SIS Triblock Copolymers and Their Performance in Flexible Electrothermal Composite Heaters

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The Macromolecular Design of Poly(styrene-isoprene-styrene) (SIS) Copolymers Defines their Performance in Flexible Electrothermal Composite Heaters. [Manuscript Hiruni T. Dedduwakumara, Christopher Barner-Kowollik, Deepak Dubal, Nathan R.B. Boase. (2023). submitted for publication]

Winter happens..

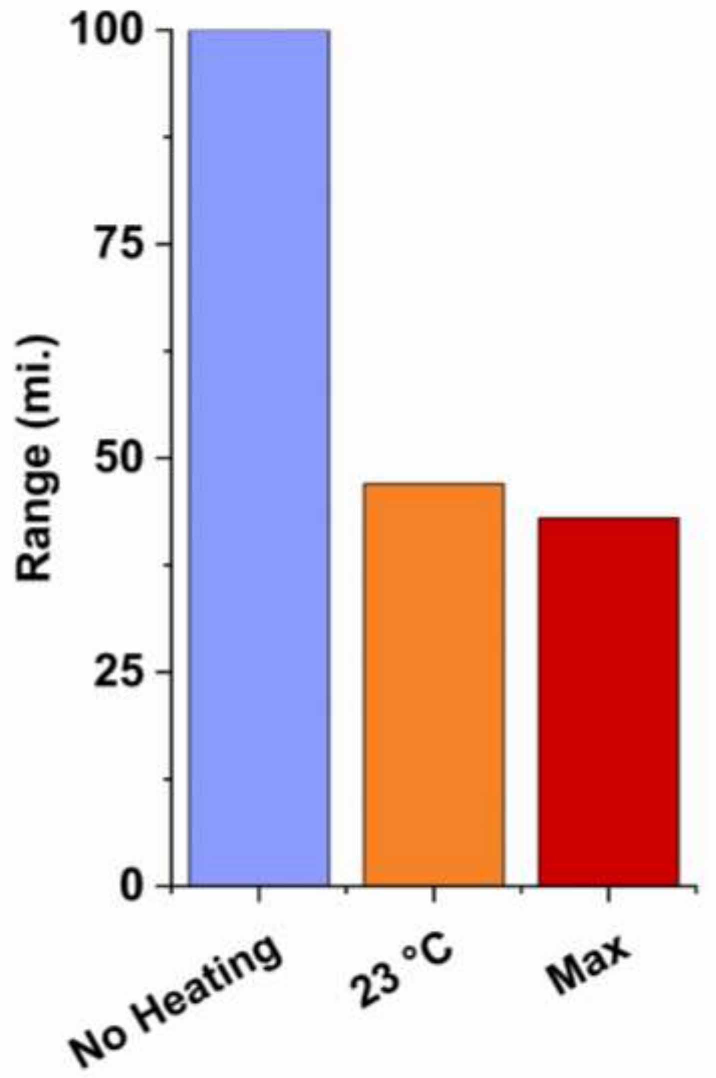
At -7 °C outside temperature, EV’s range reduction is 41%

Challenge

Minimizing the excessive energy consumption while improving battery capacity in cold conditions

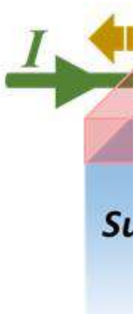
Solution

Electrothermal Heaters



Delos R., IEEE Transactions on Vehicular Technology 2016, 65 (6), 4016-4022

Why electrothermal heaters?




Conventional materials :

Transparent conductive oxides

- Aluminium- doped zinc oxide
- Indium tin oxide
- Fluorine- doped tin oxide

Drawbacks :

- Rigid, non-flexible structure
- Scarcity of materials like Indium

Thermally conductive polymeric materials

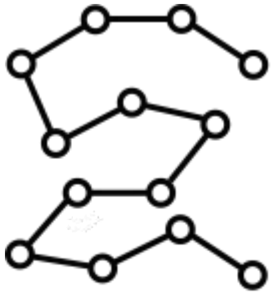
Adv ing , Low cost

App ers, Displays, Thermotherapy pads,

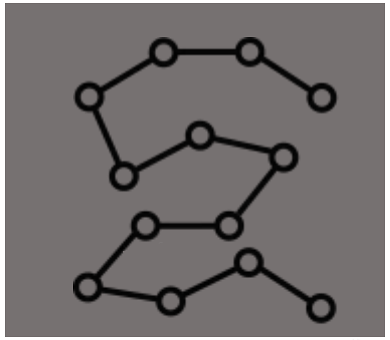
Sensors

1. Pandya, S.,*NPG Asia Materials,2019* (Vol. 11, Issue 1). Nature Publishing Group.
2. Papanastasiou, D.,*Advanced Functional Materials*,2020, 1910225.

