MATERIAL SCIENCE ANSWERS TO AIRCRAFT ELECTRIFICATION CHALLENGES

ACKNOWLEDGMENTS

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INVOLVED IN AVIATION SINCE 1943

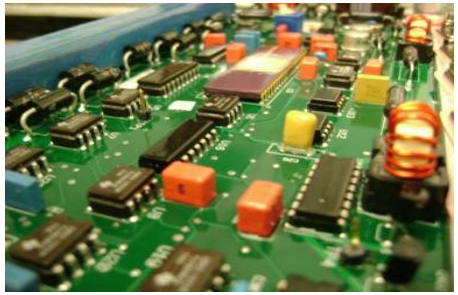
Dow silicones used for:

Cabins, ground support, engines, airframe, and electronic protection

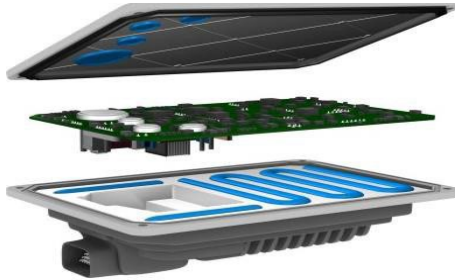
- *Resistance to fuels, water, oils*
- *Remains flexible from -115°C to 150°C continuous, up to 250°C for short durations*
- *Injectable, non-curing when needed*
- *From high flow for fast dispensing to controlled rheology for use on vertical surfaces*
- *Vibration/shock dampening*
- *Reduced maintenance cost*
- *Flame retardant options*
- *High movement capable*

OUR CONTRIBUTION TO THE INDUSTRY

Silicone solutions from Dow

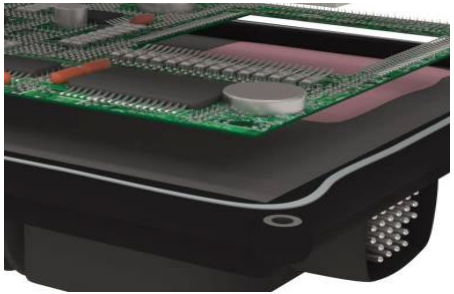


Encapsulants and conformal coatings



Thermally-conductive gap fillers and printable pads

Thermally-conductive encapsulants



Thermally- and electrically-conductive adhesives

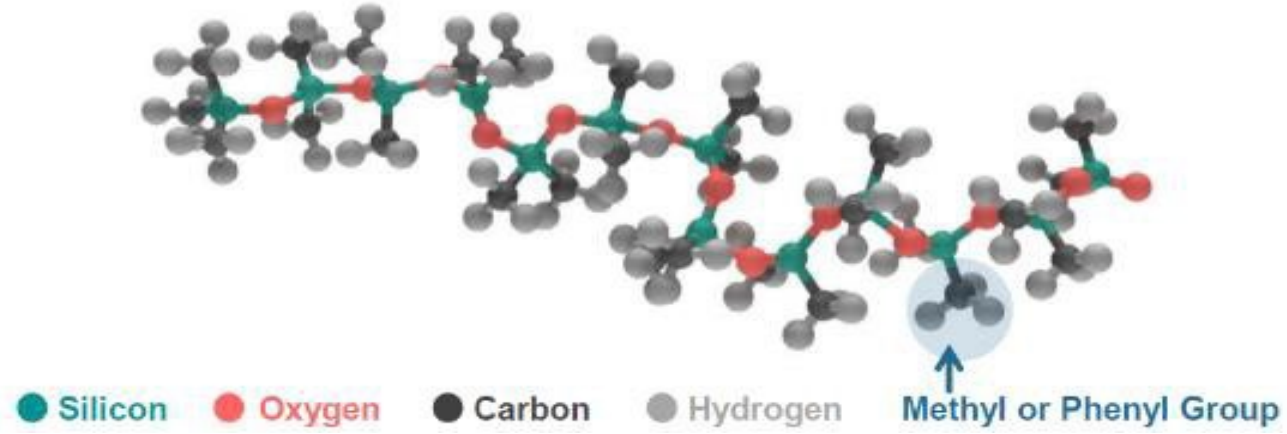
Structural sealing and bonding

Foam gasket material

WHY SILICONES?

