Improved Organics for Power Electronics and Electric Motors

A. A. Wereszczak, C. W. Ayers,* R. H. Wiles,*
H. Wang, and H. –T. Lin
Oak Ridge National Laboratory (ORNL)
*** National Transportation Research Center (NTRC/ORNL)**

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Overview

Timeline

- Project start: October 2010
- Project end: September 2013
- Percent complete: 50%

Budget

- Total project funding
  - DOE 100%
- FY11: $250k
- FY12: $150k
- FY13: $150k

* VTP Multi-Year Program Plan 2011-2015

Barriers*

- Barriers Addressed
  - Reliability and lifetime of power electronic devices (PEDs) and motor components degrade rapidly with temperature increase.
  - PEDs and motor components need improved thermal management to operate at higher temperatures.
  - New paradigms in cooling would enable achievement of higher power densities without compromise to device reliability.
- Targets:
  - DOE VTP* 2020 target: 105°C Coolant
  - DOE VTP* 2020 target: 4 kW/liter power density

Partners

- NTRC – ORNL
- SolEpoxy (EMC manufacturer)
- Ube (powder manufacturer)

Objectives

- Identify and develop lower-cost and better-performing organic compounds or "epoxy molding compounds" or EMCs for dielectric and thermal management applications in power electronics, electric motors, and film capacitors.
- Reduce volume and improve thermal reliability of power electronics, electric motors, and film capacitors through improved thermal management strategies.
- Develop EMCs that have:
  - Sustained dielectric performance
  - Optimized filler particle size distribution and volume %
  - High thermal conductivity (> 5 W/mK)
  - Use non-toxic and inexpensive filler
  - Equivalent potting and injection molding characteristics to existing EMCs

Milestones

- **FY11: Established baselines by measuring thermal properties of unused and serviced organic molding compounds from power electronic devices, electric motors, and film capacitors.**

- **FY12: Model, design, and fabricate filler-containing-EMC having 10x thermal conductivity increase over monolithic epoxy.**

Technical Approach

- Optimize filler particle size distribution and volume fraction.
- Fabricate EMCs with organic matrices that allow transfer molding and potting.
- Demonstrate thermal conductivity (κ) > 5 W/mK.

Candidate Filler Properties

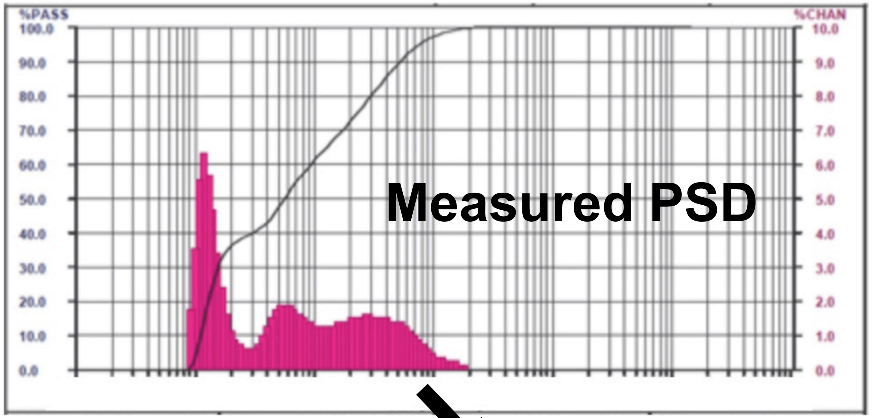
Material	Electrical Resistivity at 25°C ($\Omega \cdot$cm)	Thermal Conductivity at 25°C - k - (W/m·K)	Heat Capacity - Cp - (J/kg·K)	Density - r - (kg/m^3)	Coefficient of Thermal Expansion - CTE - (x 10^{-6}/°C)	Estimated Cost ($/kg)
Silica (SiO_2) silicon dioxide	> 10^{14}	2	700	2600	0.5	2
Alumina (Al_2O_3) aluminum oxide	> 10^{14}	30	900	3900	8	5
Boron nitride (BN) * Anisotropy	> 10^{14}	275*	1600	1900	1*	100
Magnesia (MgO)	> 10^{14}	40	900	3600	10	5
Silicon carbide (SiC)	> 10^{2}	120	800	3100	4	40
Aluminum nitride (AlN)	> 10^{14}	250	700	3200	5	400
Beryllia (BeO) berylium oxide	> 10^{14}	280	600	2900	9	800
Epoxy	> 10^{12}	0.05 - 0.4	1500	1200	30-60	5