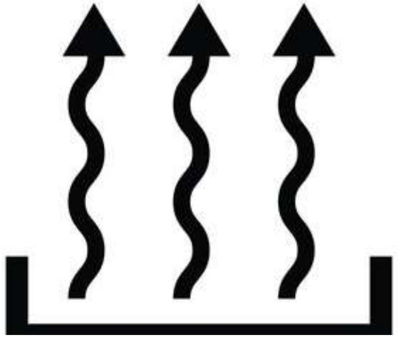
Research problem



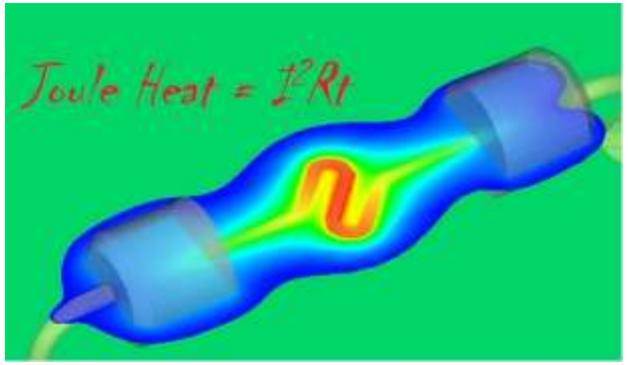
Polymers



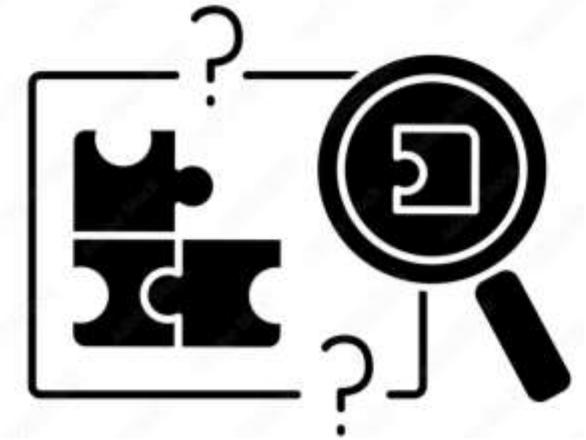
Composites



Thermal conductive materials

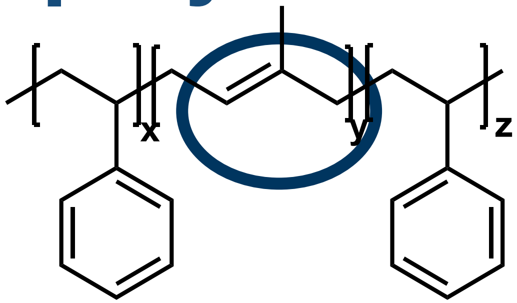


Electrothermal heaters

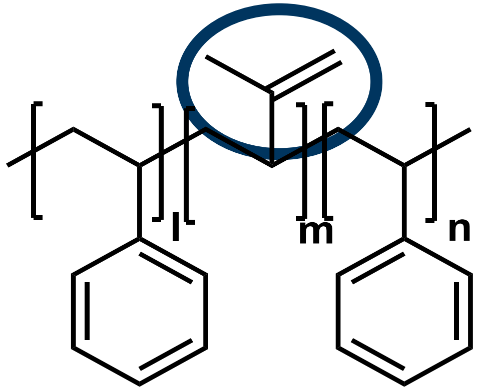


- ✓ Industry viable
- ✓ Cost-effective
- ✓ Efficient
- ✓ Flexible
- ✓ Enhanced heat stability

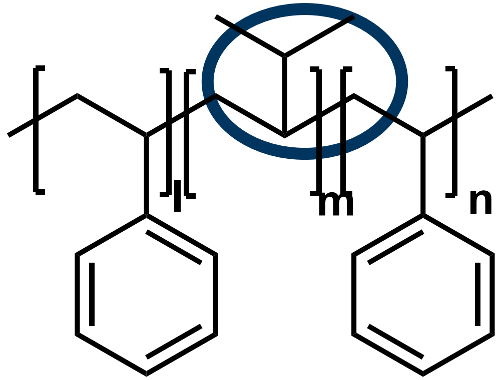
Copolymer structures and isomerism



1,4-SIS



3,4-SIS



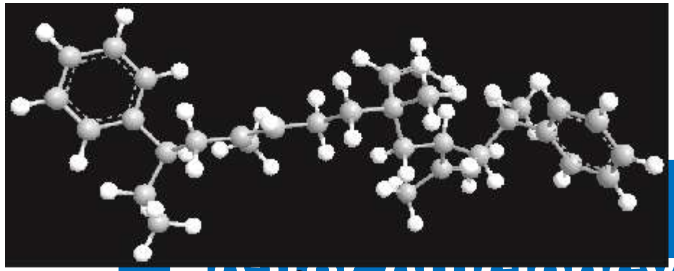
SEPS

\+ **Carbon black**

Hypothesis:

- Double bonds are important to achieve the electrical performance require in electrothermal applications
- It might be a source for polymer degradation

Experimental plan



1. Presence of double bond of isoprene block

(3,4 SIS copolymer & SEPS copolymer)

2. Position of double bond in isoprene block

(1,4 SIS and 3,4 SIS copolymers)

3. Loading of carbon black

(Neat polymers, 16% and 28%)