Typical features

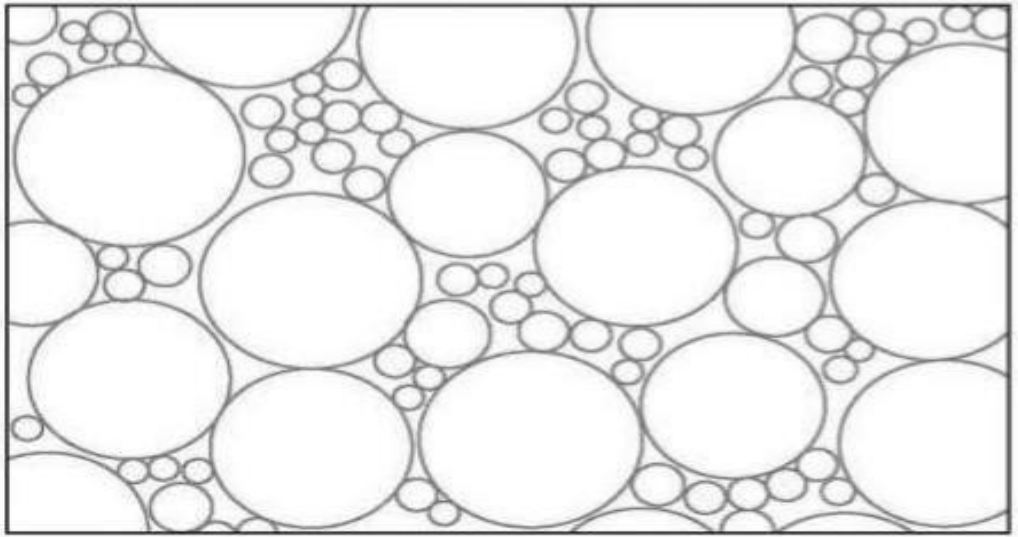
- Low variability of properties with temperature and time
- Various curing chemistries available such as fast room-temperature reaction for easier part handling
- Excellent surface-wetting ability
- Very high material purity



WHY SILICONES?

Silicone compounds loaded with thermally-conductive fillers

- Typically non-flammable (UL94 V-0)
- Remain flexible even at very high filler content (> 80 vol.%)
- If desired, the material can still be made flowable



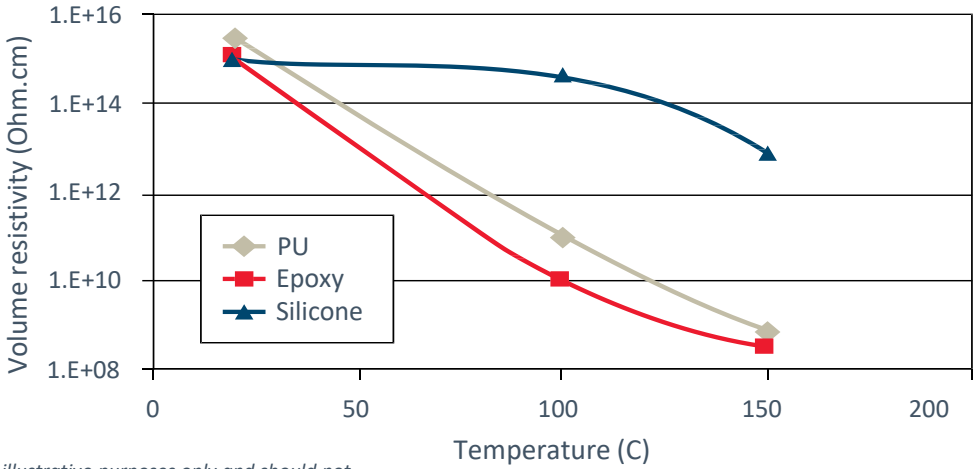
Multimodal particle size distribution to achieve very high loading

COMPARISON WITH ORGANIC POLYMERS

Durability	Contact corrosion	Electrical insulation
Thanks to the Si–O bond, silicones are more stable and more flexible than their organic counterparts • Better flowability during process • Better resistance to processing and operating conditions	**Low risk of contact-corrosion- no water in the material** • With their hydrophobicity, silicones have low water absorption • Silicones also allow entrapped water to escape	**Ideal for high-voltage insulation** • Very limited water absorption • Electrical insulation retains at high temperatures • Very low ionic content* * < 1 ppm for some products

