Innovations in Flexible Graphite for Thermal Management Applications

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Research Associate

GRAFTech International | Redefining limits

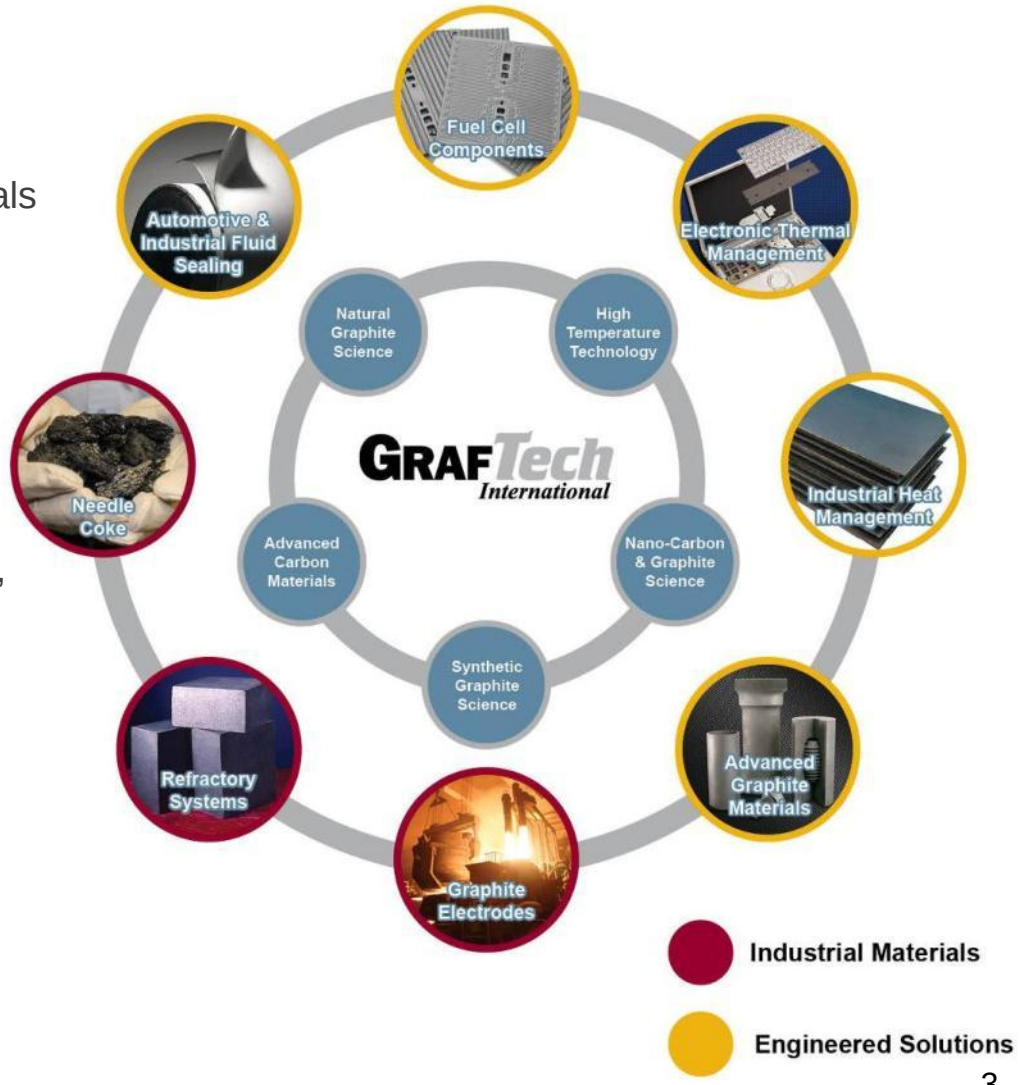
Topics

- GrafTech International Holdings, Inc.
- eGRAF® Materials and Products
- eGRAF® SPREADERSHIELD™ Applications
  - Displays
  - LED Lighting
  - Smartphones – SS1500
  - Lithium Ion Battery Thermal Management

GrafTech International

Business Segments

- Industrial Materials **(IM)**
  - Needle coke
  - Graphite electrodes, refractory materials
  - Key markets include steel and ferroalloys
- Engineered Solutions **(ES)**
  - Engineered synthetic graphite products
  - Flexible graphite products
  - Key markets include solar, electronics, energy and chemical
- $1.3 billion in sales in 2011
- 126 years graphite materials science experience (founded in 1886)
- 3,200 Team Members on 5 continents



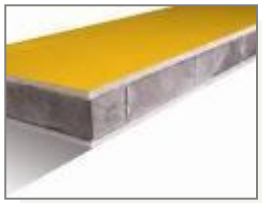
GrafTech International - Innovation

Seven ***R&D 100 Awards*** in the last nine years for revolutionary technologies newly introduced to the market

2003

2004

2005



2006

2007

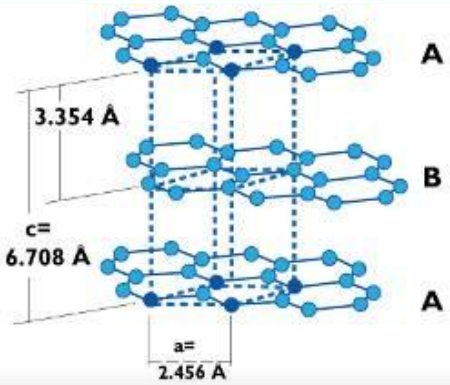
2009

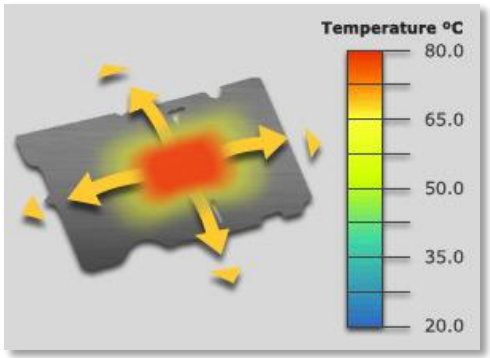
- 2003 winner for HS-400 heat sinks
- **2004 winner for eGRAF® SPREADERSHIELD™ heat spreaders**
- 2005 winner for Apollo® / Zeus graphite electrodes
- 2006 winner for GRAFOAM® graphite foam
- 2007 winner for GRAFCELL® flow field plates
- 2009 winner for GRAFIXH® flexible heat transfer plates
- **2011 winner for eGRAF® SPREADERSHIELD™ SS1500 heat spreader**

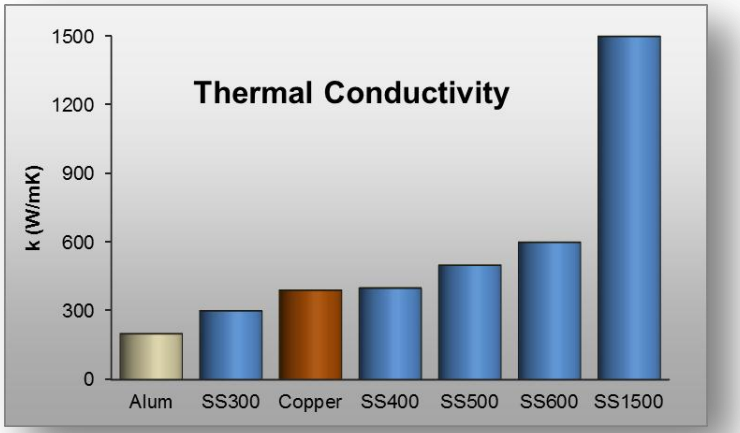
2011

eGRAF® Flexible Graphite Properties

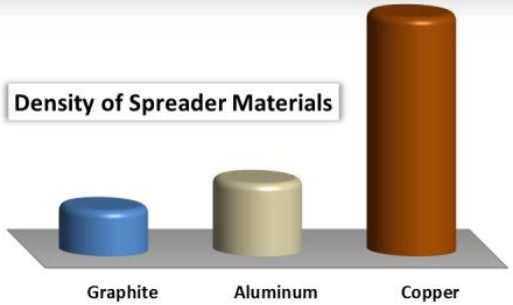
- Anisotropic Material Properties
  - Derived from the graphite crystal structure
- High Thermal Conductivity
  - 300-1500 W/mK in plane– good heat spreading
  - Spreads heat over a large area
  - Transfers heat to external sink (case, chassis, cold plate, etc.)
  - 3-16 W/mK through thickness