TGA in N_2 and air

DSC, GPC

NMR, FTIR

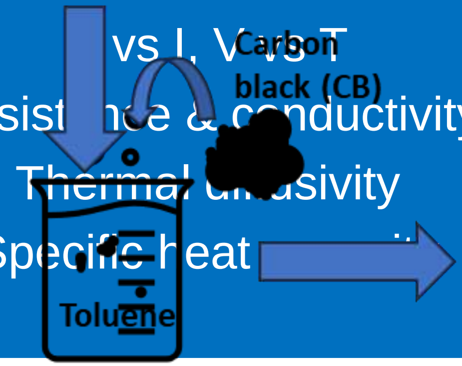
Heater efficiency

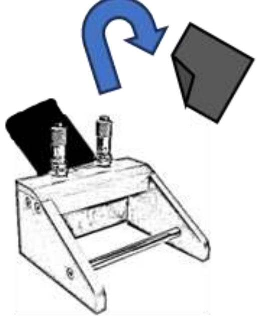
vs I, V vs T

Resistance & conductivity

Thermal diffusivity

Specific heat





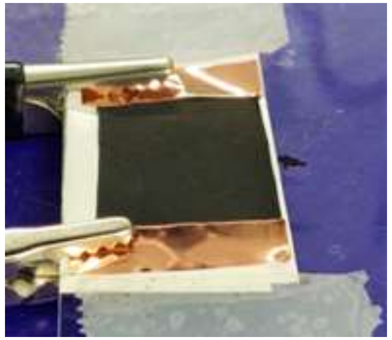
Heater stability

Electrical failure test

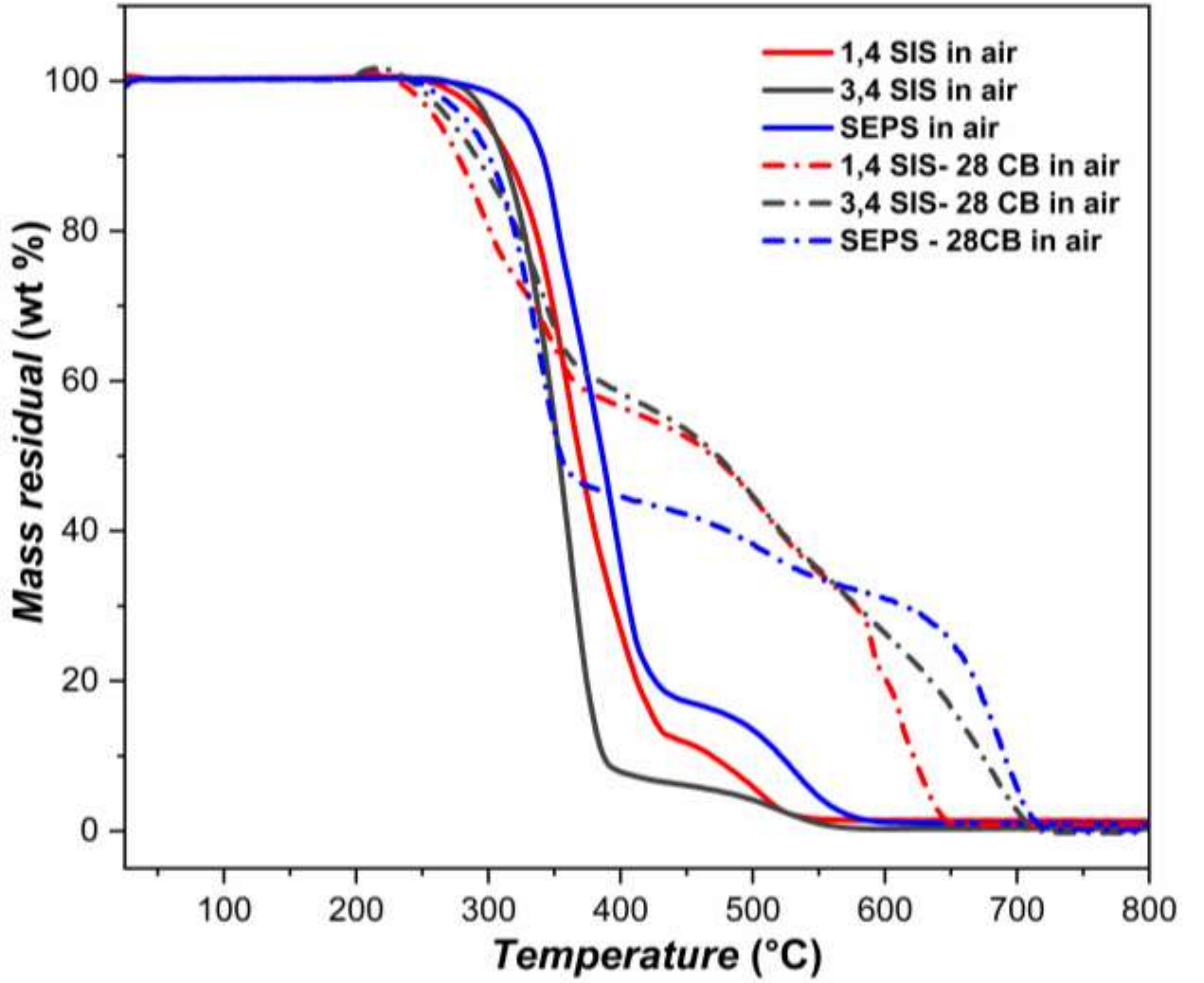
Stability at high voltage (V vs T)

GPC

TGA,DSC, FTIR & NMR



How does the copolymer structure and CB loading affect thermal stability?