Technical Accomplishments (1 of 8)

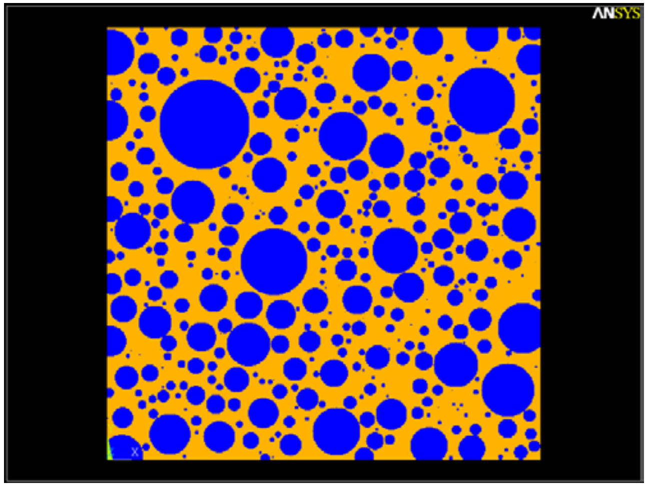
- Identified approximate filler particle size distribution (PSD) and volume fraction (Vol%)
- Transient thermal model developed using PDS and Vol%
- Modeled effect of higher κ on components
- Established interaction with EMC manufacturer to make first set of high κ EMCs
- Thermal conductivity of 2.8 W/mK achieved with first set

Technical Accomplishments (2 of 8)

Software Was Developed to Create 2D Images of PSDs That in Turn Enables Thermal Conductivity Modeling



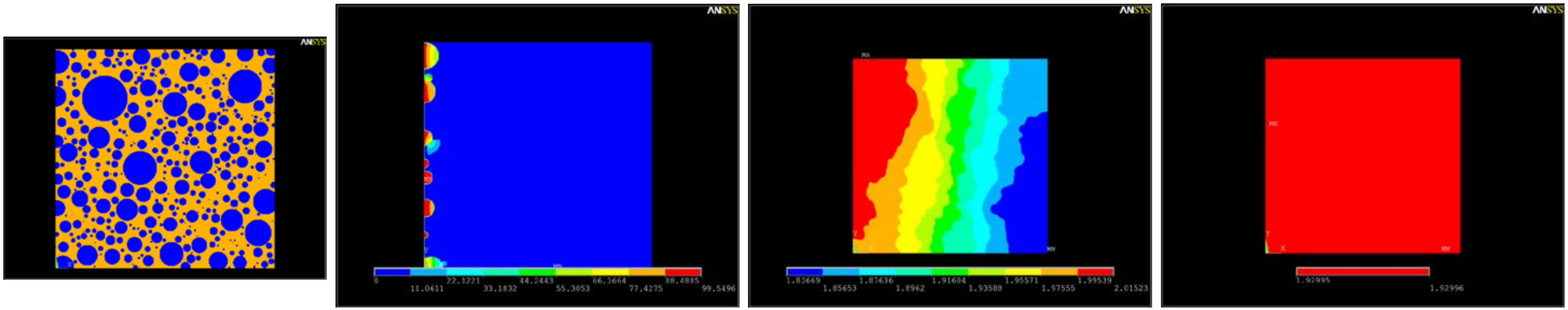
- Particle size distribution (PSD)
- Volume fraction
- Percolation limit
- Effects on thermal conductivity