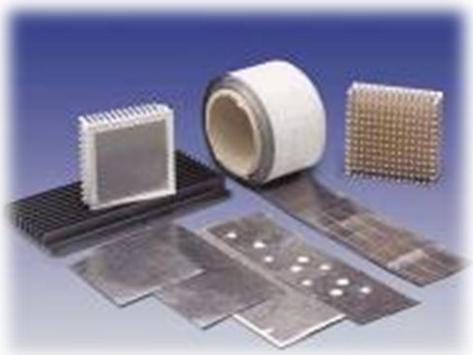


- Lightweight and Thin
  - 1.3-2.2 g/cm³ density
  - 17 micron to 1.0 mm thickness
- Flexible and conformable
- Simpler TIM application than paste or grease



eGRAF® Products Overview

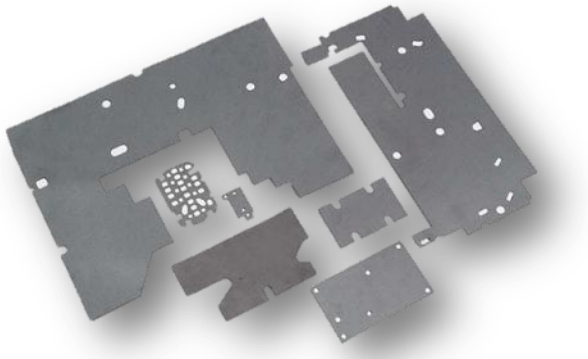
Thermal Interface Materials



HITHERM™

- HT-700 Series
- HT-1200 Series
- HT-2500 Series

Heat Spreaders



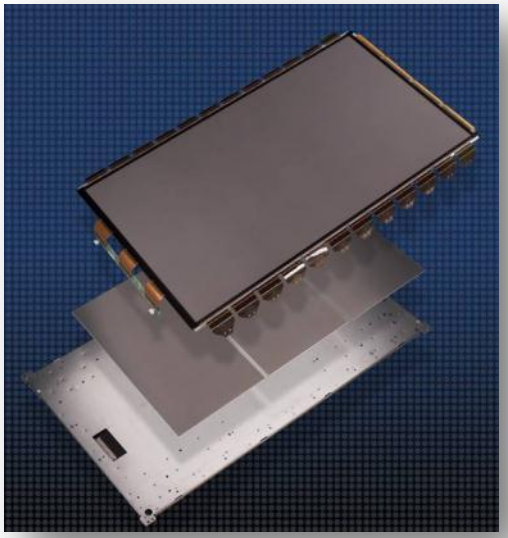
SPREADERSHIELD™

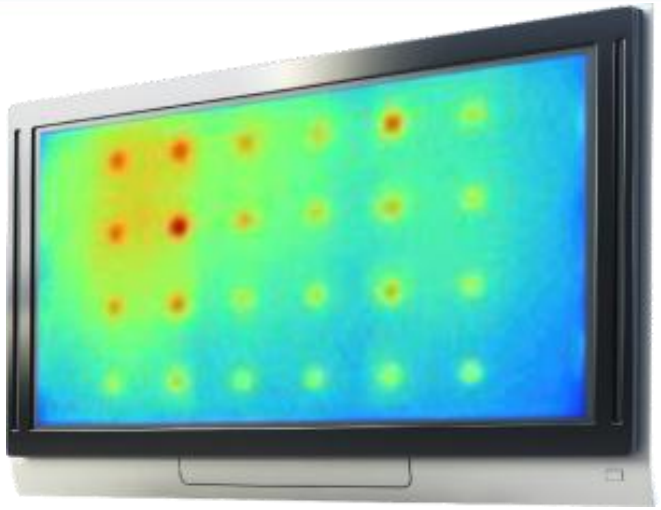
- SS300 Series
- SS400 Series
- SS500 Series
- SS600 Series
- SS1500 Series

- eGRAF® flexible graphite is produced in large rolls in a continuous process
- Rolls can be coated/laminated with adhesives, plastics and metals
- Thickness can be controlled in the range of 20-1000 µm
- Finished rolls are converted into peel and stick die-cut parts in high speed processes

First Spreader Product – Plasma Display Panels

- Flexible graphite heat spreaders for PDPs have been in production since 2003
- 960 mm x 565 mm x 1.5 mm
- Flexible graphite heat spreaders improve performance
  - Reduces image sticking & burn-in
  - Improves brightness uniformity
  - Lowers mechanical stress on chassis
  - Allows for use of low cost stamped steel chassis



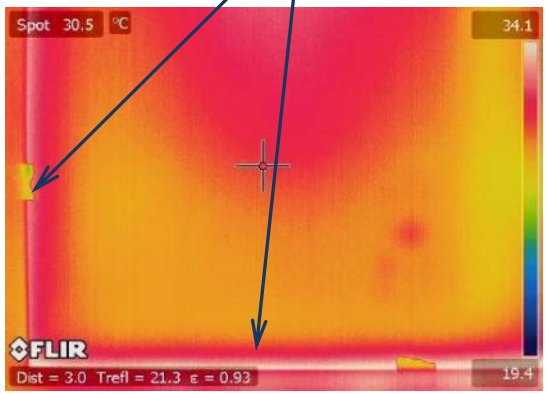


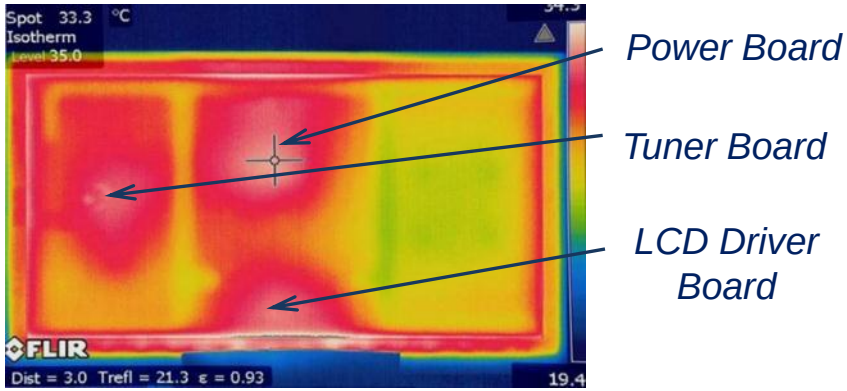
Acrylic TIM with Al Sink T_{max} = 43.8 °C

SS400 Spreader T_{max} = 34.3ºC

Thermal Challenges: Thin LED/LCD Displays

- Edge-lit LED/LCD TV's are less than 25 mm thick
- Thermal Objectives
  - Display parameters negatively impacted by temperature or temperature gradients
    - Image sticking/ghosting
    - Brightness uniformity
    - Reduced OLED lifetime
  - Warping of light guide plates, brightness enhancing filters
- Design Constraints
  - Edge lit LED light bars create hot spots
  - Heat generating components located behind the screen
  - Active cooling (fans) highly undesirable
  - Super-thin form factor
  - Edge-lit designs result in large temperature gradients