Hydrogenation ➡ ↑ **thermo-oxidative stability of polymer**

CB addition ➡ ↓ **thermo-oxidative stability of composite**

Thermally stable up to 200 °C in air

How does the copolymer structure and CB loading affect composite thermal performances?

$$\lambda(T) = \alpha(T) \times C_p(T) \times \rho(T)$$

λ(T) - **Thermal conductivity at T (W m^{-1}°C^{-1})**

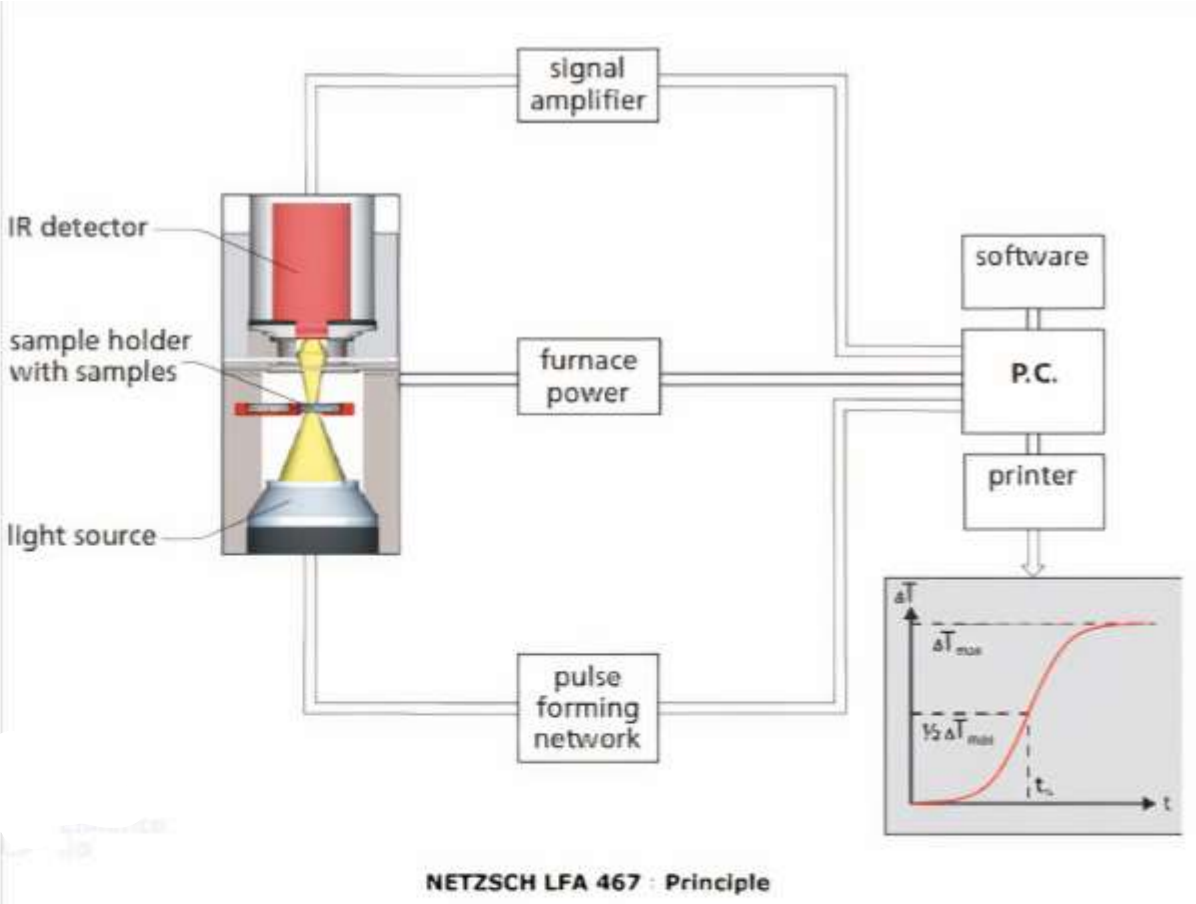
α (T) - **Thermal diffusivity of the material (mm^2S^{-1})**

C_p (T) - **Specific heat capacity at P (J kg^{-1}°C^{-1})**

ρ (T) - **Relative density (kg m^{-3})**

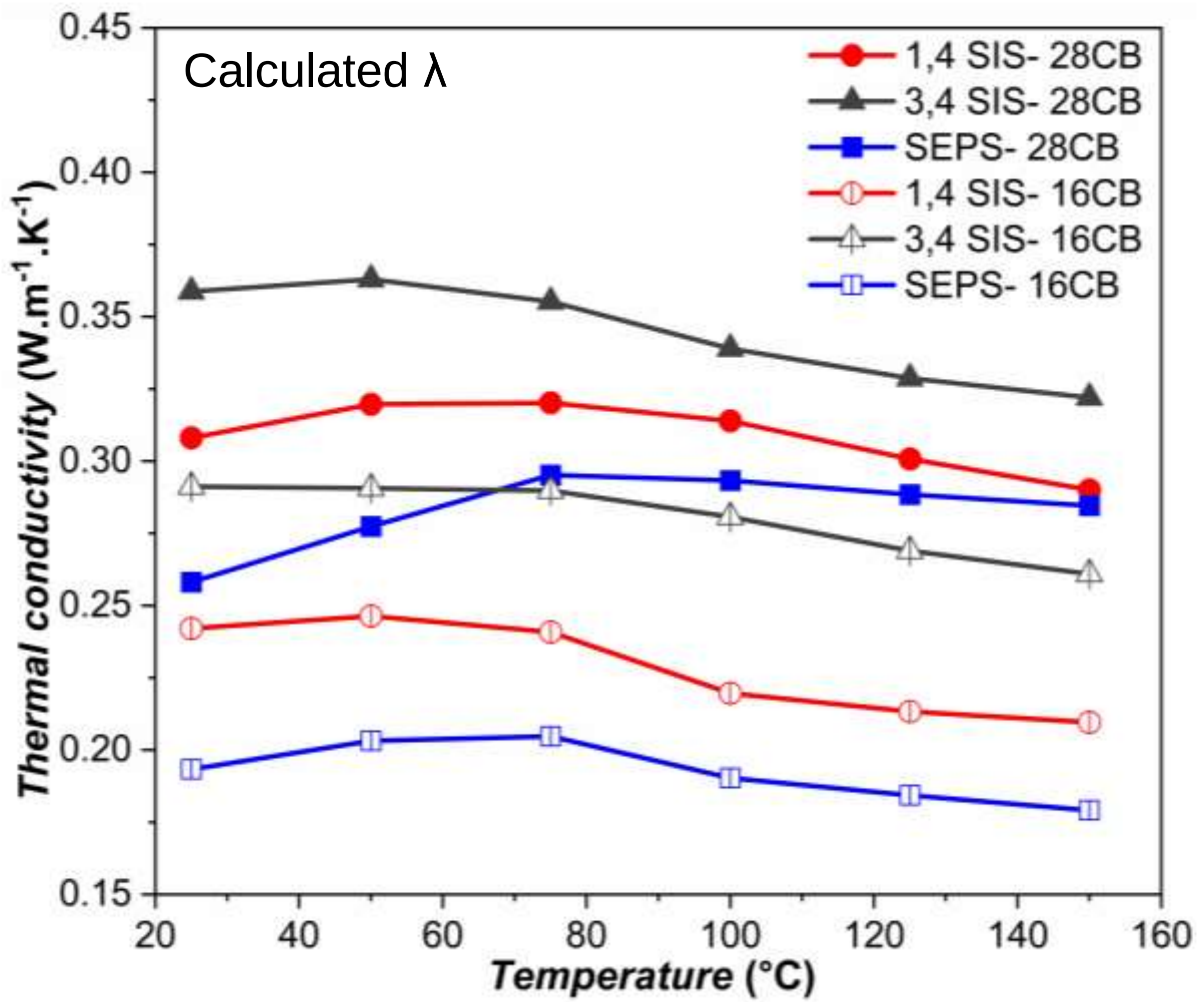
Thermal Diffusivity → Laser Flash analysis (LFA)