COMPARISON WITH ORGANIC POLYMERS

Covalent bonds	Energy [kJ/mol]	Bond length [Å]	Polymer	Water absorption (24 h)	Moisture vapor transmission
Si - O	445	1.63	Silicone	0.06 %	250 g
C - C	346	1.53	PU	0.09 %	12 g
C - O	356	1.42	Epoxy	1.20 %	7 g



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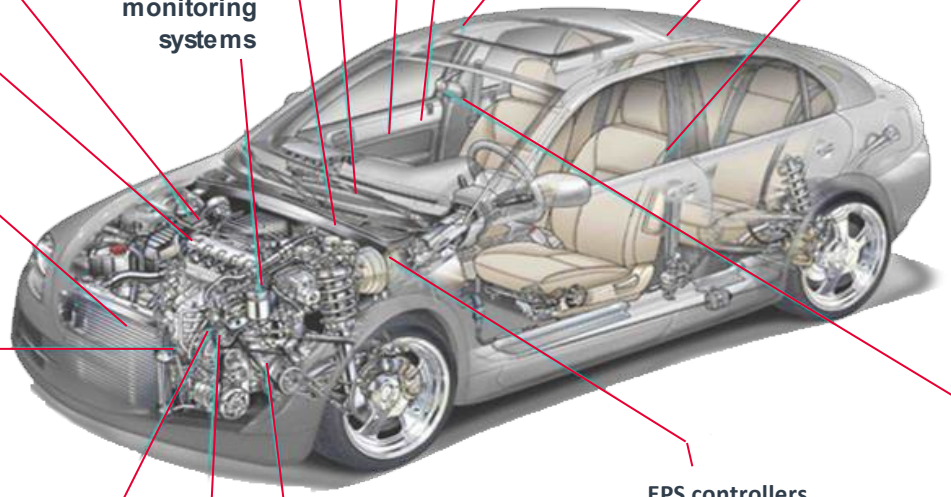
LEVERAGING OUR KNOWLEDGE FROM AUTO APPLICATIONS



Instrument clusters / display units / audio / navigation systems

Airbag controllers and sensors

Security systems

Sunroof and door modules

Air conditioning and heating

Body and chassis controllers

Seat position controllers / seat occupant detectors

Engine control units (petrol/diesel)

Battery monitoring systems

Ignition modules, coils / glow plug controllers

Sensors / actuators MAP, MAF, TPMS, knock sensors, camshaft position sensors, gearbox position sensors, piezo actuators

Fan controllers

Connectors

HEV (hybrid electric vehicle) controllers

Wipers/ rain sensors

Transmission controllers

EPS controllers

Voltage regulators

Starters / alternators

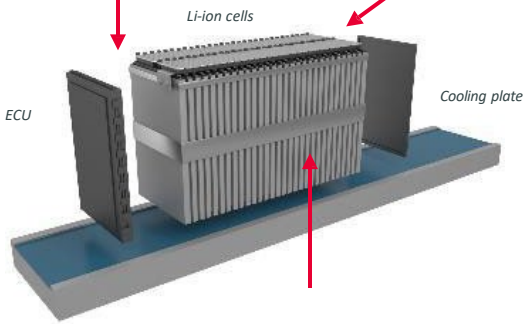
Lighting modules

SILICONES IN BATTERY PACK ASSEMBLY

Prismatic or pouch cell

Adhesives for parts assembly

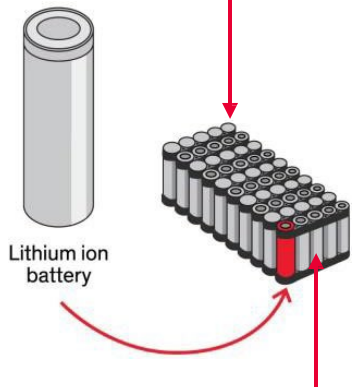
Encapsulants for thermal management



Gap fillers for thermal management

Cylindrical cells

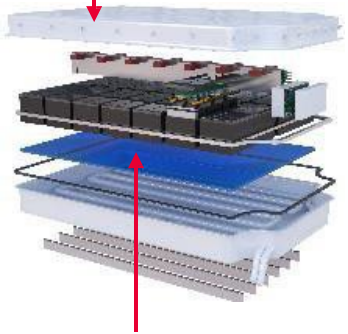
Encapsulants or **gap fillers** for thermal management



