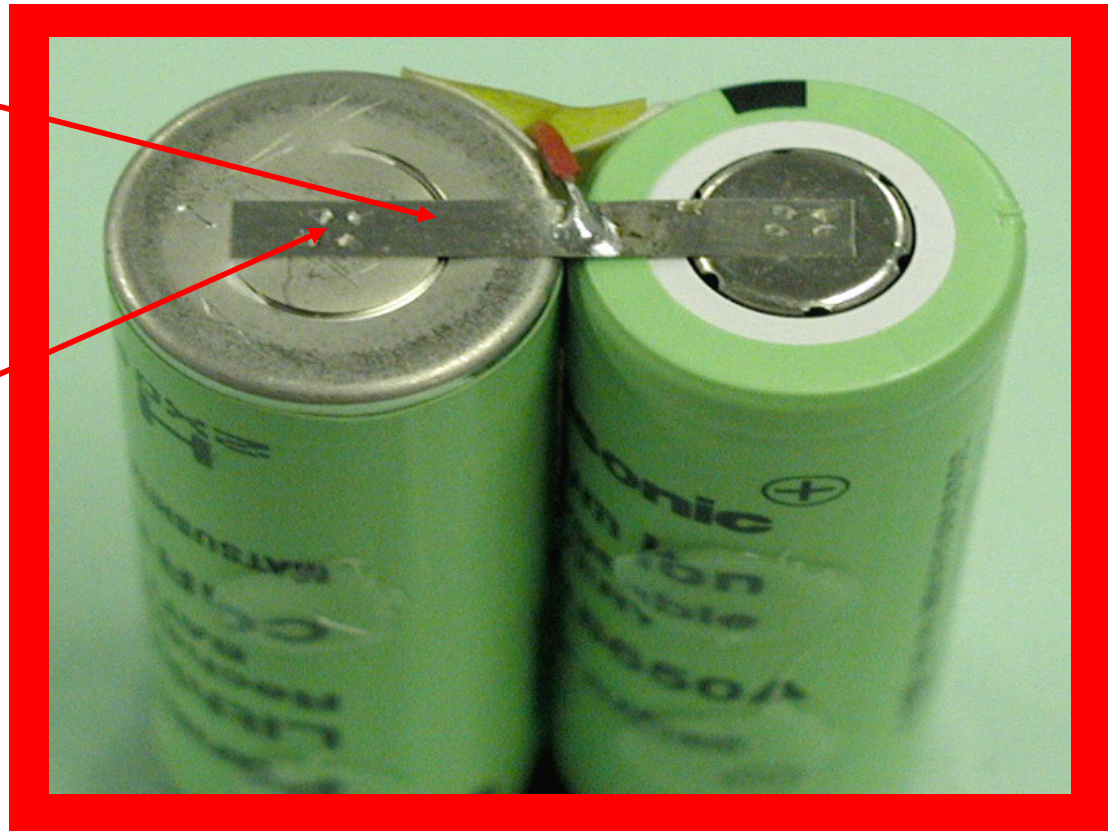
Challenges with Resistance Welding

Cell safety vent at negative end has been covered, compromising effectiveness of safety vent

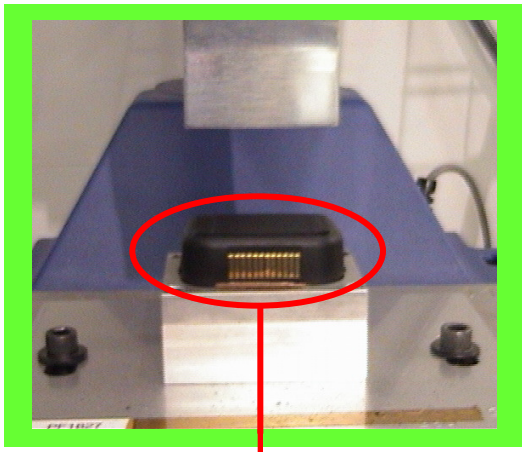
Cell was welded in keep-out area (middle of cell) where can is very thin. This increases the possibility of an internal short