Specific heat capacity → DSC, ASTM E1269-11 standard



1) Gnanachelvam, S.; Fire and Materials 2021, 46 (1), 12-28.

What is the impact of copolymer structure and CB loading on thermal conductivity?

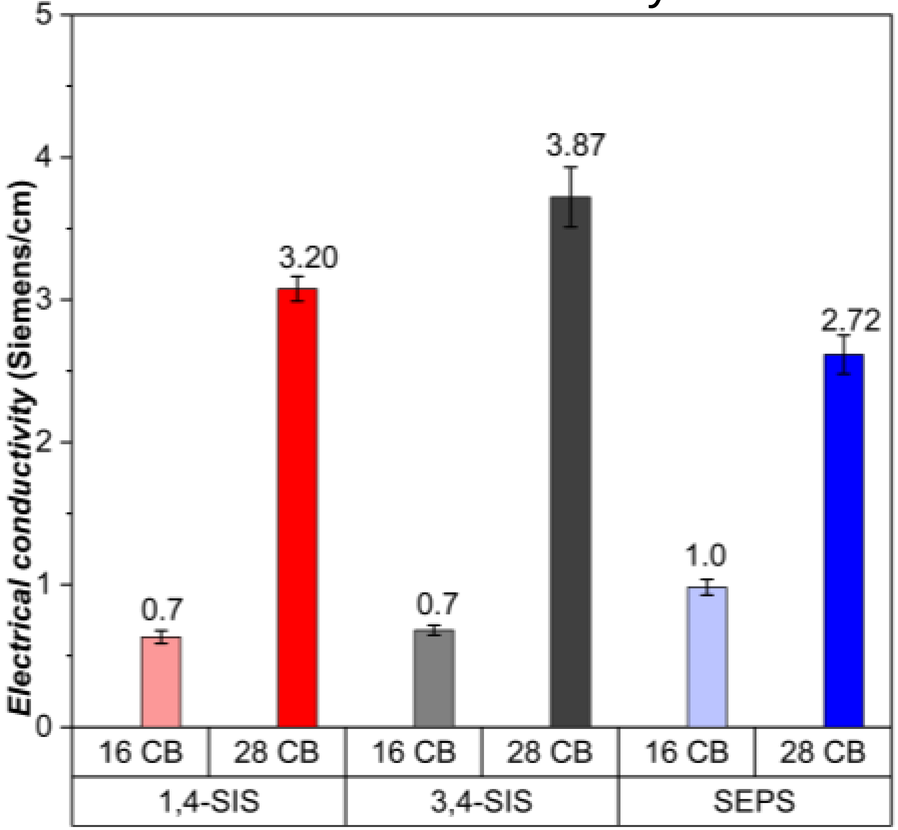


- **Increasing CB loading increase the thermal conductivity**
- **Olefinic structure enhance thermal conductivity** (by increasing segmental rotation stiffness by conjugated π-bonds[1])