Encapsulants or **foams** for fire protection

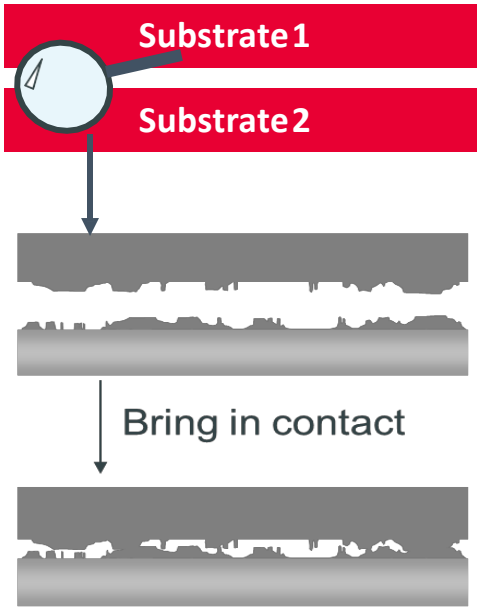
Battery packs

Adhesives for parts assembly

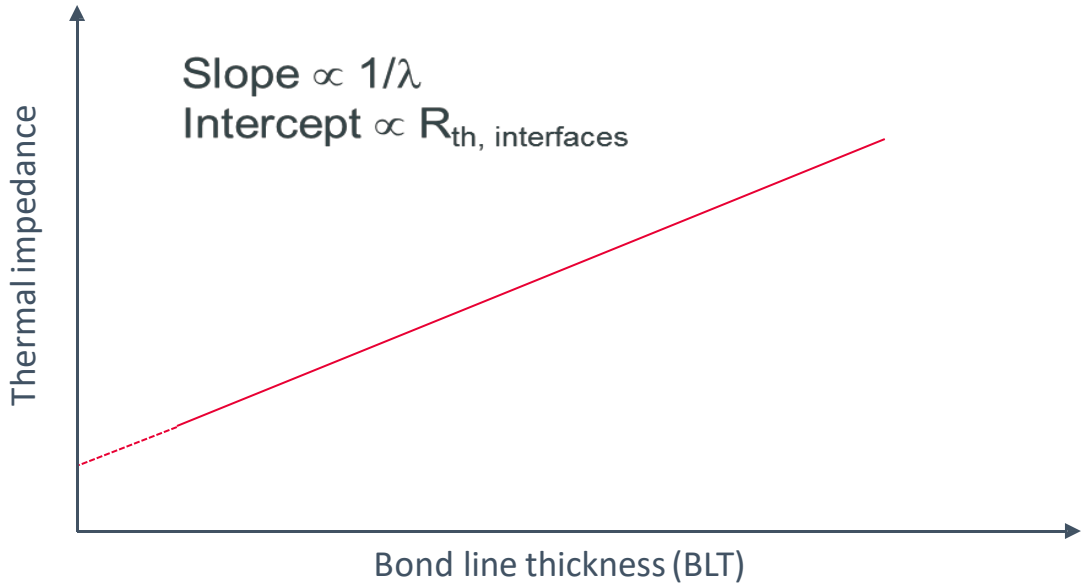


Encapsulants or **gap fillers** for thermal management

THERMAL MANAGEMENT — WHAT MATTERS?



- Device degradation
- Reliabilty issues
- Loss of performances



BATTERY THERMAL MANAGEMENT — ENCAPSULANTS

Battery modules and battery packsare commonly encapsulated with soft,thermally- conductive materialsto fill existing voids and optimize heat dissipation.