Welds should withstand 8 pound pull tests

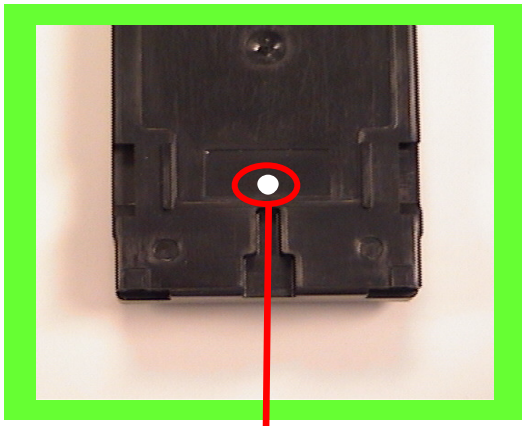
Nickel strips should be at least 3 mm wide, preferably 5 mm



Guidelines for Pack Enclosures



Battery pack undergoing ultrasonic welding



Exhaust hole for venting gas

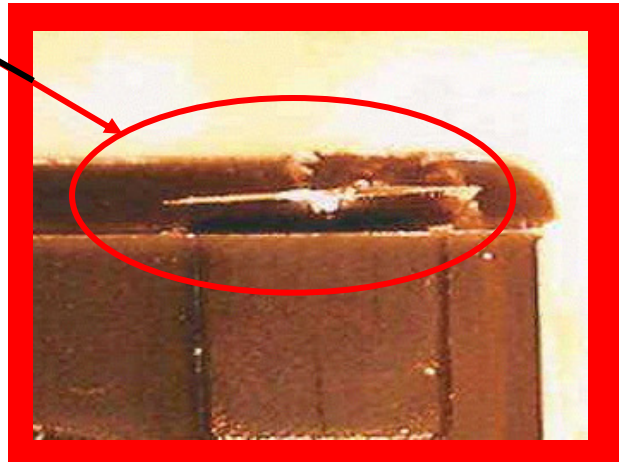
- Ultrasonic welding is recommended to join plastic case surfaces
- Unlike alternative methods of sealing enclosures, such as gluing or snap-tight seals, the resultant joint strength is high, and hermetic seals are possible
- Ultrasonic welding ensures the enclosure is resistant to shock or impact, and retain any electrolytes that may leak from the cells

- Gases liberated during catastrophic cell failure should have means of escape from the enclosure
- Exhaust hole may require micro-porous membrane to repel moisture in wet environments

Connector Alignment and Placement

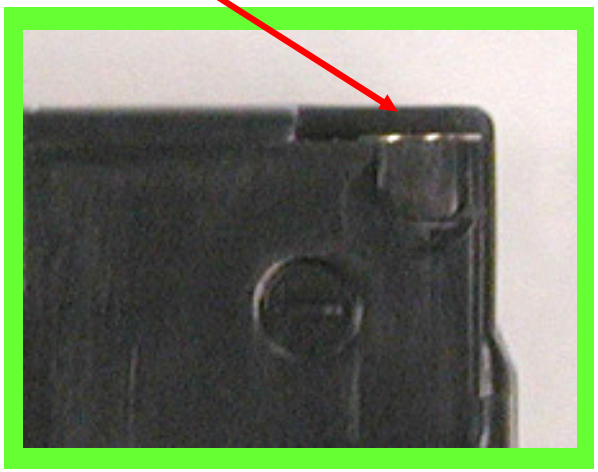
External contacts should not protrude from pack enclosure

