High Temperature, High Voltage and High Thermal Epoxy Molding Compound

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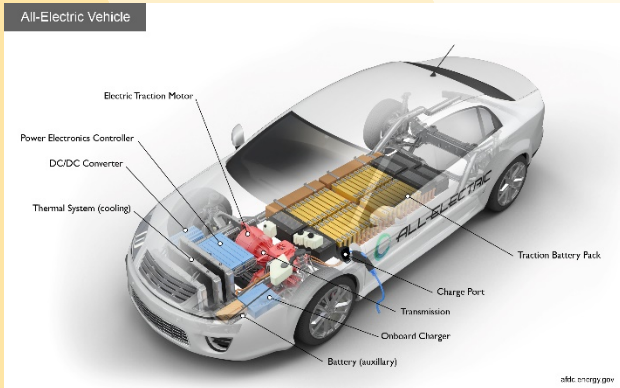
Outline

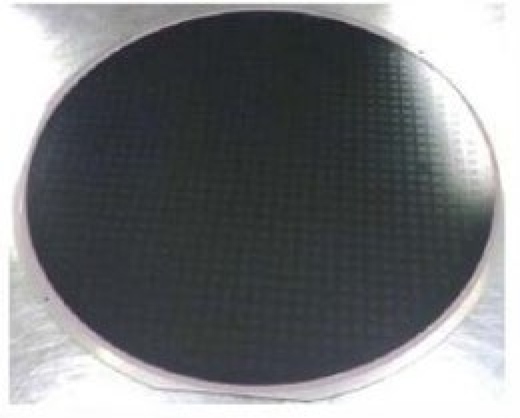
- ☐ Strategic Need
- ☐ Goals & Objectives
- ☐ Technical Approach Beyond Prior Art
- ☐ Research Highlights
- ☐ Results
- ☐ Summary
- ☐ Project Plan

1. Overview

1.1 Strategic Need

Growing needs of reliable plastic encapsulant materials with fast heat removal capability for high temperature high voltage power applications.





Fast adoption of modular molded power cards in (H)EVs

Increasing max. junction temperatures in WBG power dies (250 ºC)

Increased operation voltages (12V-48V/up to 800V)

Further package minimization in high performance packaging (FOWLP etc.)

1. Overview

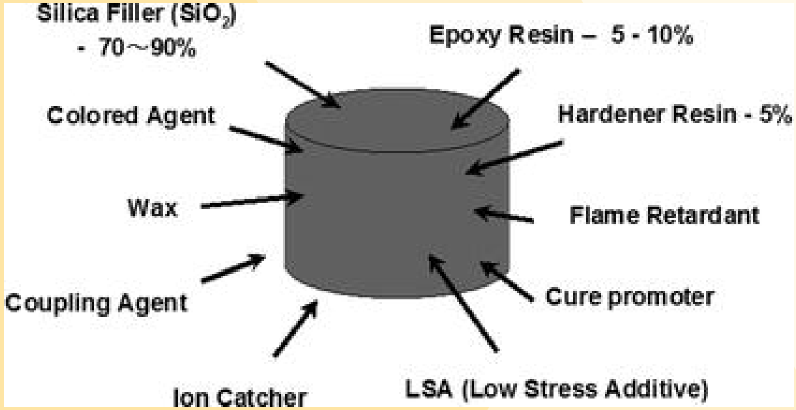
1.2 Goals & Objectives

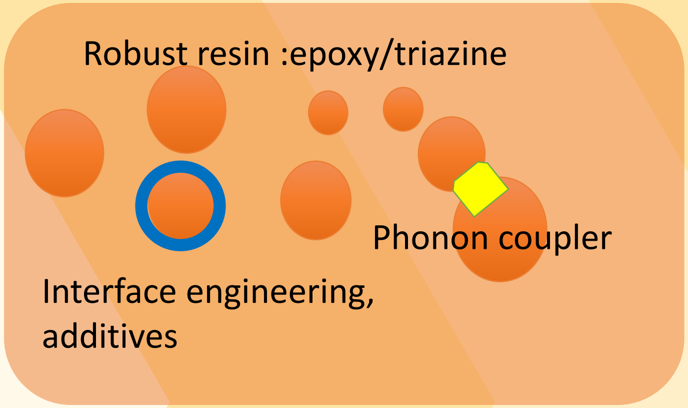
☐ Design and demonstration of a new class of molding compounds with high-temperature stability, breakdown voltage and thermal conductivity that meet the requirements for next-generation high-power/voltage electronics packaging.