Typical requirements

- Thermally conductive:1~2 W/m.K
- Low viscosity to fillintricate geometries
- Electrically insulative
- Non-flammable: UL94 V-0 or FMVSS 302
- Vibration dampening: material has to remain flexible

Property	DOWSIL™ TC-4605	DOWSIL™ TC-4605 HLV
Thermal conductivity [W/m.K]	1.0	
Specific gravity	1.65	
Flammability	UL94 V-0 at 1.5 mm	
Cure time	1 h at 120°C	
Viscosity (mixed) [cP]	2900	1900
Dielectric strength [kV/mm]	21	24
Adhesion on anodized Al[MPa]	0.8	1.5

Main difference with a gap filler is with lower viscosity
Higher thermal conductivities under development

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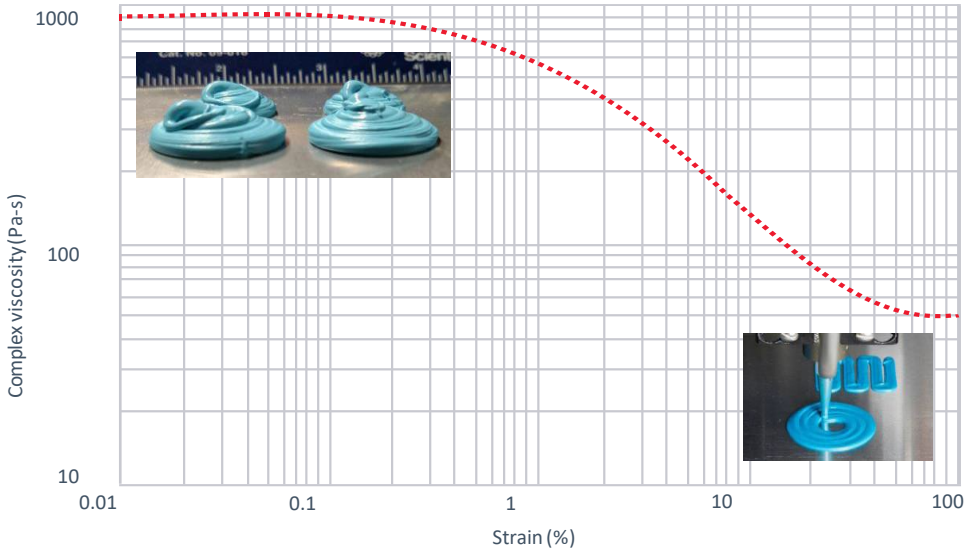
BATTERY THERMAL MANAGEMENT: GAP FILLERS – DISPENSING

Thixotropic behavior useful for

- High-throughput dispense
- Good wetting of the substrate
- Accurate dispense (no afterflow)
- Stay in place, even in vertical position



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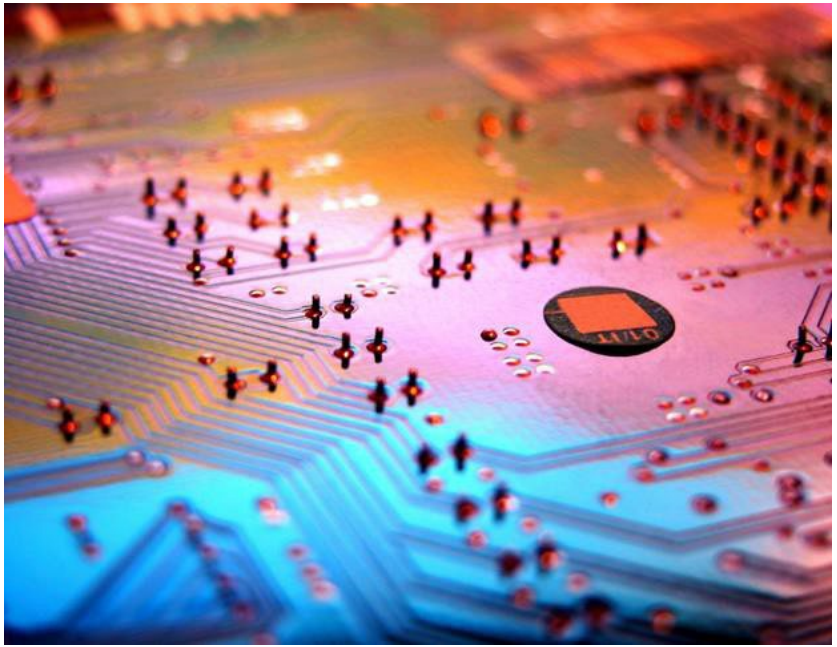
DIELECTRIC GELS FOR PROTECTING SENSITIVE COMPONENTS

Silicone gels offer remarkably low modulus to protect the even some of the most delicate components against mechanical stress and the effects of thermal cycling.