External shorting hazard is created when contacts are not flush with plastic

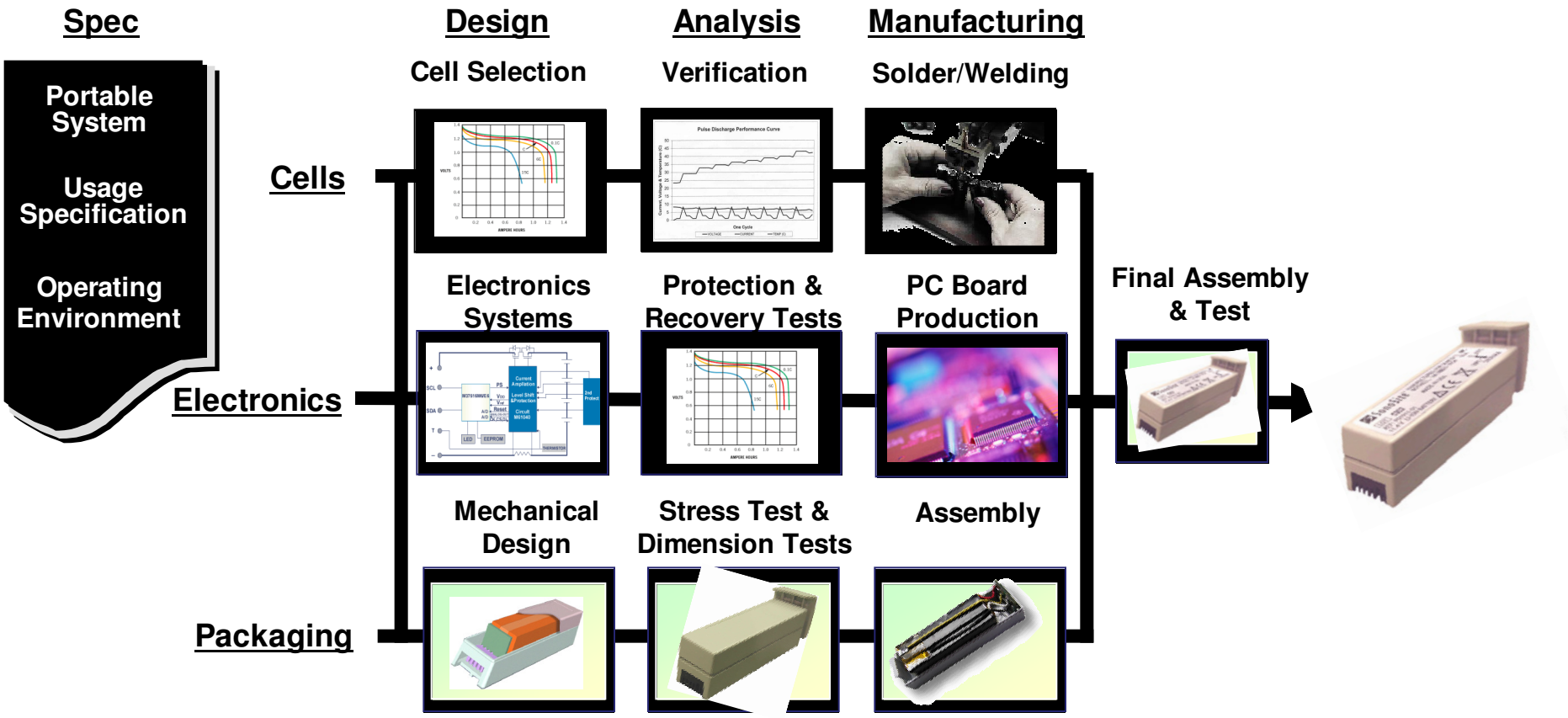


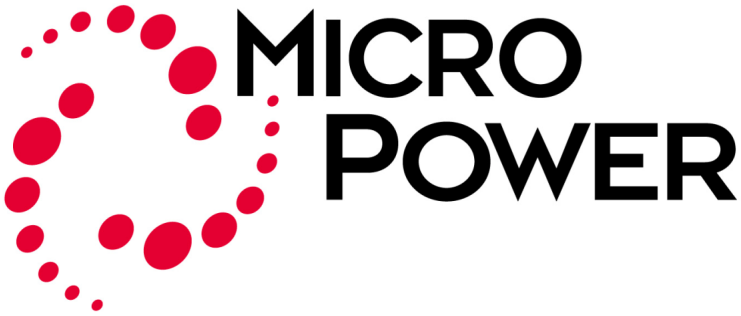
Crooked contacts cause fit issues with end unit, which can cause intermittent contact and data loss

In comparison, well designed contacts are recessed to prevent shorting hazard



Total system approach to pack design and manufacture increases safety





Questions