#	Parameter	Target	Prior Art	Challenges	Research Tasks
1	Thermal stability	>1000 h at 250 °C	Serving temp. < 200°C	• High temperature degradation of polymers; • Stability of physical properties at high temperature aging.	Design and demonstration of a new class of mold compounds resin material with high T_g , high decomposition onset and good stability during aging.
2	Breakdown voltage(BDV)	>50 kV/mm	30kV/mm	• Thermal and mechanical breakdown; • Defects and electronic impurity ; • Absorbed water.	Design and modify molding compound for 1) dielectrically robust resin and complete reaction with reduced polarity and 2) improved filler/resin interface that mediates permittivity difference.
3	Thermal Conductivity	>10 W/mK	5W/mK	• Limit of high thermal filler loading and size; • Interfacial thermal resistance between fillers.	Design the structure and surface of high thermal conductivity filler to create thermal pathway and couple phonon transport at 1) filler-polymer interface and 2) filler-filler interface

1. Overview

1.3 Technical Approach Beyond Prior Art





property	Prior art	Unique approach
HT stability	High crosslink epoxy – phenolic resin	Cyanate ester/ epoxy copolymer
BDV	Clean resin, ion catcher	Filler design, low polarity resin
Thermal Conductivity	High loading of conductive filler/ silane coupling agent	Designed structure and phonon coupler on conductive filler

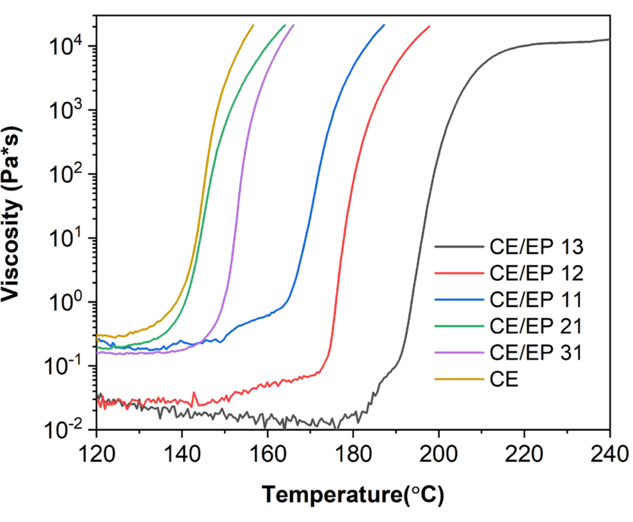
1. Overview

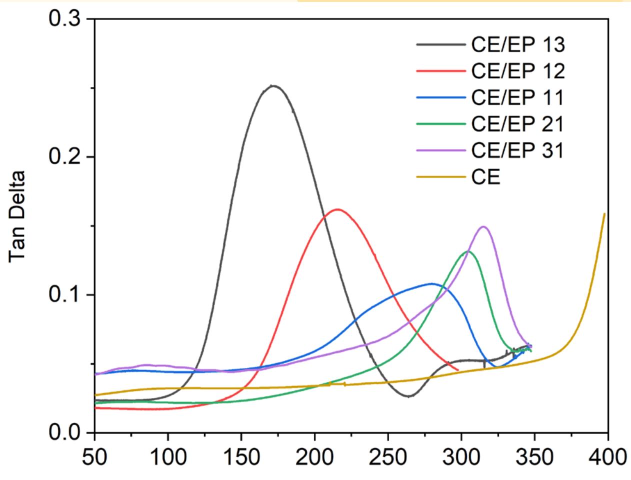
1.4 Research Highlights

Research Tasks	Challenges		Research Highlight
1) High Temperature Resin	Incorporation of high heat resistant cyanate ester in epoxy	🟢	Concentration effects of CE/EP blend on thermo-mechanical properties Long-term HT aging examined and analyzed
	Understanding of HT storage effects on resin properties	🟢	
2) Thermal Conductivity	Surface modification of BN	🟢	Modification of particle surface potential Control of self-assembly process between BN and SiO_2
	BN self-assembly on SiO_2	🟡	
3) Breakdown Voltage	Addressing the impurity level effects and moisture absorption on BDV	🟡	Epoxy sample preparation HV thin film and oil insulation set up