- Maximum stress-relief
- Self-healing
- Flame-resistant gels with UL 94V flammability classification
- Unique options for solvent and fuel resistance, rapid UV-cure, and enhanced strength in toughened gels



DIELECTRIC GELS PROVIDE NOVEL SOLUTIONS FOR ENHANCED THERMAL RESISTANCE

Standard

- Room-temperature cure
- Colorless / pigmented
- One- or two-part

Low temperature

- DOWSIL™ 3-6635 Dielectric Gel down to -60°C
- DOWSIL™ Q3-6575 Dielectric Gel down to -80°C
- DOWSIL™ 3-4155 HV Dielectric Gel

Toughened

- Room-temperature / heat cure
- Colorless / pigmented
- Two-part
- Filled for durability
- Primerless adhesion

Specialty

- Low volatility
- UV Cure – DOWSIL™ X3-6211 Encapsulant
- SYLGARD™ 535 Thixotropic Dielectric Gel
- DOWSIL™ TC-3015 Thermal Gel

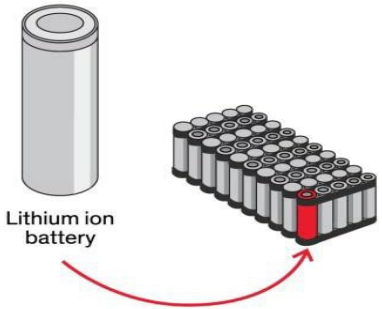
BATTERY FIRE PROTECTION — ENCAPSULANTS AND FOAMS

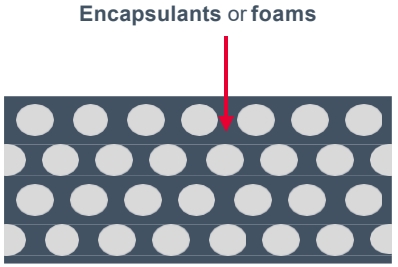
By providing individual cell protection in the case of a thermal event, silicone encapsulants and foams can slow thermal runaway propagation in lithium-ion battery systems.

Typical requirements

- Non-flammable: UL94 V-0
- Low viscosity to fill intricate geometries
- Vibration dampening: material has to remain flexible
- Electrically insulative
- Permeable to emergency degassing for pressure balancing during a thermal event

Source: NASA Presentation at Sustainable Aircraft Symposium May 2016





Encapsulants or foams are filling the gap between cylindrical cells

BATTERY FIRE PROTECTION: ENCAPSULANTS AND FOAMS – KEY PROPERTIES

Type	Material	Specific gravity	Cure condition (at 25°C)	Viscosity (mixed) [cP]
Encapsulant	SYLGARD ™ 170 Silicone Elastomer	1.37	24 h	2,100
	SYLGARD ™ 170 Fast Cure Silicone Elastomer	1.38	12 min	2,400
Foam	DOWSIL™ 3-6548 RTV Silicone Foam	0.2 ~ 0.4	1.5 min (snap time)	Part A: 50,000 Part B: 60,000

In case of fire protection, silicone foams are a lightweight alternative to traditional encapsulants

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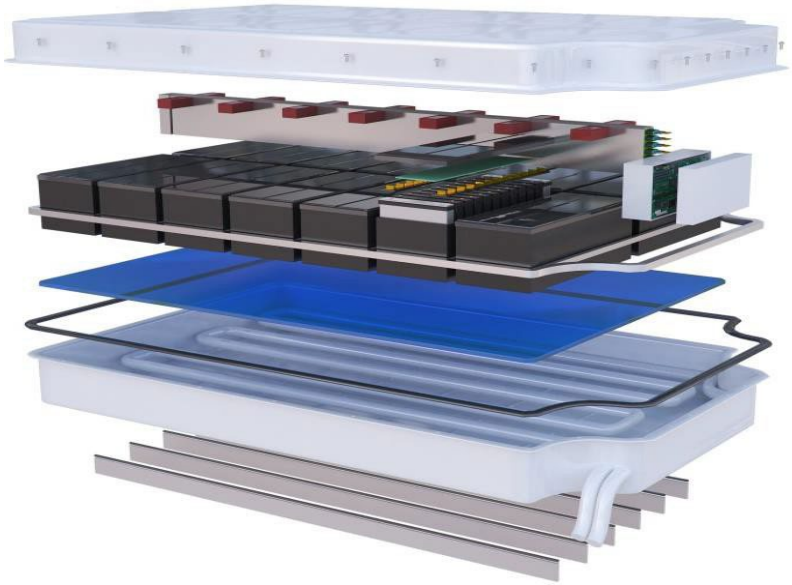
Flammability test on 3mm-thick DOWSIL™ 3-6548 Foam