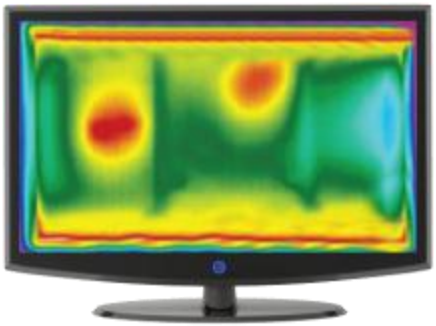




SPREADERSHIELD™ Difference in LCD Displays

Without SPREADERSHIELD™ solution

Thermal Gradients



Thermal gradients gradually develop due to heat sources

Screen Deformation

Heat causes chassis and films to deforms

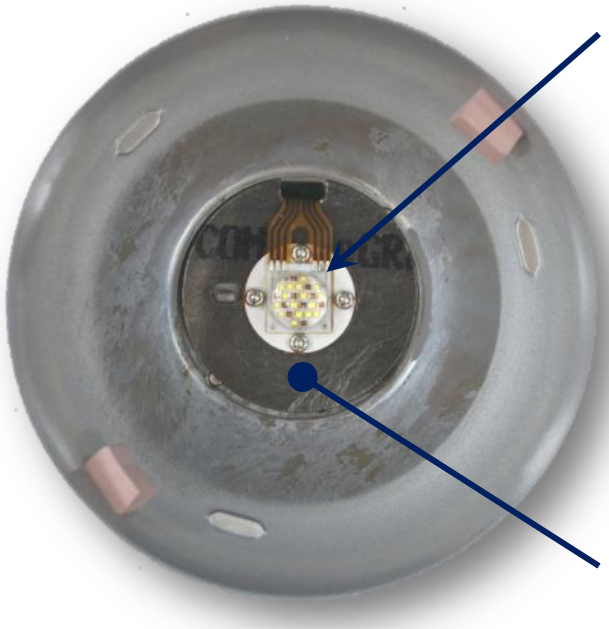
Brightness Uniformity

As components shift, brightness uniformity degrades

With SPREADERSHIELD™ solution

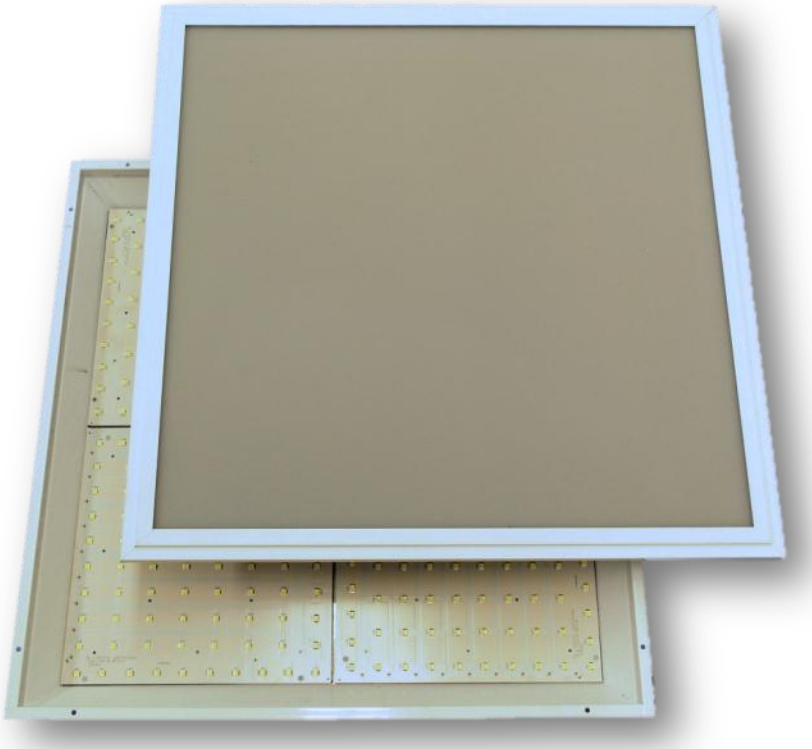
LED Lighting – Directional Light

- Warm white LED Directional Light
  - 12 W input, 600 Lumens
  - Rated lifetime 25,000 hours
  - Finned, cast aluminum reflector acts as a heat sink

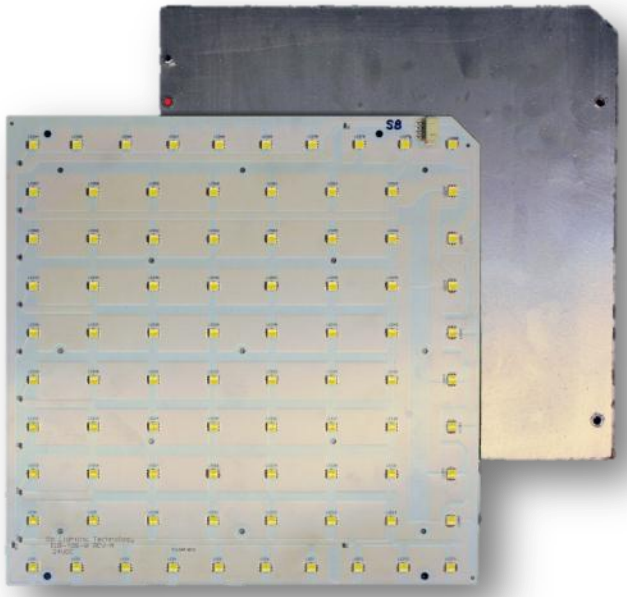


- HiTHERM HT-710A
  - Bonded to cast housing
  - Larger than LED light engine
  - Combined thermal interface & heat spreader

LED Lighting – Flat Panel Light

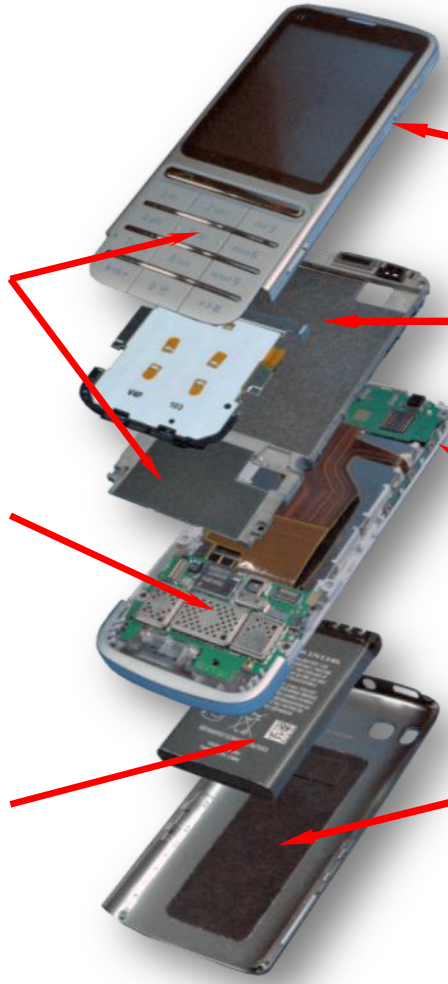


- 61 cm x 61 cm LED light panel
  - For drop ceilings
  - 84 LEDs on each of 4 circuit boards



- SPREADERSHIELD SS400 heat spreader covers each circuit board for thermal management

Thermal Issues for Smartphones



Cool Heat Source
LED backlights

SHIELD Heat
From reaching user through **keypad**

SHIELD Heat
From reaching ***LCD*** or ***OLED display***

COOL Heat Source
Power amplifiers and tuners

COOL Heat Source
"Flash" LED

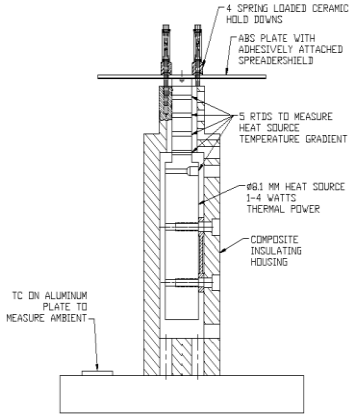
SHIELD Heat
From reaching user through battery cover

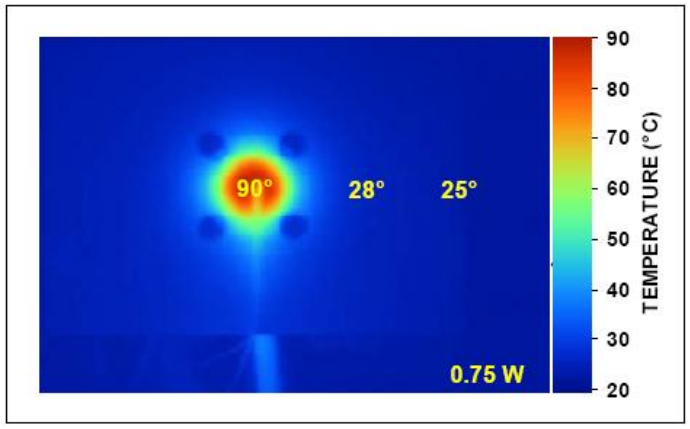
SHIELD Heat
From reaching **Li-ion battery** and causing premature cell failure