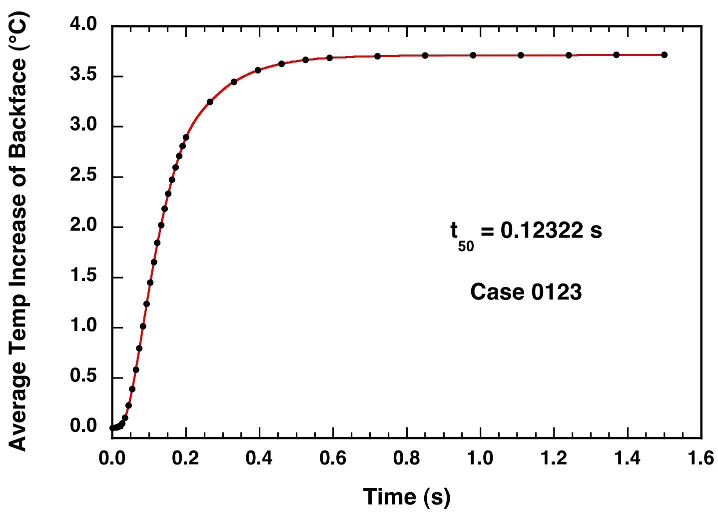


Technical Accomplishments (3 of 8)

Transient Thermal Modeling Enables Estimation of EMC κ

Temperature as a function of time →



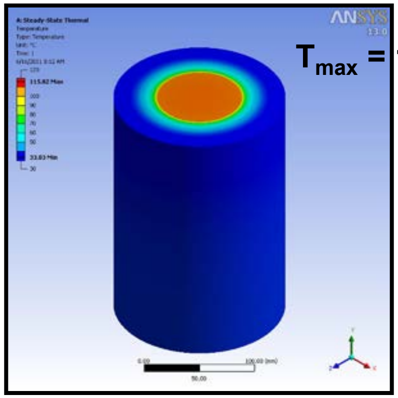


$$D = \frac{\kappa}{\rho \bullet Cp} = \frac{0.1388 \bullet T^2}{t_{50}}$$

D = diffusivity
κ = thermal conductivity
ρ = density
Cp = heat capacity
T = thickness
t_{50} = time to reach 50% max temp

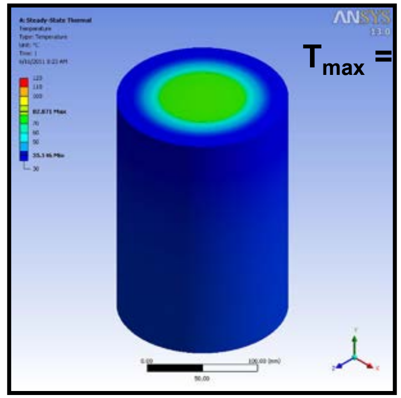
Film Capacitor FEA Example: Effect of EMC κ