BATTERY ASSEMBLY — ADHESIVES

In a battery system, numerous parts have to be assembled together: battery housing, battery modules, cooling plate, ECU, temperature sensor, heat sinks, PTC heater…

Typical requirements

- Unprimed adhesion to a variety of metallic and plastic substrates
- Curing at room temperature to avoid heat generation in vicinity of the battery cells
- Electrically insulative
- Depending on the application, thermally conductive adhesives can be considered



BATTERY ASSEMBLY: ADHESIVES – FASTER RT CURING

New DOWSIL™ EA-4700 CV Adhesive offers faster room-temperature curing to customers.

Two-part, room-temperature vulcanization

- **Cure in 2 hours at 25°C**
- 20 minute pot life
- Controlled silicone volatility

Room-temperature adhesion

- **Achieve cohesive adhesion within 24 hours**
- Durable adhesion to typical substrates

Two-part, room-temperature vulcanization

- **150°C aging**
- 85°C/85% RH aging
- Thermal shock

Substrate	Lap shear [MPa]
Die cast Al	2.4
PA	2.0
PBT	2.4
PPS	2.4
PC	2.3
Glass	2.0

Bond line thickness: 1 mm
Curing: 1 week at 25°C

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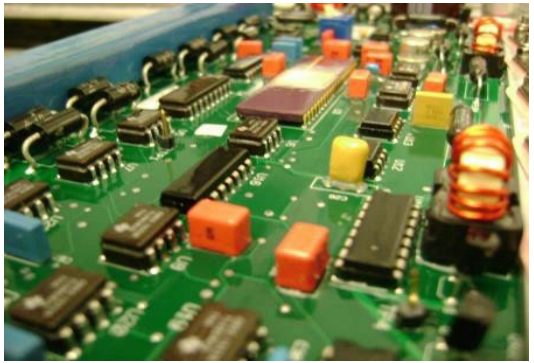
ELECTROMAGNETIC SHIELDING: WHERE IS *YOUR* DESIGN FOCUS?

- Reducing the electromagnetic field in a space by blocking it with barriers made of conductive or magnetic materials.
- EMI shielding can be performed at different levels.
- Many silicone products can be used to help deliver effective EMI shielding.

The unique silicone characteristics, in combination with fillers blends, can deliver customized electrical conductivity.