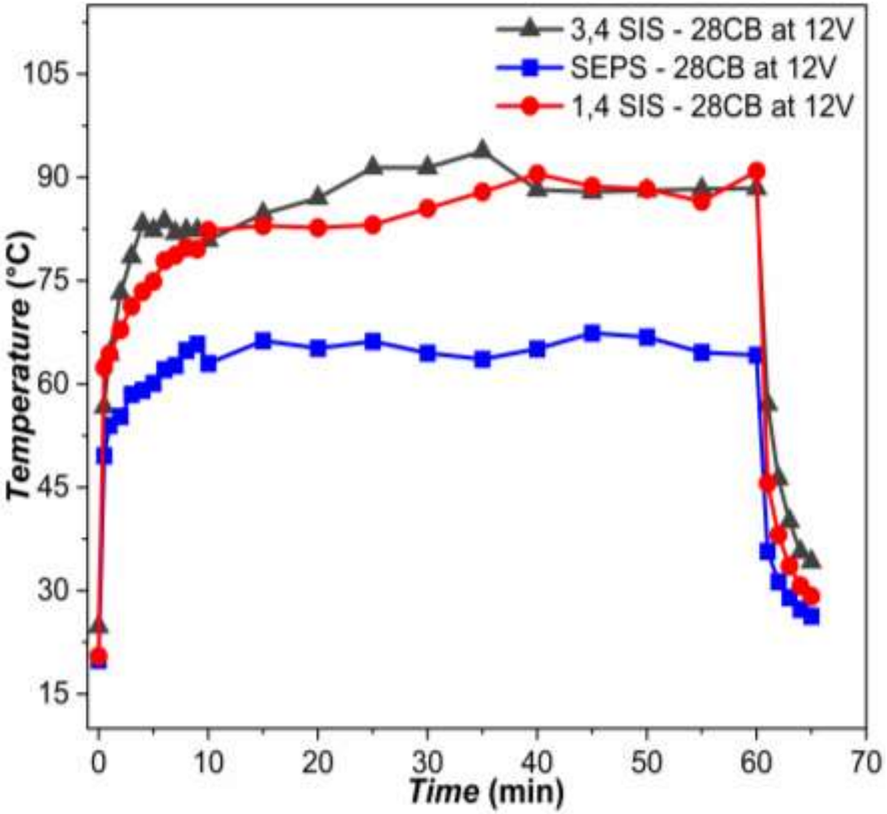
1) Huang, C.; *Materials Science and Engineering:* R: Reports 2018, 132, 1-22

How does the copolymer structure affect electrothermal performances of protype heaters?