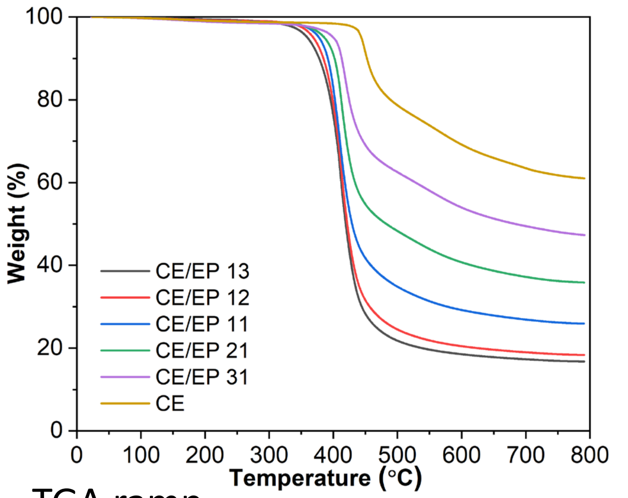
2. Results

2.1 High Temperature CE/EP Copolymer



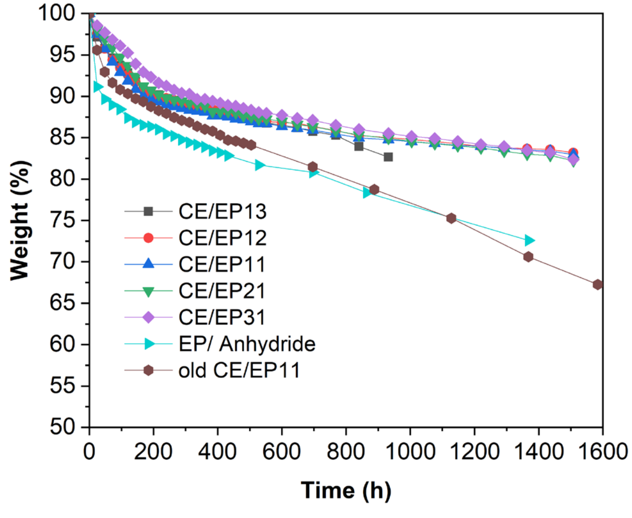


DMA Tg



TGA ramp

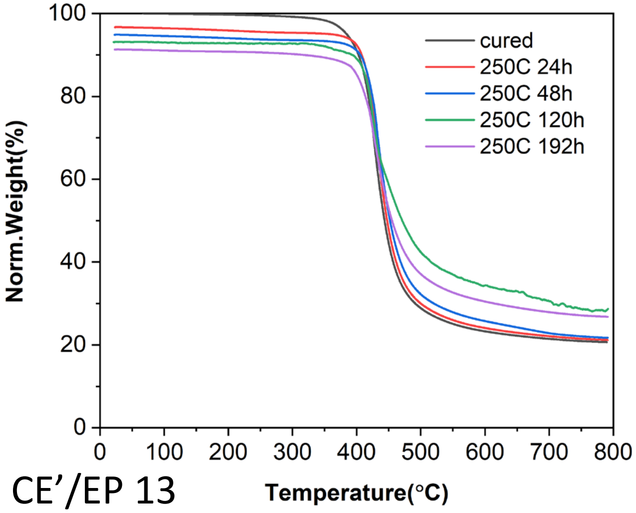
- Epoxy dilutes CE, rendering processable feature;
- Increasing CE content results in increased Tg and decomposition temperature;
- High crosslink density occurs at medium ratio of CE/EP;
- Novel CE components provides much improved aging stability compared to epoxy control and previous formulation