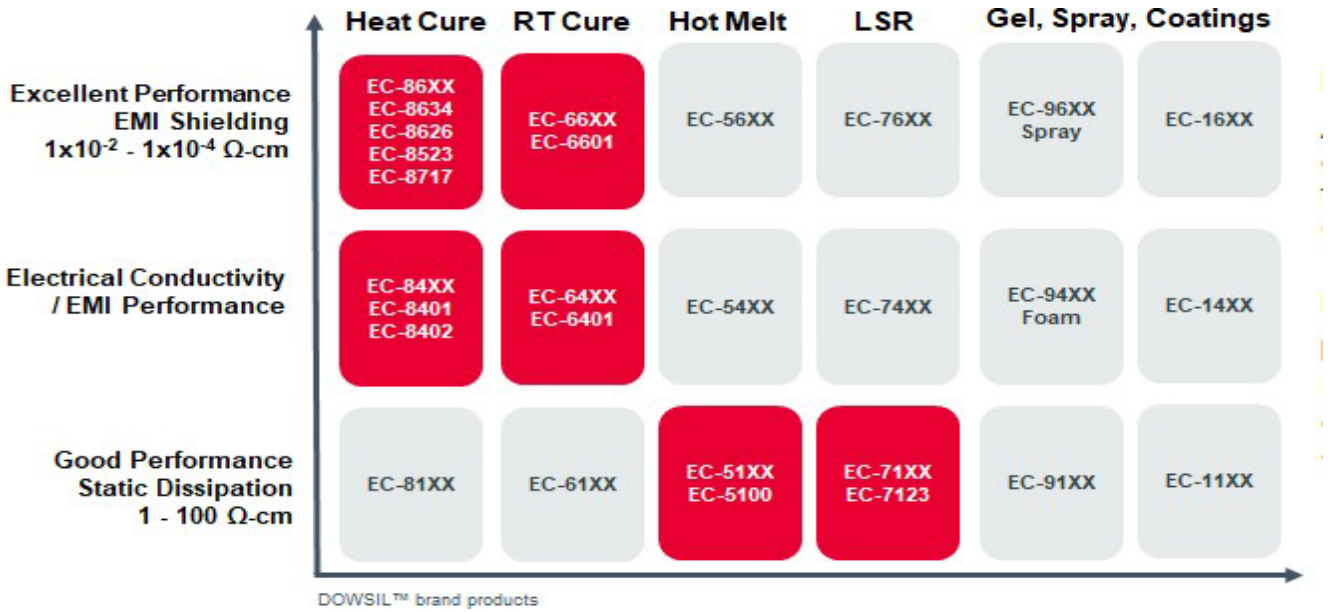


PCB Design

Module design, material selection and assembly

System design and assembly

DOWSIL™ EC/EMI SILICONE PORTFOLIO AT A GLANCE



Delivery - multiple productforms

Adhesive, sealant, low modulus elastomer,cure-in- place and form-in-place gasket (FIPG), emulsion, coating, gel, foam, spray

Formulation expertise

- Innovative toolbox of key intermediates, polymers, and additives that can be modified and formulated to fit your needs
- Expertise in electrically conductive fillers

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DOW IS YOUR EMI PARTNER

Bring us your challenges–
We want to help you design your solutions

Innovative approach

- Close collaboration to help you design the solutions you need
- Deep technical expertise in material design and engineering

Formulation expertise

- Multiple product forms: adhesives, elastomers, gaskets, low-modulus emulsions, coatings
- Innovative toolbox of key intermediates, polymers and additives that can be modified and formulated to fit your needs

DOW IS YOUR EMI PARTNER

Bring us your challenges–
We want to help you design your solutions

Supply chain integration

- Backward integration to source materials to build silicone polymers and intermediates

Proven performance

- More than 15 years of electrically conductive adhesive experience in demanding semiconductor markets

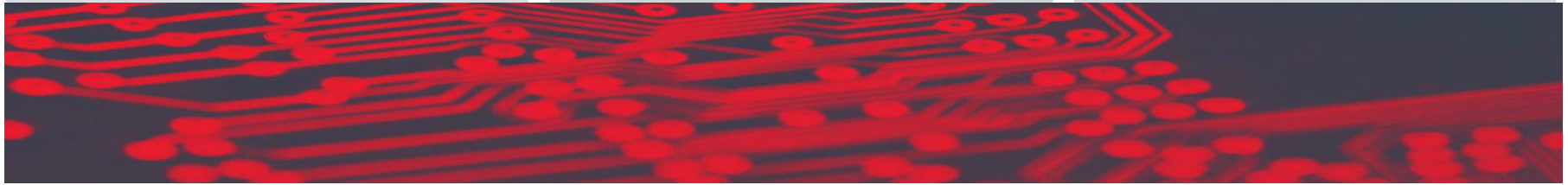
Silicone EMI solutions

- **Shielding, absorption, grounding**
- **Shielding effectiveness**
- **Electrical resistivity**
- **Filler type**
- **Mechanical (elongation, strength)**
- **Thermal stability**
- **Processing**

CUSTOMER SATISFACTION STARTS WITH DESIGN

DOWSIL™ Silicone solutions can help with:

Process optimization	Product handling optimization	Improving product robustness
• Energy-saving (Lower temperature of cure, shorter time) • Minimize substrates preparation • Reduce equipment maintenance	• Storage • Shelf life • Dispensing • Assembly • Cure	• Void-free • Vertical holding • Cure • Adhesion



Seek

Together™

THANK YOU

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