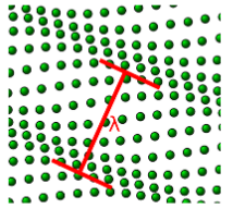
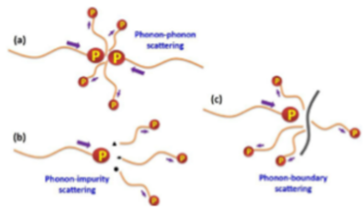
Thermal Conductivity Basics

What is Thermal Conductivity?

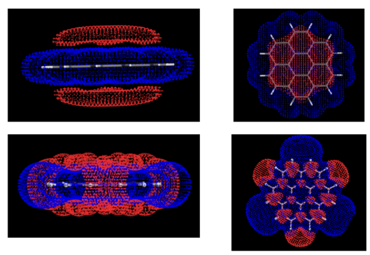
- In metals, valence electrons conduct heat energy + electric current
- Phonons – lattice vibrations – transport heat through non-metals
- = *Cp*
  - = density
  - = thermal diffusivity
  - *Cp* = heat capacity
- Transport is intrinsically important for thermal conductivity
- Phonon scattering insulation





Mehra, *et al*, *Appl Materials Today*, 2018

Thermal Conductivity, Electrical Insulation



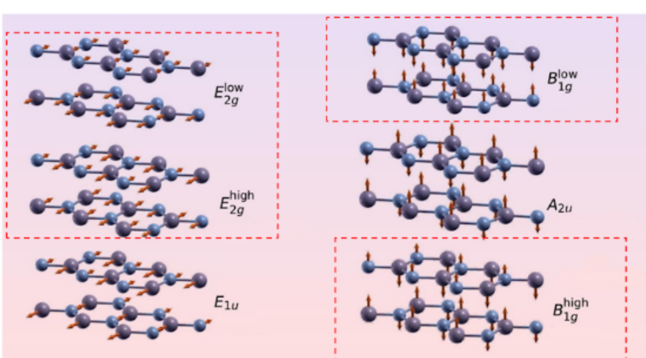
Graphite:

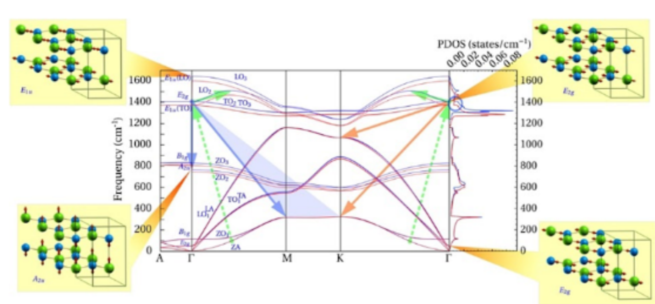
- Full delocalization of electrons full aromaticity
- Electrical delocalization in graphite leads to high electrical conductivity and high thermal conductivity

hexagonal-Boron Nitride:

- Electrons are mainly distributed on N atoms partial aromaticity
- Thermal conductivity arises from phonon vibrations

Lattice Vibration Modes of h-BN





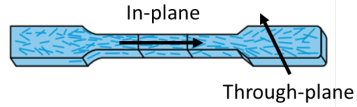
9 optical modes which decompose at the Brillouin zone center as E1u + A2u + 2 E2g + 2 B1g

In plane and out-of-plane vibrational modes in TC THz frequency range (B1g, E2g)

Nanophotonics 2020, 9 (11), 3483 – 3504

In-Plane vs Through-Plane Thermal Conductivity

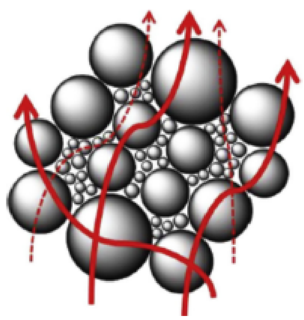
For many applications, high through-plane thermal conductivity is desired to transport heat away from motors and sensitive electronics.



Anisotropic fillers (glass fiber, plate-like BN) will orient in the flow direction during injection molding. Different degrees of orientation will be achieved depending on part geometry, part thickness, injection gate design, and injection molding process parameters such as temperature and pressure.

Particle Packing & Percolation

Percolation pathways through the more thermally conducting fillers will enhance the overall thermal conductivity of the formulation. Factors such as particle size, shape, dispersion, and orientation will be affected by processing conditions and part design.



Thermal Conductivity of Common Polymer Resins

Taken from Chen, Du, Ginzburg, *Progress in Polymer Science*, 2006

Thermoplastic polymers	Thermal conductivity at room temperature (W/(m K))
High density polyethylene (HDPE)	0.33–0.53
Ultrahigh molecular weight polyethylene (UHMWPE)	0.41–0.51
Commercial thermotropic liquid crystalline polymers (LCP)	0.30–0.40
Polyoxymethylene (Homo) (POM)	0.30–0.37
Low density polyethylene (LDPE)	0.30–0.34
Poly(ethylene vinyl acetate) (EVA)	0.35
Polyphenylene sulfide (PPS)	0.30
Poly(butylene terephthalate) (PBT)	0.25–0.29
Polytetrafluoroethylene (PTFE)	0.27
Polyamide-6,6 (PA66)	0.24–0.33
Polyamide-6 (PA 6)	0.22–0.33
Polyetheretherketone (PEEK)	0.25
Polysulfone (PSU)	0.22
Polymethylmethacrylate (PMMA)	0.16–0.25
Polycarbonate (PC)	0.19–0.21
Urethane base TPE (TPU)	0.19
Poly(acrylonitrile-butadiene-styrene) copolymer (ABS)	0.15–0.20
Polyvinyl chloride (PVC)	0.13–0.29
Polyvinylidene difluoride (PVDF)	0.19
Styrene/polybutadiene copolymer (SB)	0.17–0.18
Styrene-acrylonitrile copolymer (SAN)	0.15–0.17
Poly(ethylene terephthalate) (PET)	0.15
Polystyrene (PS)	0.10–0.15
Polyvinylidene chloride (PVDC)	0.13
Polyisobutylene (PIB)	0.12–0.20
Polypropylene (PP)	0.11–0.17
Polyimide, thermoplastic (PI)	0.11