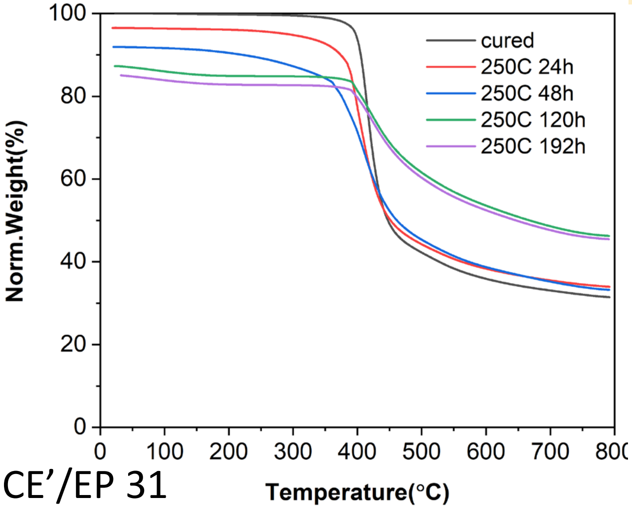
250 C aging weight loss

2. Results

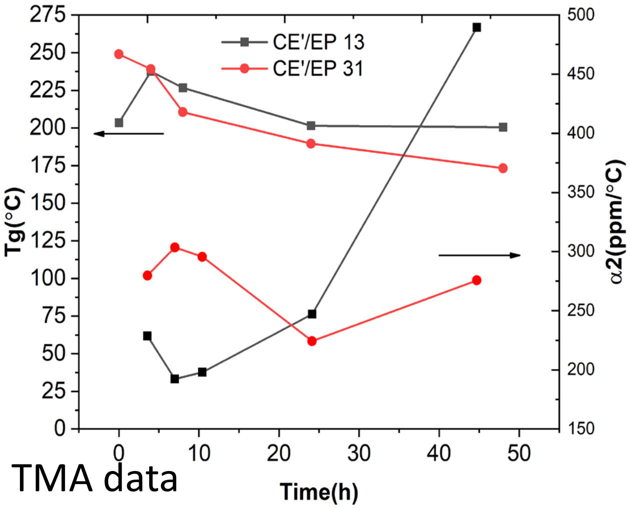
2.1 HT (250°C) aging analysis on old CE/EP formulation



CE’/EP 13



CE’/EP 31



TMA data

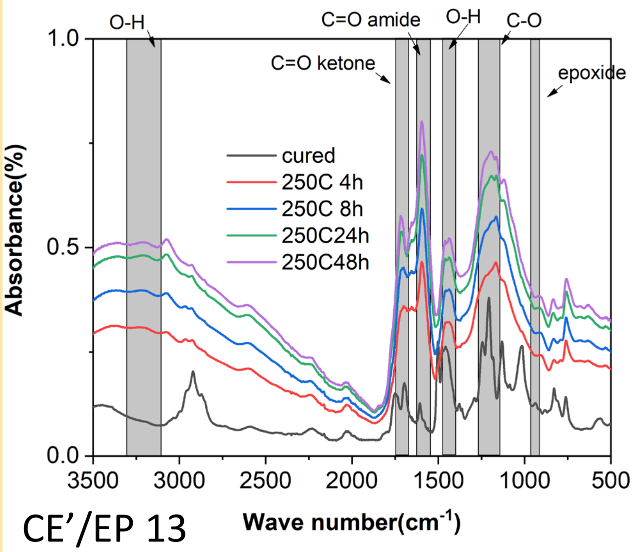
- In CE’/EP 13, the HT aging degradation followed similar route compared to TGA ramp

- In CE’/EP 31, dramatically inferior thermal stability was found after aging, other degradation mechanism involved

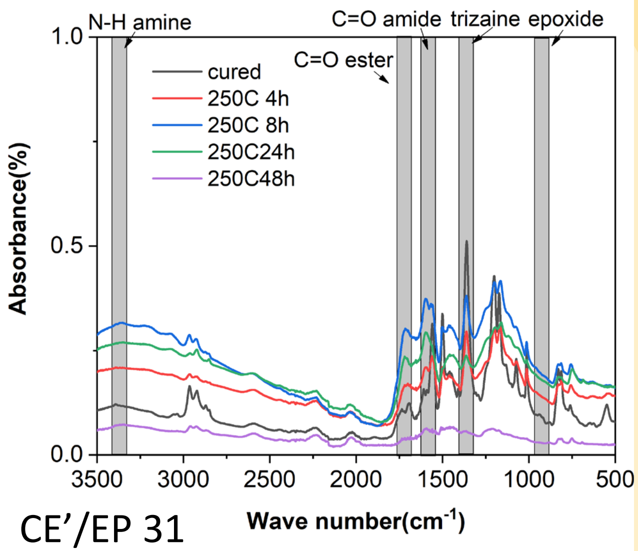
- In CE’/EP 13, first increase of Tg (4-8 h) and then decrease, α2 was in the opposite trend, further curing occured
- In CE’/EP 31, continuous decreasing Tg was found