Uniquely challenging thermal environment in SmartPhones

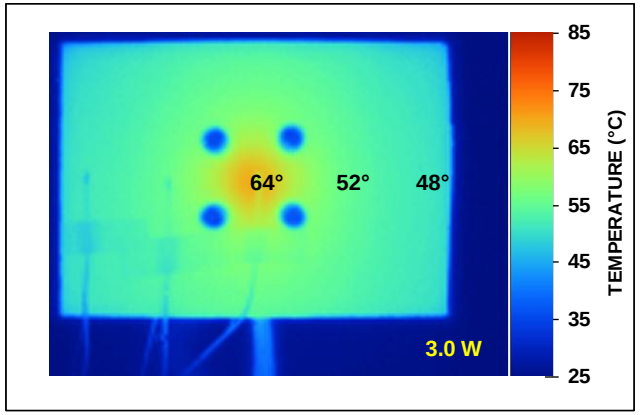
Heat Spreaders for Smartphones

- Test setup simulating a Smartphone chipset contacting an ABS Smartphone case
  - ABS plastic case, 70 mm x 50 mm
  - 8 mm diameter heat source
  - Natural convection cooling





Bare ABS Case
- A 0.8 W heat source generates a 90ºC hot-spot on the outside of the case

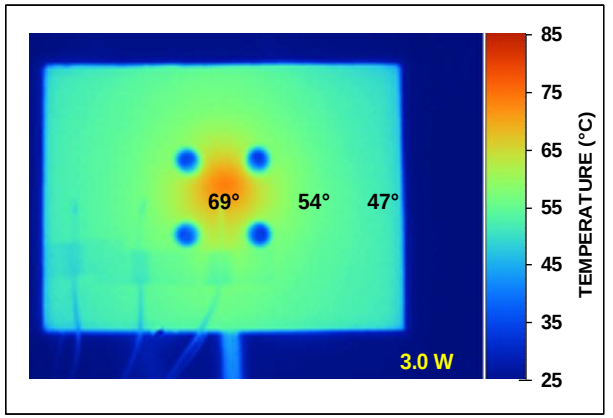


ABS case with 110µm thick SS400 (400 W/mK) graphite heat spreader contacting the heat source
- Power increases to 3.0 W
- Hot-spot temperature 26°C lower

Thin Heat Spreaders in Smartphones – SS1500

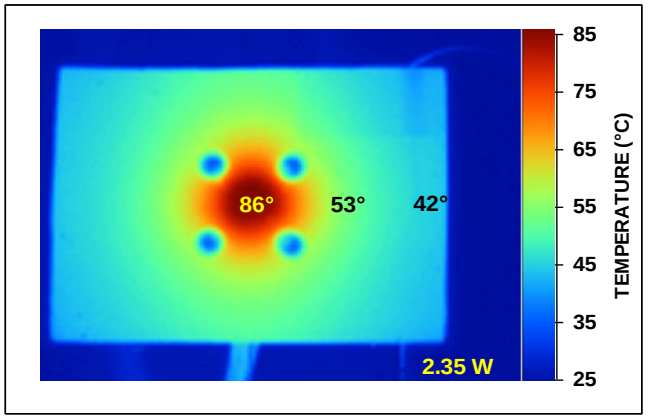
- Thermal architects think in terms of a few microns thickness!
- SS1500 - 17 to 45 microns thick

- Thermal performance comparison
  1. SPREADERSHIELD SS1500
     - 1500 W/mK In-plane thermal conductivity
     - 3.4 W/mK Thru-thickness thermal conductivity
     - 30 µm thickness
  2. Copper foil
     - 388 W/mK Isotropic thermal conductivity
     - 30 µm thickness
- Thermal performance of SS1500 at 30 µm is similar to that of SS400 at 110 µm
- Copper spreader has an unacceptable hot spot on the case above the heat source



ABS case with 30 µm thick SS1500 graphite heat spreader contacting the heat source

- 3.0 W, 69° C source temperature



ABS case with 30 µm thick copper spreader contacting the heat source

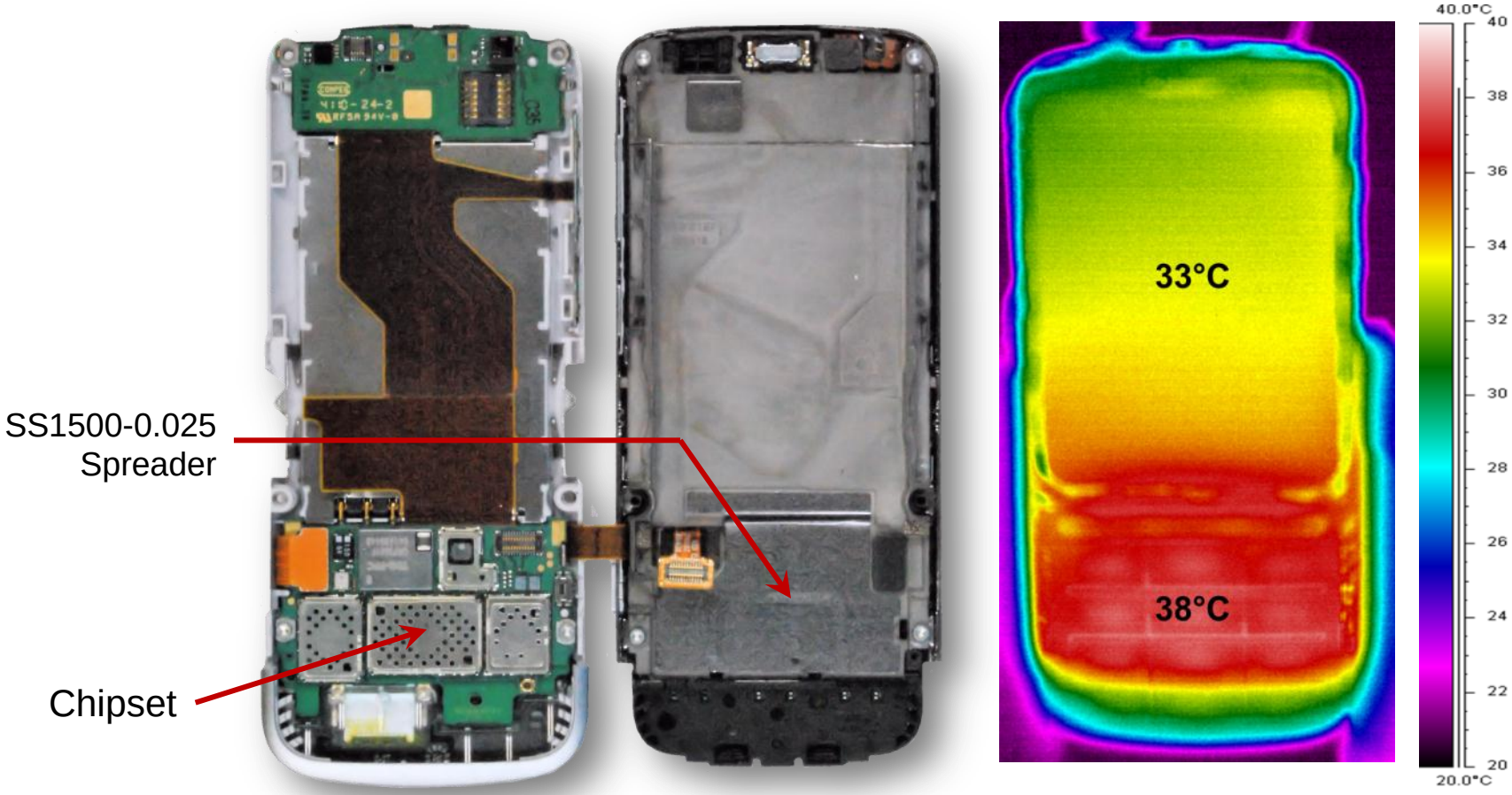
- 3.0 W, 86° C source temperature

Smartphone Case Study

- Typical Smartphone
  - Size 111mm x 47.5mm x 11mm
  - Weight 100 g
  - LCD transmissive display with resistive touch input
  - Grid keypad
  - Lithium Ion battery
  - Available worldwide
- Thermal management using SPREADERSHIELD solutions