κ = 0.5 W/mK



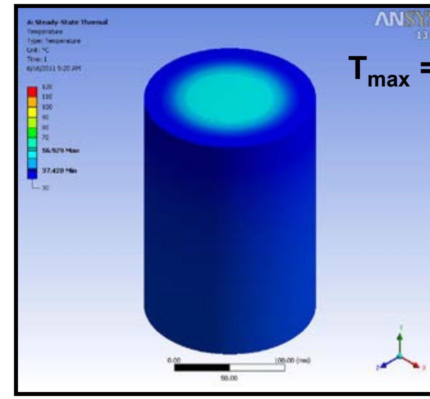
T_{max} = 116°C

κ = 1.0 W/mK



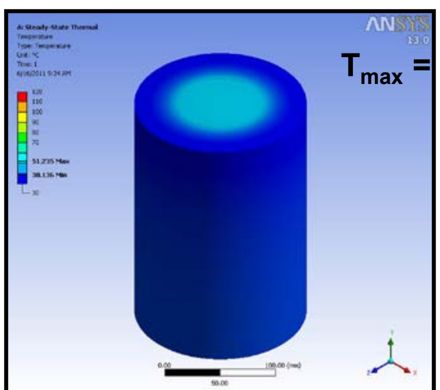
T_{max} = 83°C

κ = 3.0 W/mK



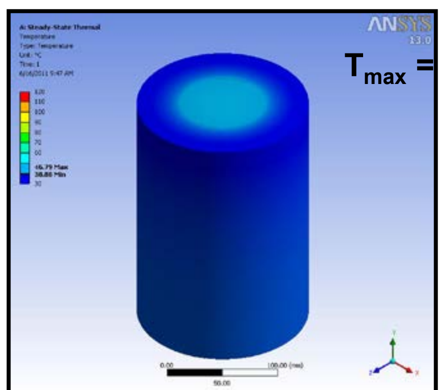
T_{max} = 57°C

κ = 5.0 W/mK



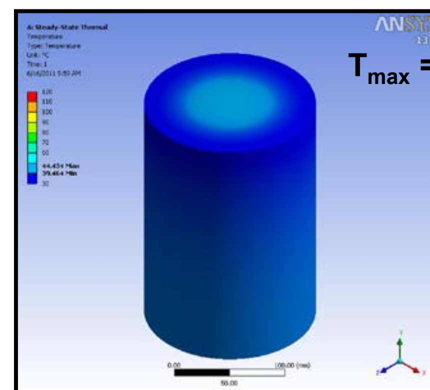
T_{max} = 51°C

κ = 10 W/mK



T_{max} = 47°C

κ = 20 W/mK

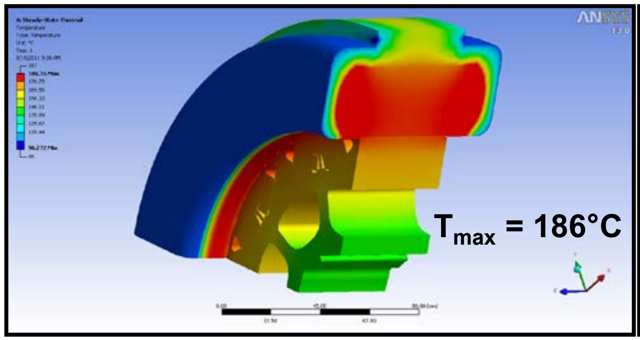


T_{max} = 44°C

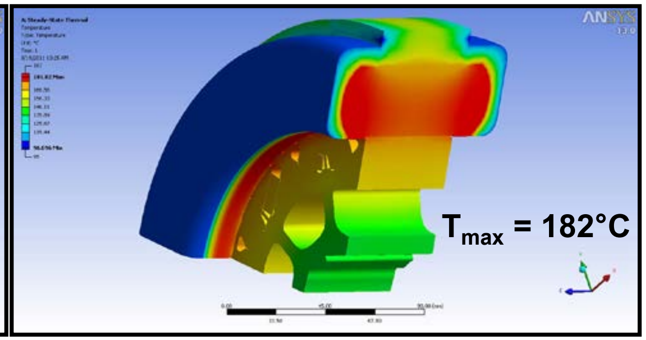
Technical Accomplishments (5 of 8)