2. Results

2.1 HT (250°C) aging analysis on old CE/EP formulation

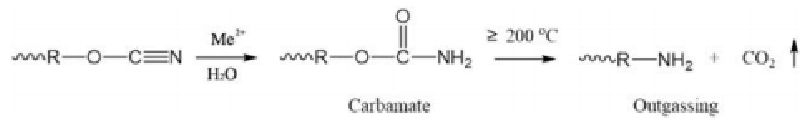


CE’/EP 13



CE’/EP 31

- Different evolution of chemical structure change in low and high CE content copolymers:
- In CE’/EP 13, consumption of epoxide groups was found during initial aging (4-8 h) followed by thermo-oxidative degradation generating carbonyl and hydroxyl groups;
- In CE’/EP 31, carbamate formation was noticed from amine and carbonyl groups;



$$\sim R-O-C\equiv N \xrightarrow[H_2O]{Me^{2+}} \sim R-O-C(=O)-NH_2 \xrightarrow{\geq 200\ ^\circ C} \sim R-NH_2 + CO_2\uparrow$$

- Low CE formulation is preferred regarding overall performance and cost

2. Results

2.2 High Thermal BN/SiO_2 Hybrid Filler

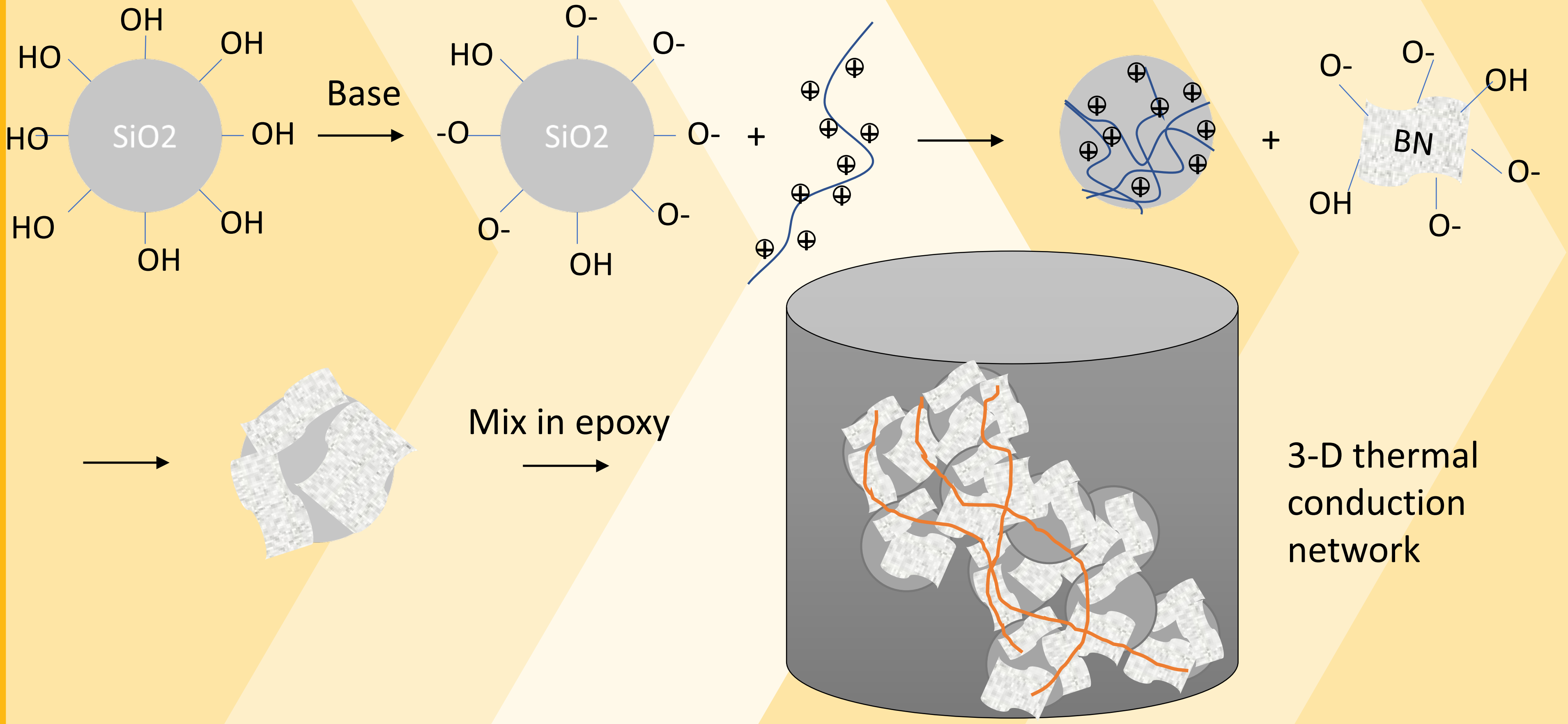
	K(W/mK)	P(g/cm³)	CTE(ppm/°C)	Dk, 1MHz, 20°C	Cost($/kg)	Comment
Al_2O_3	30	3.9	8	9.6	5	Widely used for high thermal
h-BN	400 (in plane)	1.9	38(c axis) -2.72(a axis)	4.4	40-50	2-D shape, hard to mix
Fused SiO_2	1	2.2	0.5	4.3	1	80~90 wt% in EMC
Epoxy	0.2	1.2	60	4~5	5	