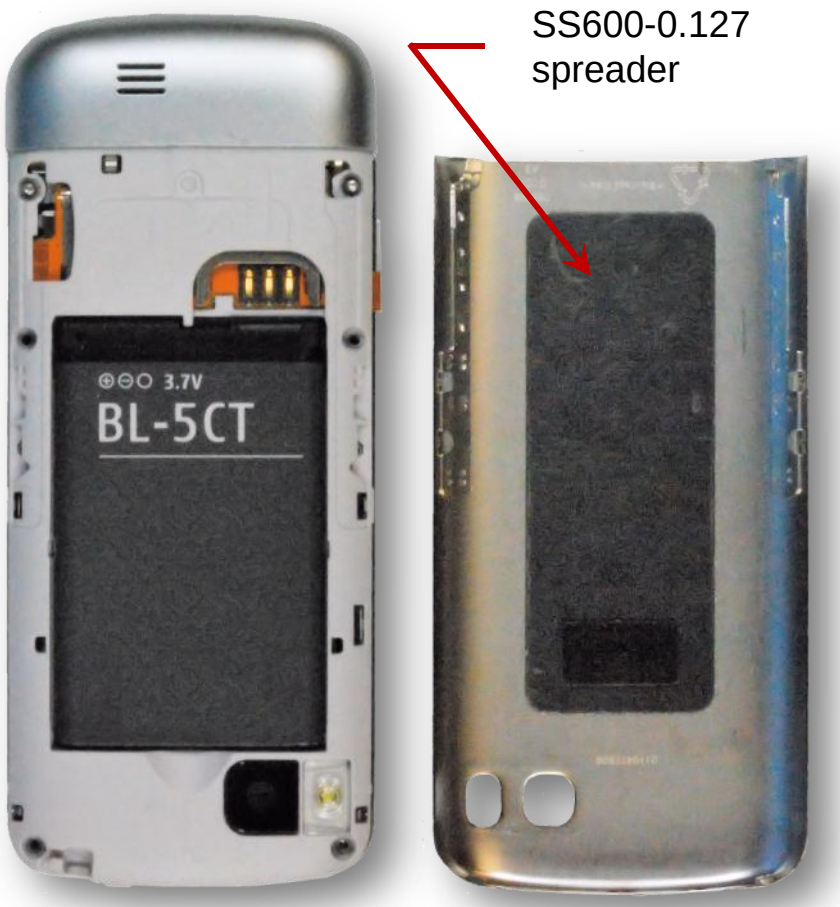
Heat Spreading on Front Cover

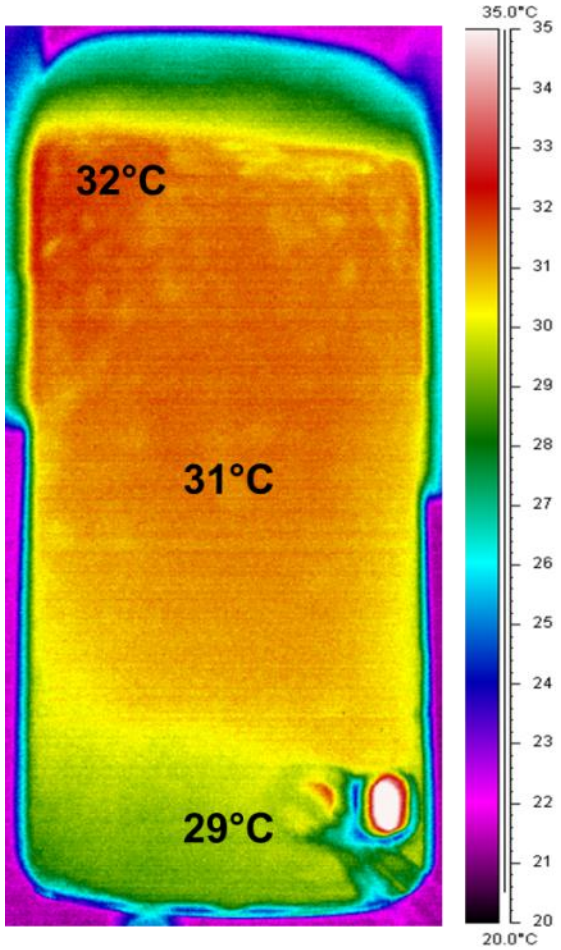
- SS1500 – 25 micron thick heat spreader above chipset
  - Spreads heat from chipset into magnesium chassis
  - Shields heat from keypad



Heat Spreading on Back Cover

- SS600 – 0.127 mm heat spreader on back cover
  - Stainless steel back cover is kept at a very uniform low temperature



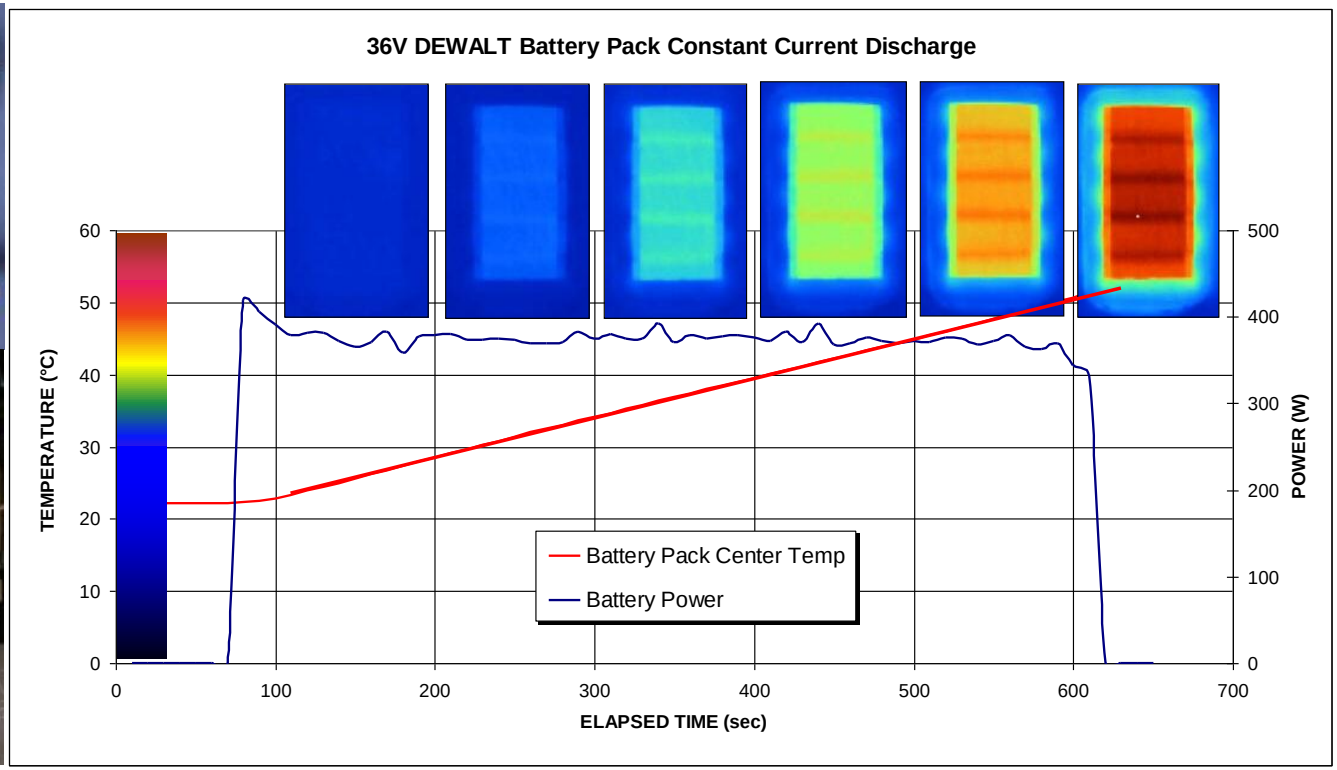


Lithium Ion Battery Thermal Management

- Thermal management enhances the battery's Performance, Durability and Safety
- Thermal management becomes increasingly critical as battery packs become larger and more powerful
  - Over Temperature
    - High battery cell operating temperatures lead to irreversible material degradation
  - Thermal Imbalance
    - High battery pack thermal gradients lead to cell voltage imbalances and decrease pack life
- Improved thermal solutions are needed to meet power density, energy density and lifetime goals