Motor Component FEA Example: Effect of EMC κ

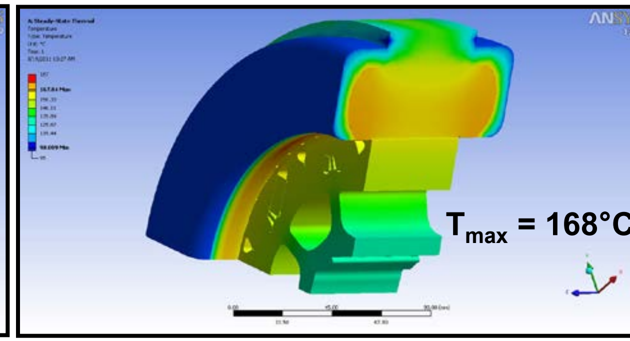
κ = 0.5 W/mK



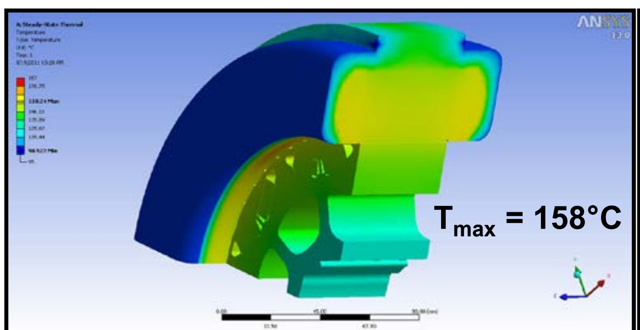
κ = 1.0 W/mK



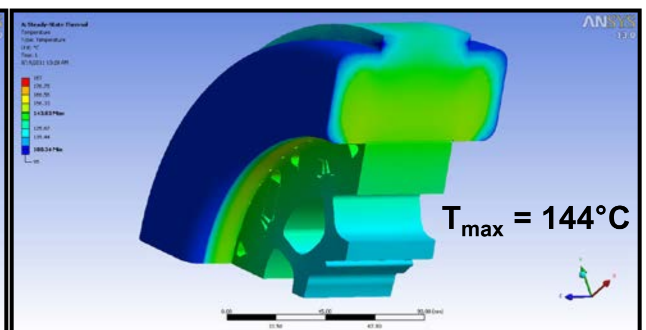
κ = 3.0 W/mK



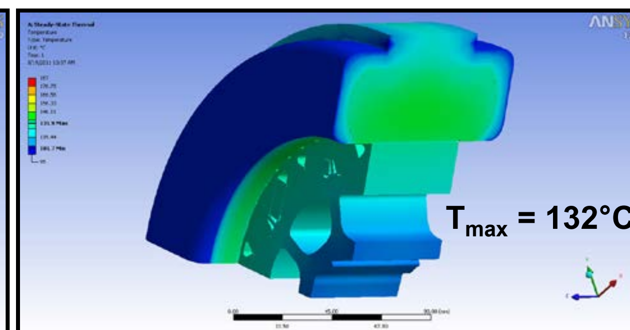
κ = 5.0 W/mK



κ = 10 W/mK



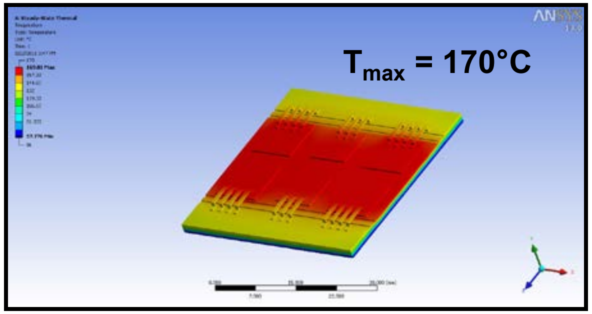
κ = 20 W/mK



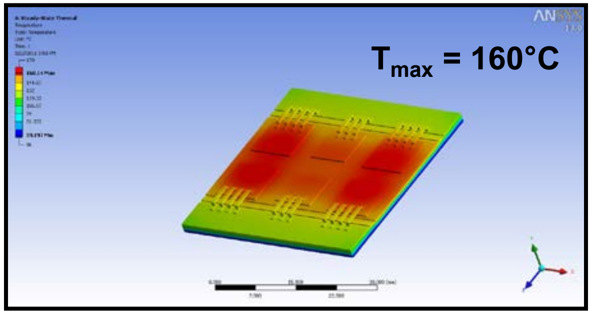
Technical Accomplishments (6 of 8)