- Silica will remain as the major filler in EMC due to the low cost and CTE, despite the poor thermal conductivity.
- Boron nitride is optimal for high thermal and low Dk epoxy compounds but is limited by cost and processability.

2. Results

2.2 High Thermal BN/SiO$_2$ Hybrid Filler

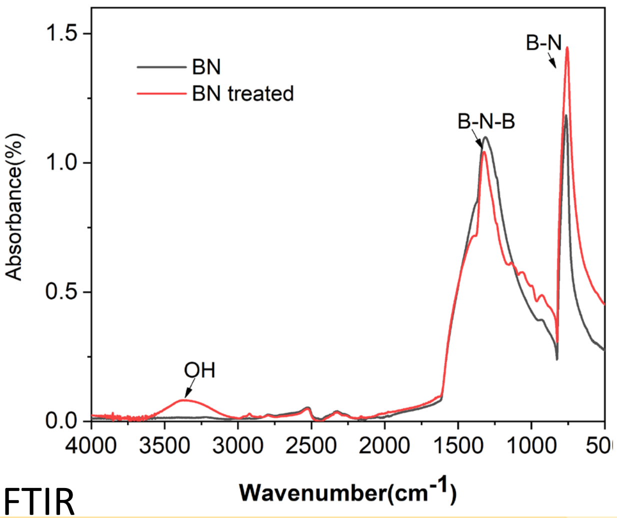
- Synthesis of BN coated SiO$_2$ for enhancing processability and constructing thermal conduction network