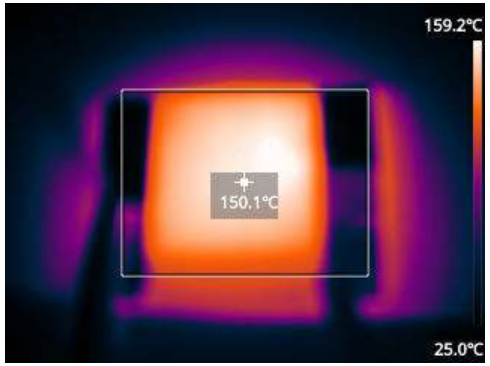
Electric conductivity



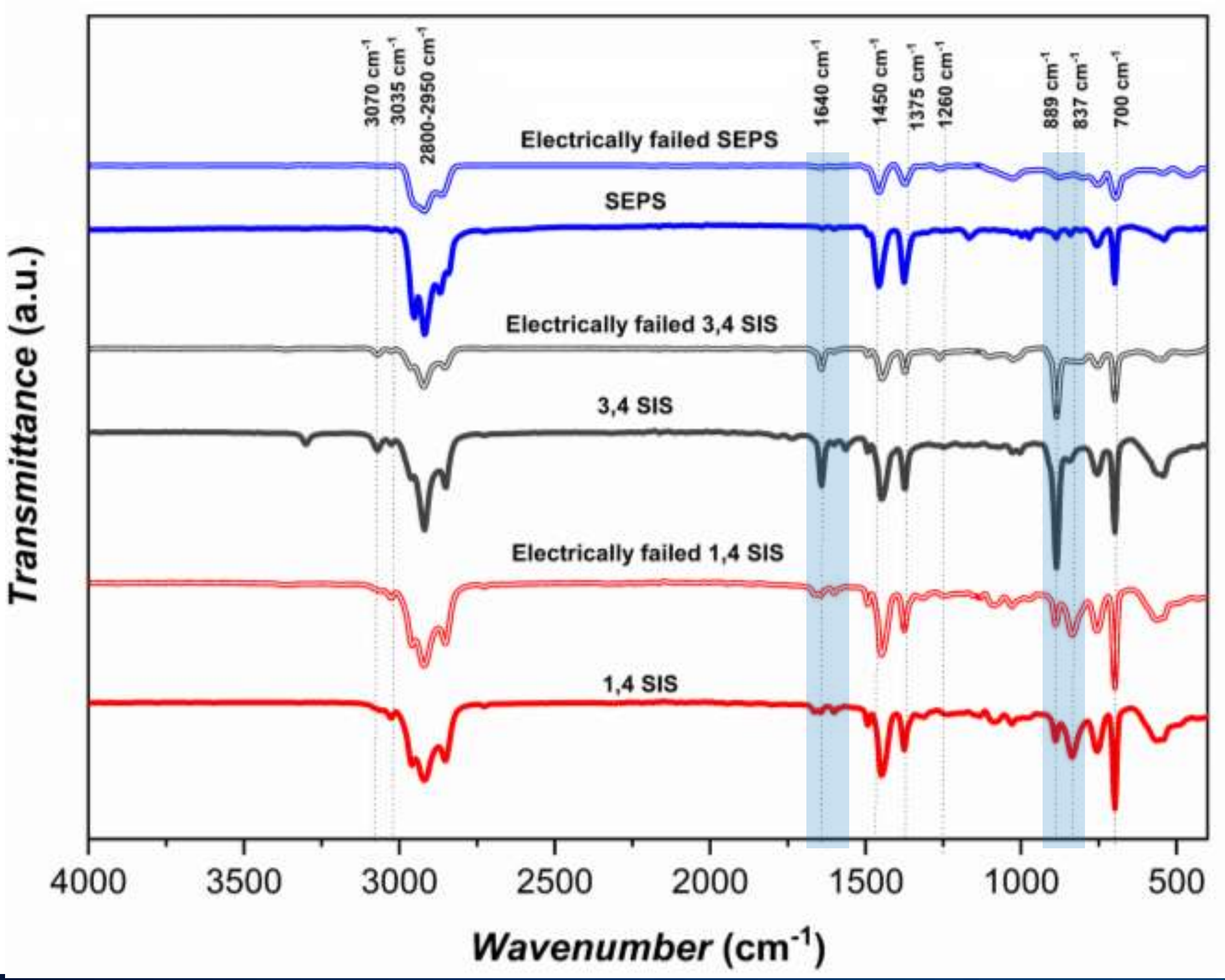
Electrothermal performance



Highest thermal, electrical conductivity leads to highest steady state temperature



How does the copolymer structure affect the electrical failure of prototype device ?



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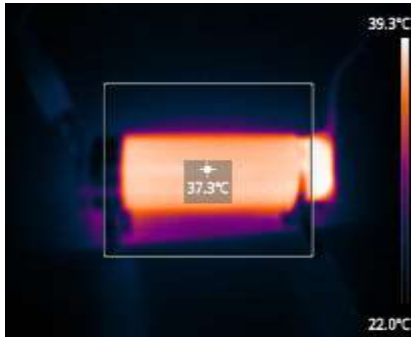
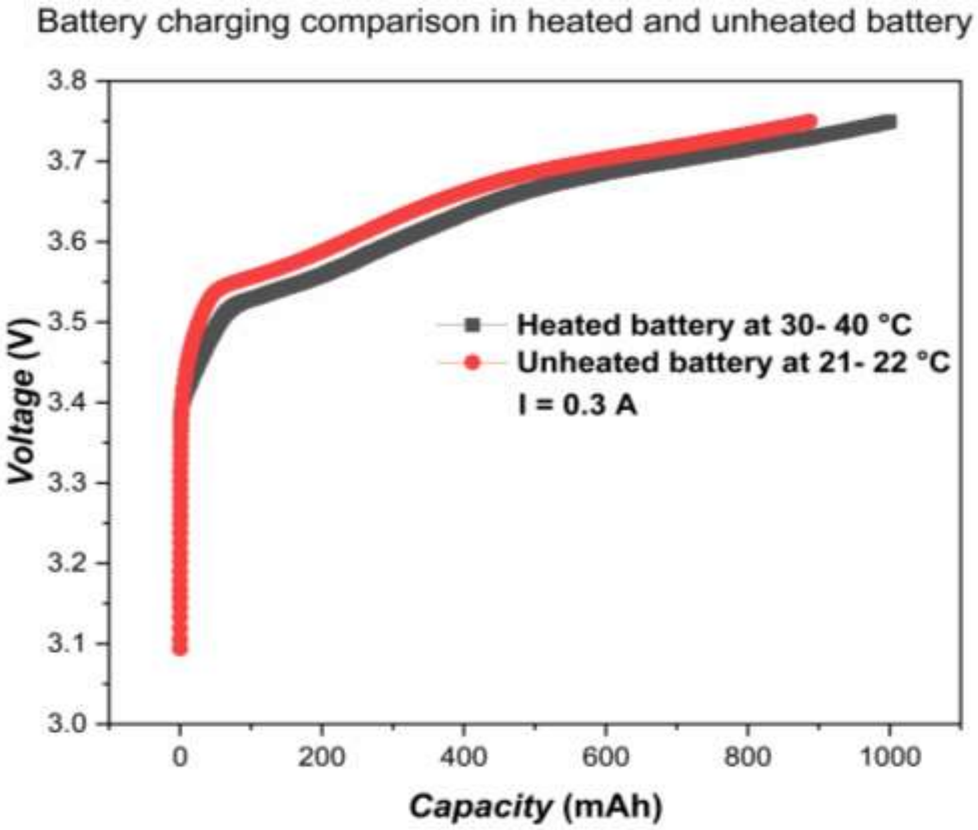
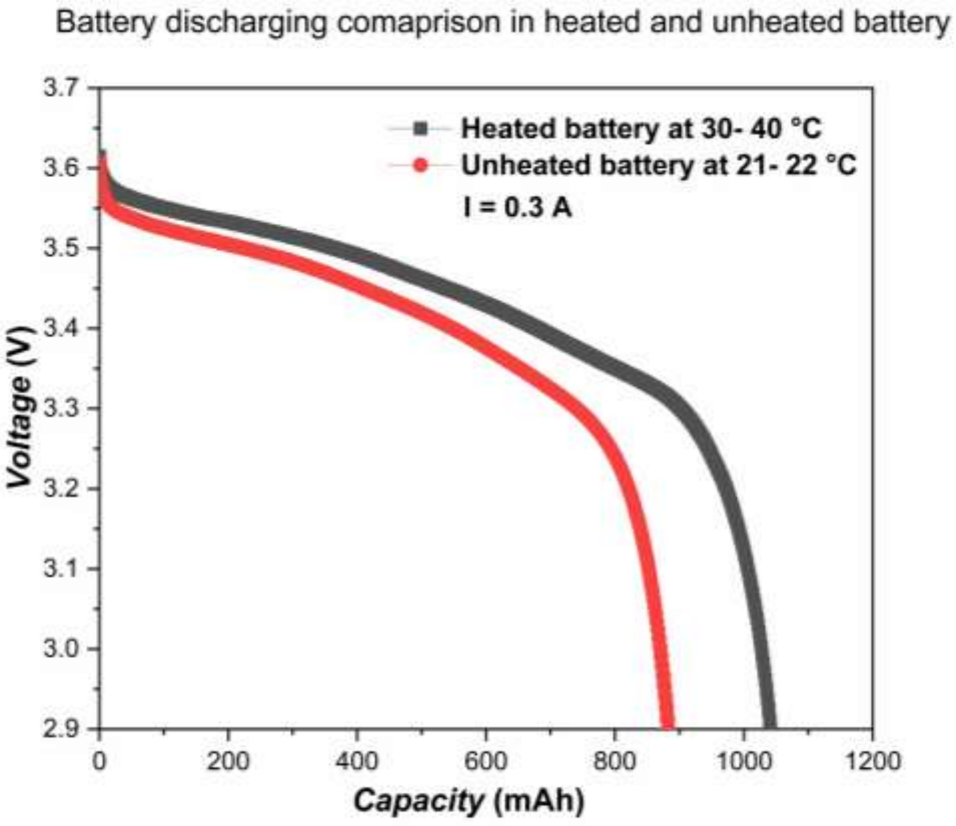
How does the heating affect the battery performance?