Power Module FEA Example: Effect of EMC κ

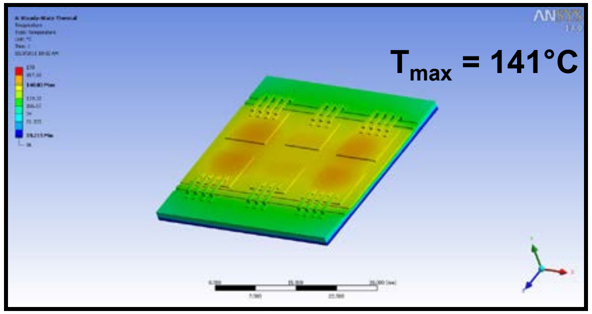
κ = 0.5 W/mK



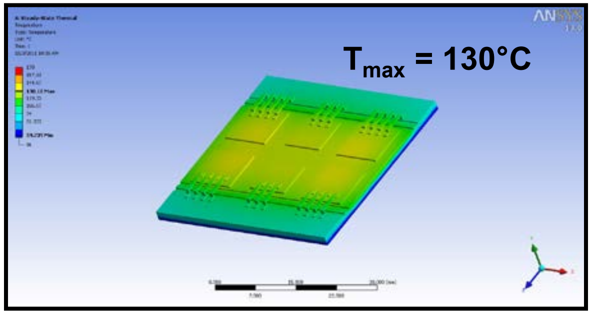
κ = 1.0 W/mK



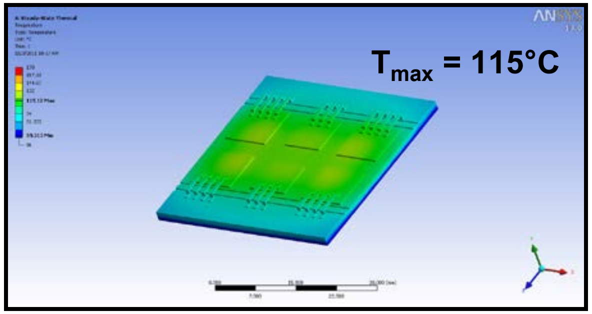
κ = 3.0 W/mK



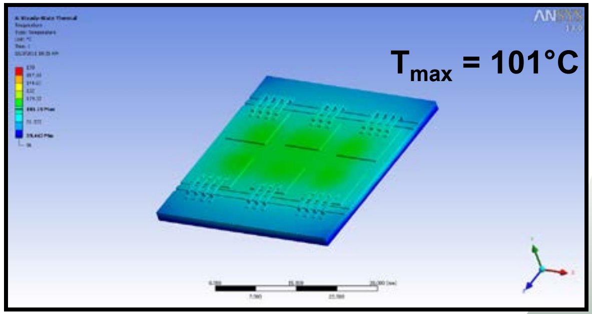
κ = 5.0 W/mK



κ = 10 W/mK

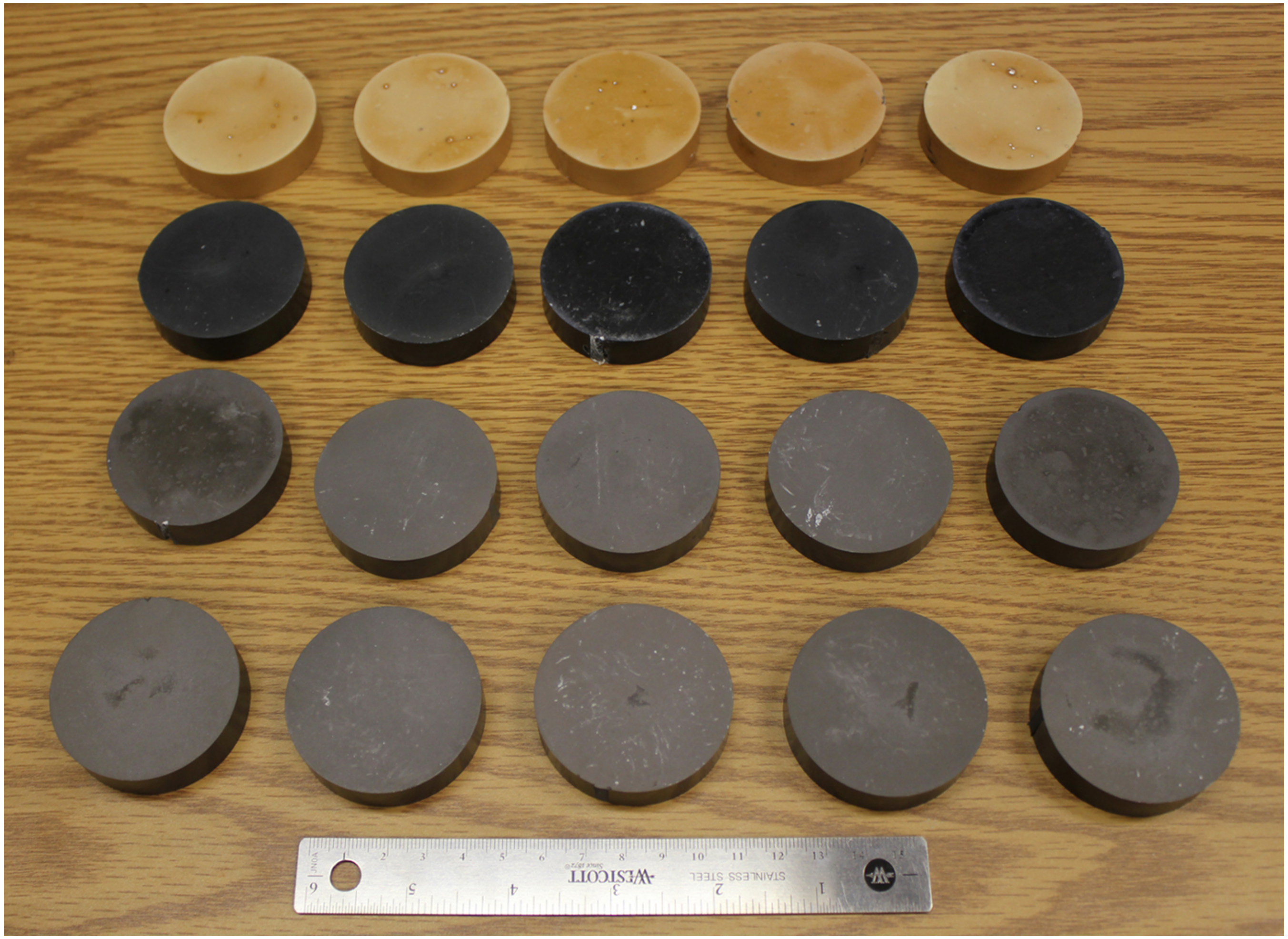


κ = 20 W/mK



Technical Accomplishments (7 of 8)

EMCs Fabricated for ORNL by EMC Manufacturer



A

B

C

D

Technical Accomplishments (8 of 8)

Properties of First Set of EMCs

	Sample A	Sample B	Sample C	Sample D
	Epoxy (only)	SiO_2-EMC Vf-1	new-EMC Vf-2	new-EMC Vf-1
Thermal Conductivity, W/m•K	0.23	1.42	1.89	2.80
Surface Resistivity, Ω	1.72E+17	1.46E+17	1.88E+10	7.3E+9
Volume Resistivity, Ω•cm	3.13E+16	6.41E+16	6.10E+10	2.0E+8

Future Work

- Attention in FY12 has turned to consideration and use of:
  - MgO as a filler, its PSD, and Vol %
  - Higher temperature-capable epoxy
- Fundamental studies using monosized spheres with known thermal conductivity as filler
- Seeking EMC thermal conductivity > 10 W/mK
- Greater interaction with VTP PEEM motor project with NTRC/ORNL's J. Miller

Summary

- **Identifying and developing lower-cost and better-performing organic compounds for dielectric and thermal management applications in power electronics, electric motors, and film capacitors.**

- **Comparing epoxy molding compounds (EMCs) of unused and used components through thermal and microstructural characterization.**

- **Developing new EMCs with high thermal conductivity, that have predictable and simple processing characteristics, and are inexpensive.**