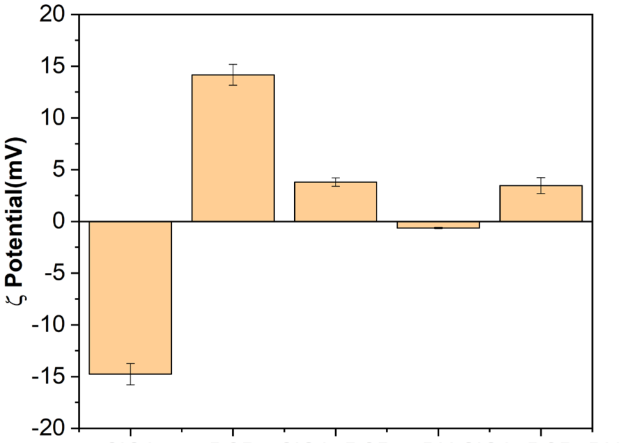
3-D thermal conduction network

2. Results

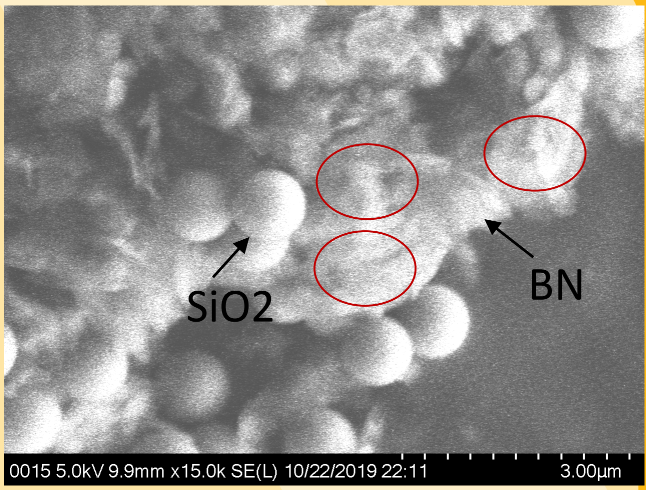
2.2 High Thermal BN/SiO_2 Hybrid Filler



FTIR



Zeta potential



PCP: Positively Charged Polymer

- Grafting of –OH groups on BN filler;
- Control of surface potential of SiO_2 and BN for self-assembly process;
- Coating of BN on SiO_2 structure revealed by SEM (red circle);
- Rheology behavior and thermal conductivity improvement compared to direct mixing SiO_2 and BN in epoxy will be investigated

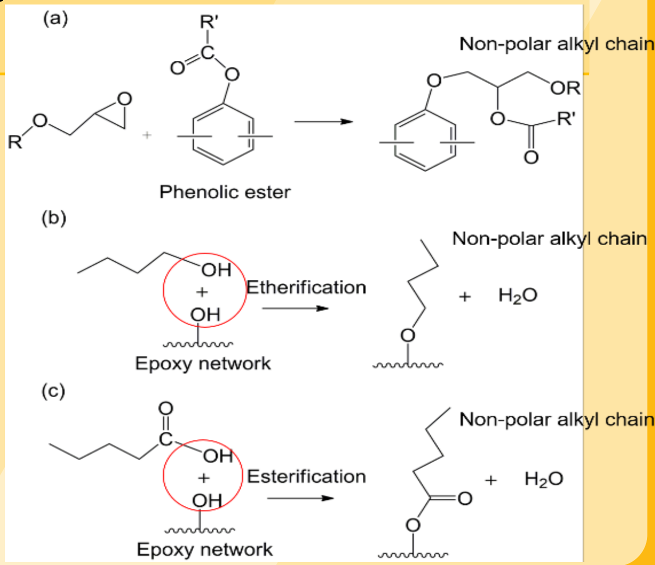
2. Results

2.3 Breakdown Voltage (BDV)

Challenge	Mechanism	Solution
Impurity level	Local dielectric stressing ; Joule heat generation from ion migration	Ion trap to reduce impurity level, High temperature resin
Filler interface	Dk difference between filler and resin generates enlarged local field; Poor interface leaving voids	Use of SiO_2 and BN instead of high Dk fillers; Surface treatment to provide adherent interface
Aging performance	Degradation of resin ; Moisture absorption	Synthesis of low polarity resin through phenolic ester and consume –OH groups after B stage

- Pure epoxy samples (1mm) have been tested showing over 40kV/mm (exceeds current setup capability), could reach over 200 kV/mm with high purity resin

- The origin of low BDV in commercial EMC far below intrinsic polymer limit is summarized in table
- The effects of reducing moisture absorption and ion impurity will be demonstrated with working on new set up