Thermal Management Needs: Temperature Reduction

- Li-Ion packs operated at high discharge rates can rapidly reach maximum operating temperatures
  - 0.38 kW drill battery pack discharging in 4½ minutes



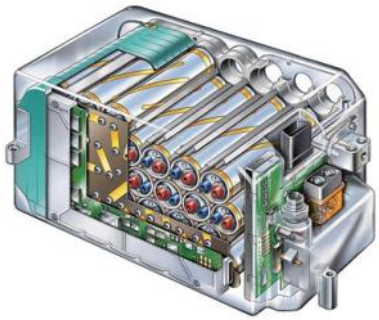
Battery Thermal Management Approaches

- Industry has responded to battery thermal management challenges with a wide range of approaches…

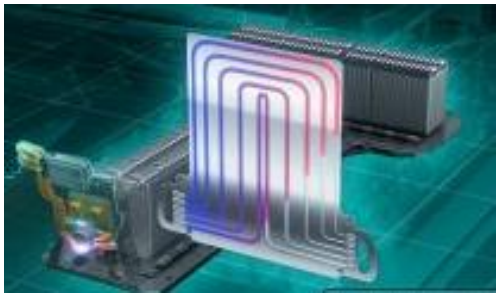
Active air cooling with finned heat spreaders

Liquid cooling conduit

Passive air cooling



Refrigerant cooling with cold plate

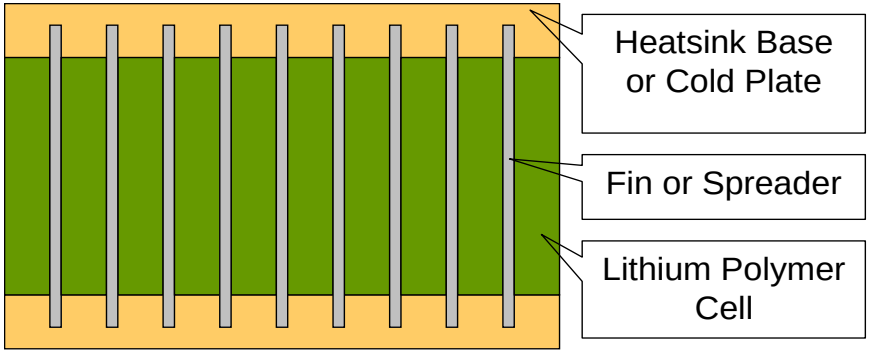


Liquid cooling with heat exchange plates

- These systems typically use heavy aluminum components to transport heat away from the cells

Benefits of a Graphite Thermal Solution

- Aluminum reference design:
  - 200 Prismatic pouch cells
  - Water cooled cold plates
  - Aluminum heat spreaders between each cell and connected to cold plates



- SPREADERSHIELD design:
  - Replace aluminum heat spreaders with SS600 with the same thermal performance

For Identical Thermal Performance		
Type of Spreader	Aluminum	SS600
Thermal Conductivity (W/m-K)	200	600
Thickness (mm)	1	0.3
Mass of Spreader (g)	104	22
Total Spreader Thickness (mm)	220	66
Weight of Spreaders (kg)	23	5

Similar results will apply to pack designs that use different formats, arrangements, and sizes of cells

eBike Battery / Prismatic Pouch Cells

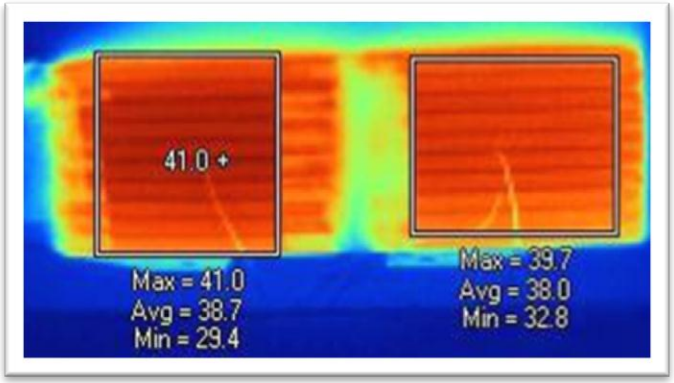
- A commercially available electric bicycle (eBike) battery
  - 0.30 kW battery pack uses twenty 3.7 V lithium polymer pouch cells
  - No cooling solution

- Discharge through a hub motor attached to a bicycle wheel
  - Mechanical resistance unit mimics wind-loading as a function of speed
  - Battery pack can propel the bike at 22 mph for 1 hour

Heat Spreaders with Integrated Heat Sink Fins

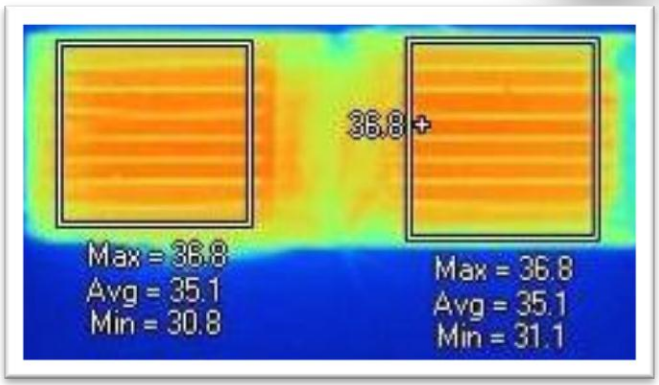
- Heat spreaders 0.5 mm thick between cells with 25 mm high integrated fin

- Initial tests in natural convection
  - Maximum temperature reduced from 41.0°C to 36.8°C
  - Temperature gradient reduced from 3.9°C to 2.9°C



eBike Battery Pack

- As received – no cooling solution

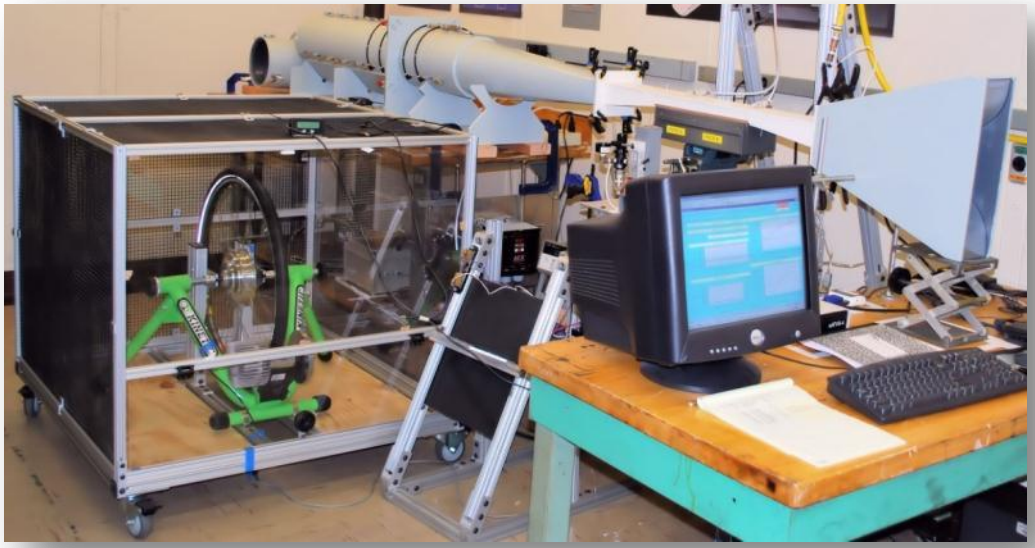


eBike Battery Pack

- SS400 finned heat spreaders

Graphite Spreader with Fins in Forced Convection

- Battery pack mounted in housing with slotted cover
  - SS400 fins exposed to forced convection air flow



- Laboratory wind tunnel used for forced convection
  - 22 mph air flow matches wheel speed
- Thermal performance
  - Maximum temperature reduced to 25.9°C
  - Temperature gradient reduced to 2.2°C

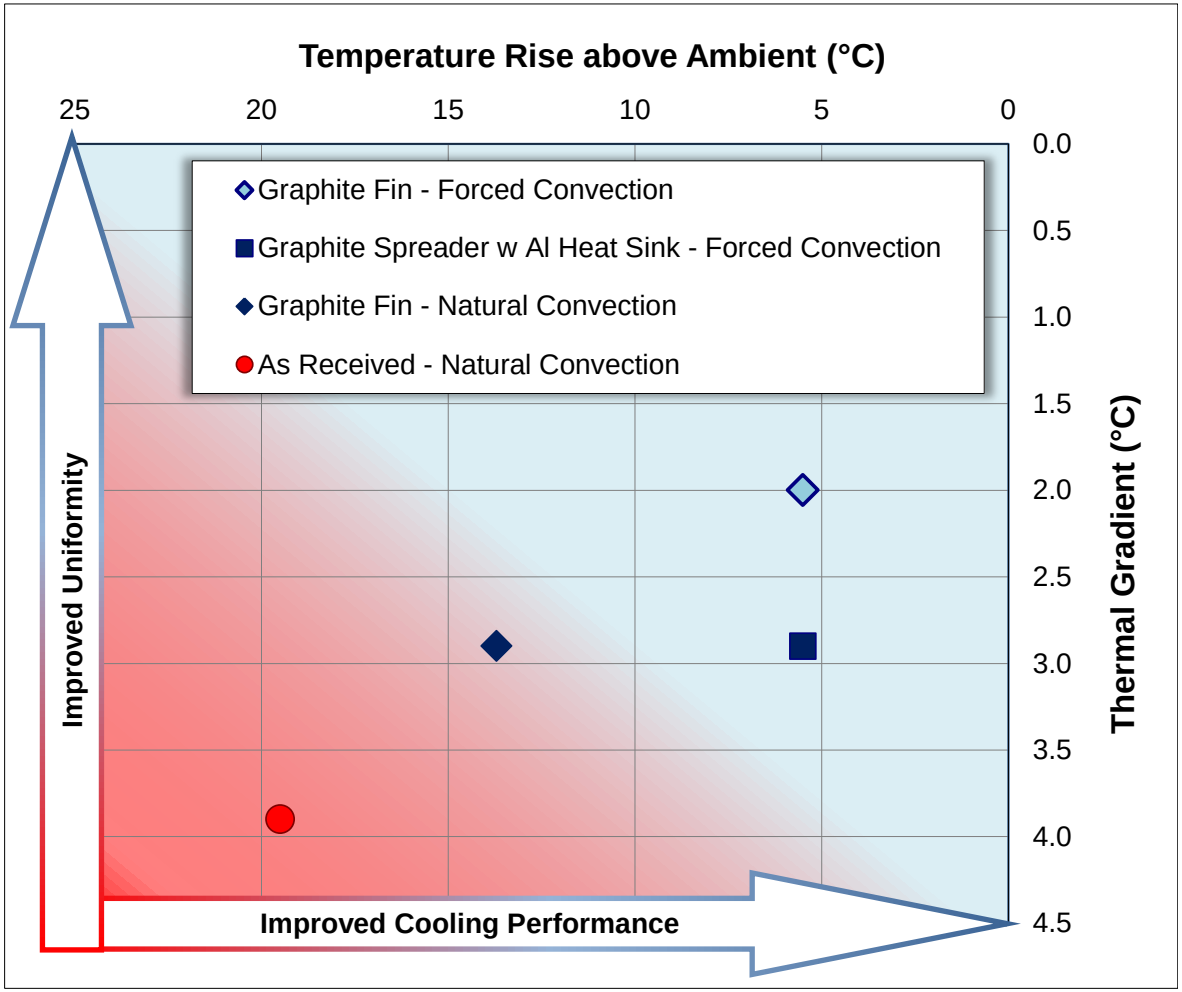
Graphite Spreader with External Heat Sink in Forced Convection

- Battery pack mounted in housing with slotted cover
  - SS400 flexible graphite fins cut back in length and folded over curved mandrels built into case
- Two aluminum heat sinks bolted to case
  - Fins match up with each other and are compressed against mandrel and heat sink base
  - Fins transfer heat to base and form weatherproof seal between case and sink

- Wind tunnel tests repeated
- Thermal performance in declines slightly
  - Maximum temperature increases slightly to 26.9°C
  - Temperature gradient increases slightly to 2.9°C

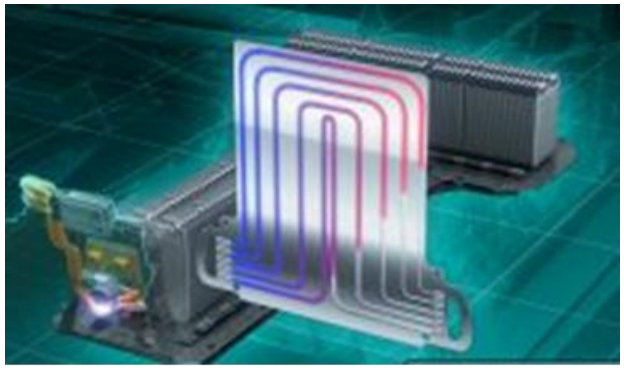
Summary of eBike Heat Spreader Performance

- Temperature Rise vs. Thermal Gradient
- Graphite thermal management solutions improve thermal performance
  - Thermal gradients reduced by 50%
  - Temperature rise reduced by 75%
- Al heat sink with graphite spreader has slightly poorer performance than graphite fin

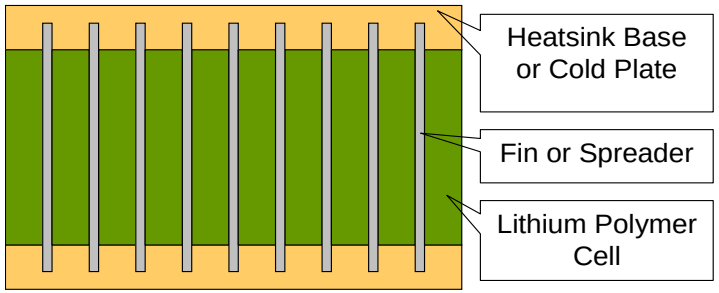


Active Cooling of Lithium Ion Batteries

- Liquid cooling is advantageous in high power applications (e.g. PHEV, HEV, EV,)
  - Higher heat generation
  - Higher energy density
- Large format cells generate heat across their faces
  - Modest heat flux
- Heat must be conducted to a cold plate or heat sink
  - Higher heat flux density
- **Collect** heat from a large area and **concentrate** it at the cold plate or heat sink
- Demonstrate use of flexible graphite heat spreaders combined with liquid cooling on a large format battery cell

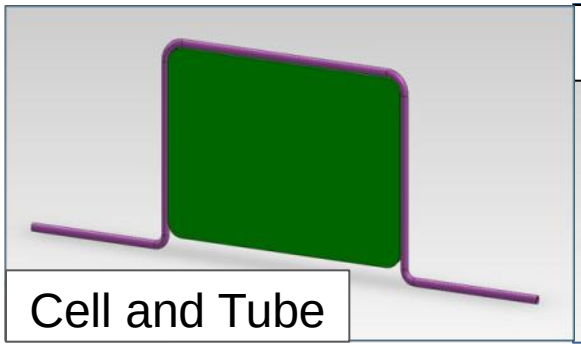


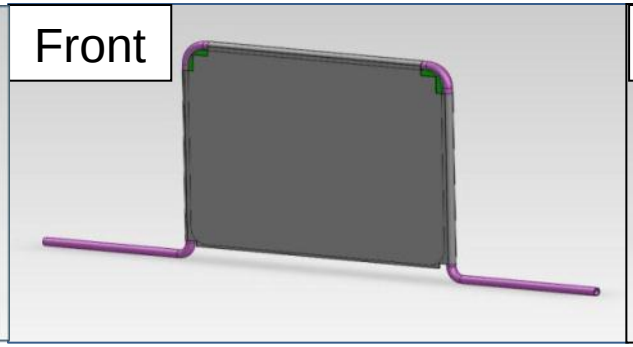
Liquid cooling with heat exchange plates