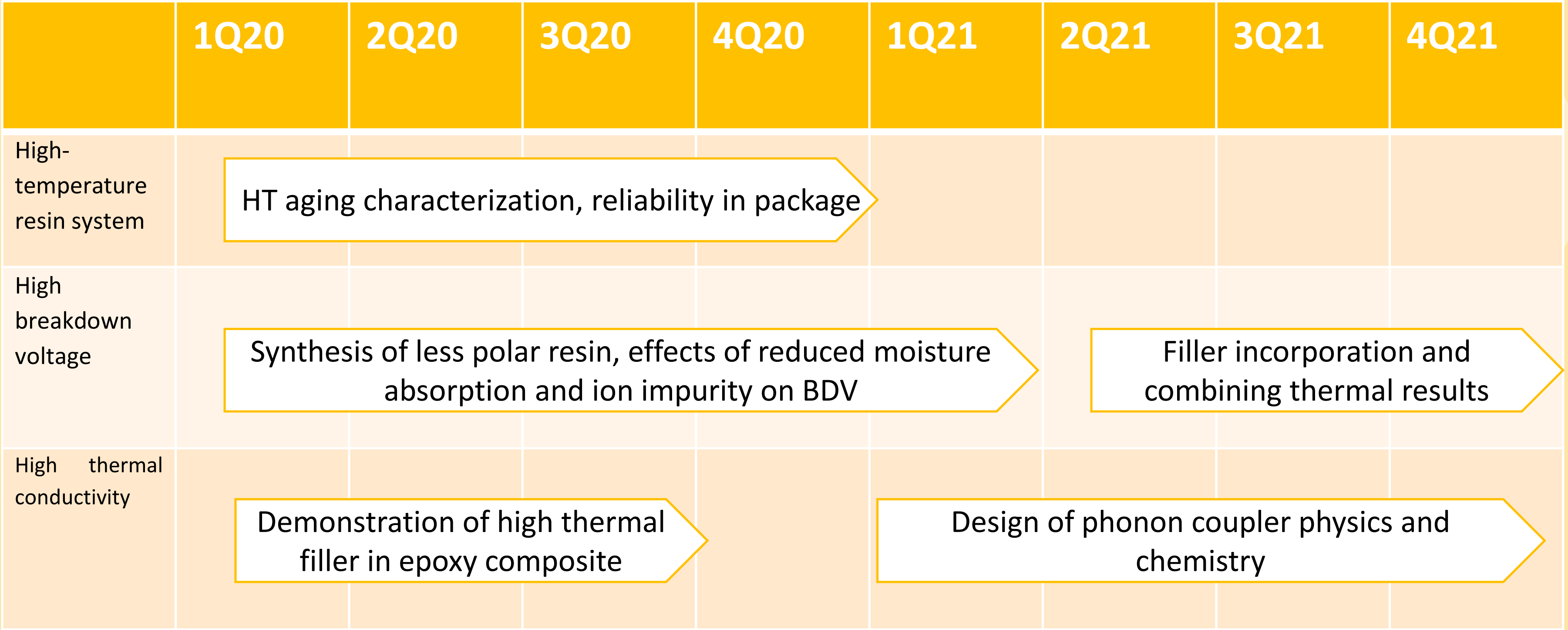
3. Summary

- Accomplishments
  - Demonstration of high Tg CE/EP copolymer (exceeds 250° C)
  - Controllable rheology, Tg with copolymer composition
  - HT aging analysis revealed different degradation mechanism in high CE and low CE formulation
  - Synthesis of BN coated SiO_2 for high thermal epoxy composite
  - Modification of BN morphology and surface potential
  - Self-assembly of BN on SiO_2 through electrostatic attraction

- Next Set of Challenges and Risks
  - Reliability test of CE/EP blend in package, characterization on physical, mechanical and electrical properties (Low Risk)
  - Demonstration of BN coated SiO_2 in epoxy composites for high thermal (Medium Risk)
  - BDV tests with base resin and modified resin, long-term characterizations (Medium Risk)

4. 2020-2021 Project Plans

- ☐ HT aging reliability tests on CE/EP blends
- ☐ Demonstration of loading capability and thermal improvement with novel filler
- ☐ BDV test set up, effects of moisture and ion impurity



	1Q20	2Q20	3Q20	4Q20	1Q21	2Q21	3Q21	4Q21
High-temperature resin system	HT aging characterization, reliability in package							
High breakdown voltage	Synthesis of less polar resin, effects of reduced moisture absorption and ion impurity on BDV					Filler incorporation and combining thermal results		
High thermal conductivity	Demonstration of high thermal filler in epoxy composite				Design of phonon coupler physics and chemistry			