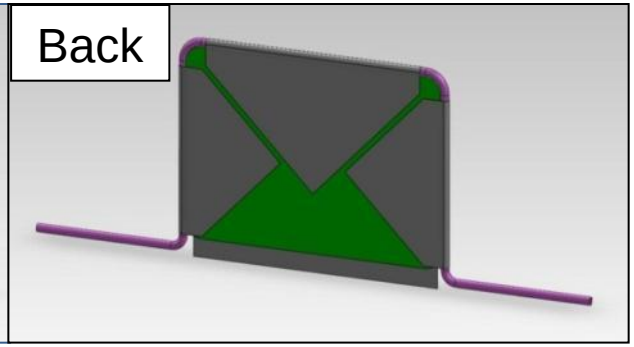


Hybrid Thermal Solution

- Liquid cooled tube wraps around 3 sides of the cell perimeter
- Heat spreaders transfer heat from faces of the cell to the liquid coolant tube
- Advantages of this design:
  - Thin, compact, and lightweight
  - Durable and robust
  - Easy to manufacture
  - Potentially low cost

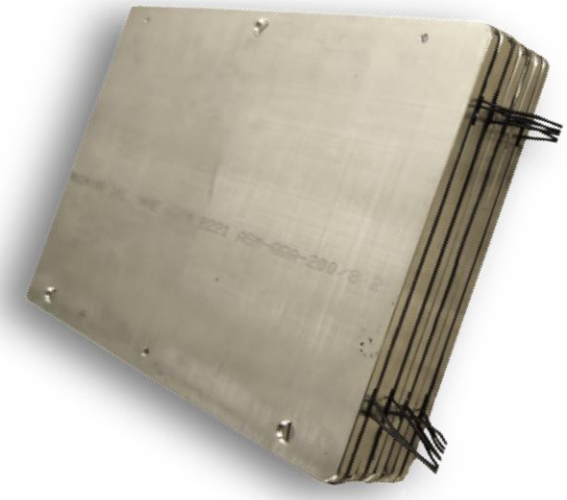


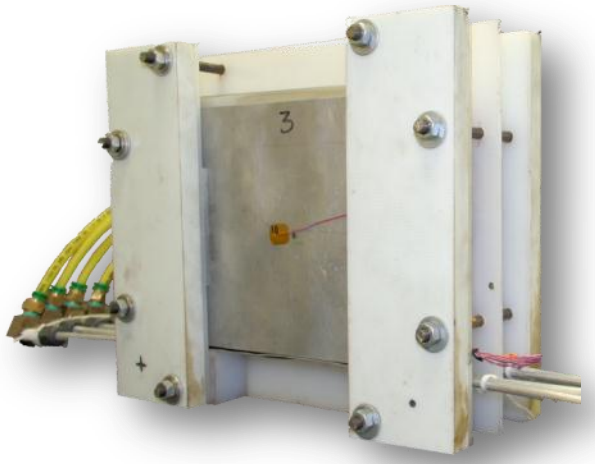




Experimental Variables

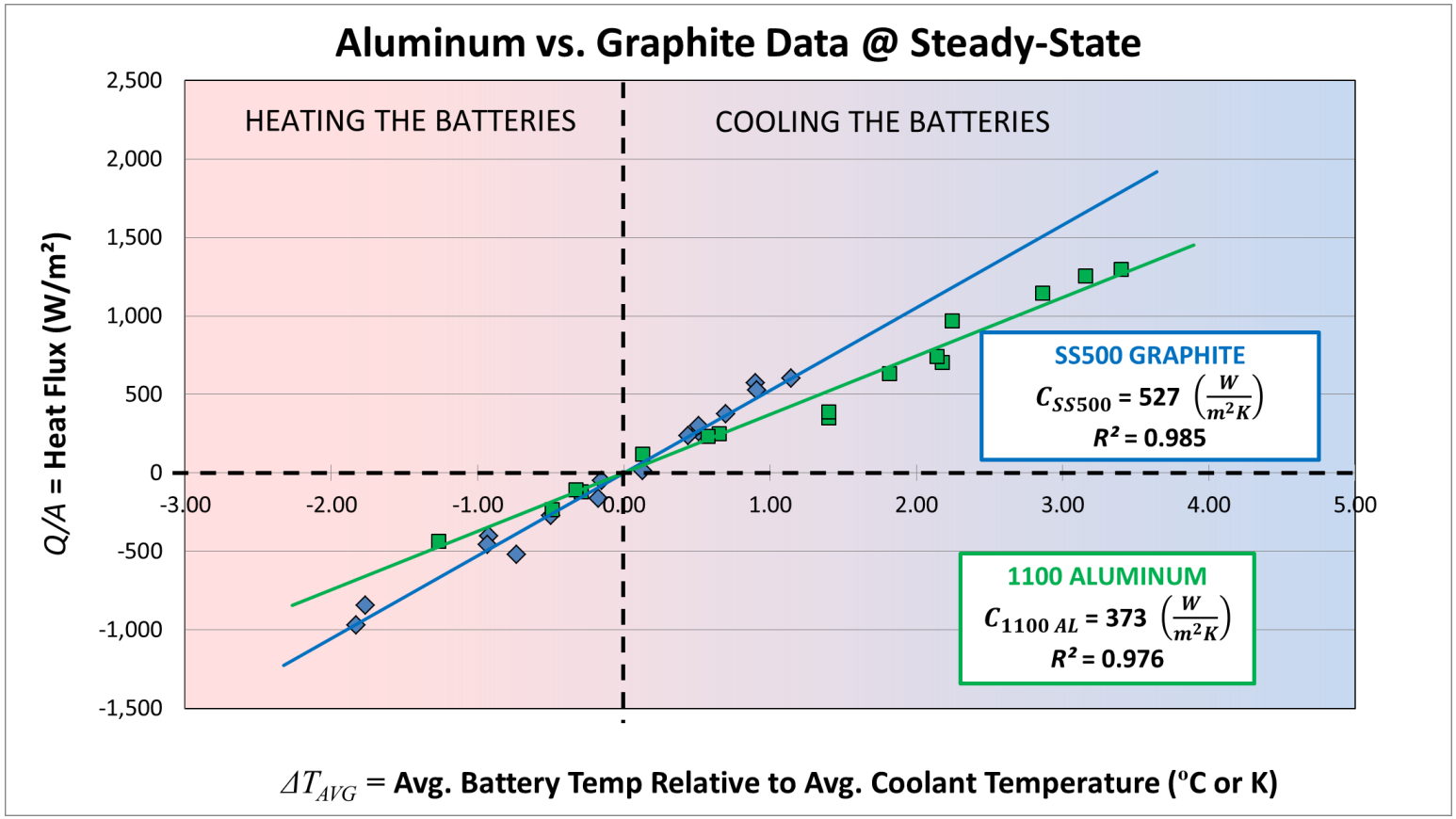
- Simulated Pouch Cell Pack
  - Size of typical automotive cell
  - 14W of heat distributed uniformly across both faces of each cell
  - Decouples testing from Li-ion effects (state of charge, battery degradation
- 1100 Series Aluminum Heat Spreader
  - 0.25 mm thick
  - 220 W/mK thermal conductivity
  - PET coating for electrical isolation
  - Acrylic adhesive on to attach to cell and tubing
- SPREADERSHIELD™ SS500 Graphite Heat Spreader
  - 0.25 mm thick
  - 500 W/mK thermal conductivity
  - PET coating for electrical isolation
  - Acrylic adhesive to attach to cell and tubing





Heat Transfer Coefficient

- The SS500 flexible graphite solution provides a **41% improvement** in heat transfer coefficient versus aluminum



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eGRAF® thermal management products, materials, and processes are covered by one or more of the following US patents: 4,961,991; 5,198,063; 5,830,809; 6,245,400; 6,395,199; 6,432,336; 6,482,520; 6,503,626; 6,538,892; 6,673,284; 6,746,768; 6,749,010; 6,758,263; 6,771,502; 6,777,086; 6,841,250; 6,886,249; 6,982,874; 7,108,055; 7,108,917; 7,138,029; 7,150,914; 7,160,619; 7,161,809; 7,166,912; 7,186,309; 7,232,601; 7,276,273; 7,292,441; 7,303,005; 7,303,820; 7,306,847; 7,365,988; 7,385,819; 7,393,587. Other US and foreign patents granted or pending.

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