- Heating cover improve the battery capacity
- Composite heater was stable more than 7 hours per day around 30 – 40 °C for 3 days

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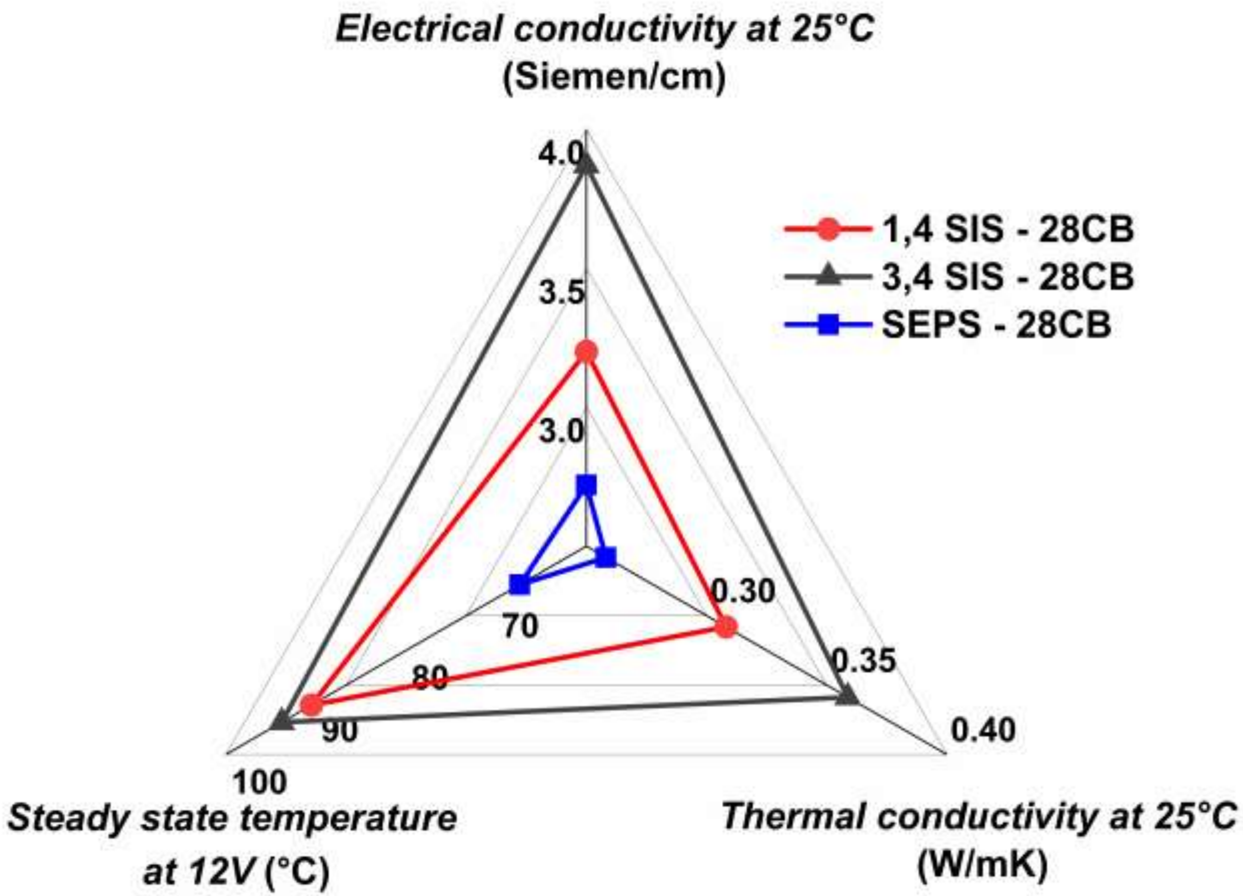
Conclusion



- ✓ Olefinic structure affects the electrical and thermal performances of heaters
- ✓ It has negligible effect on chemical and electrical stability of heater

Acknowledgments

Supervisory Team :

- Dr. Nathan Boase
- Prof. Christopher Barner-Kowollik,
- Prof. Deepak Dubal

Korea Evaluation Institute of Industrial Technology (KEIT) grant funded by the Korean government (MOTIE) (Grant No. 20014690).

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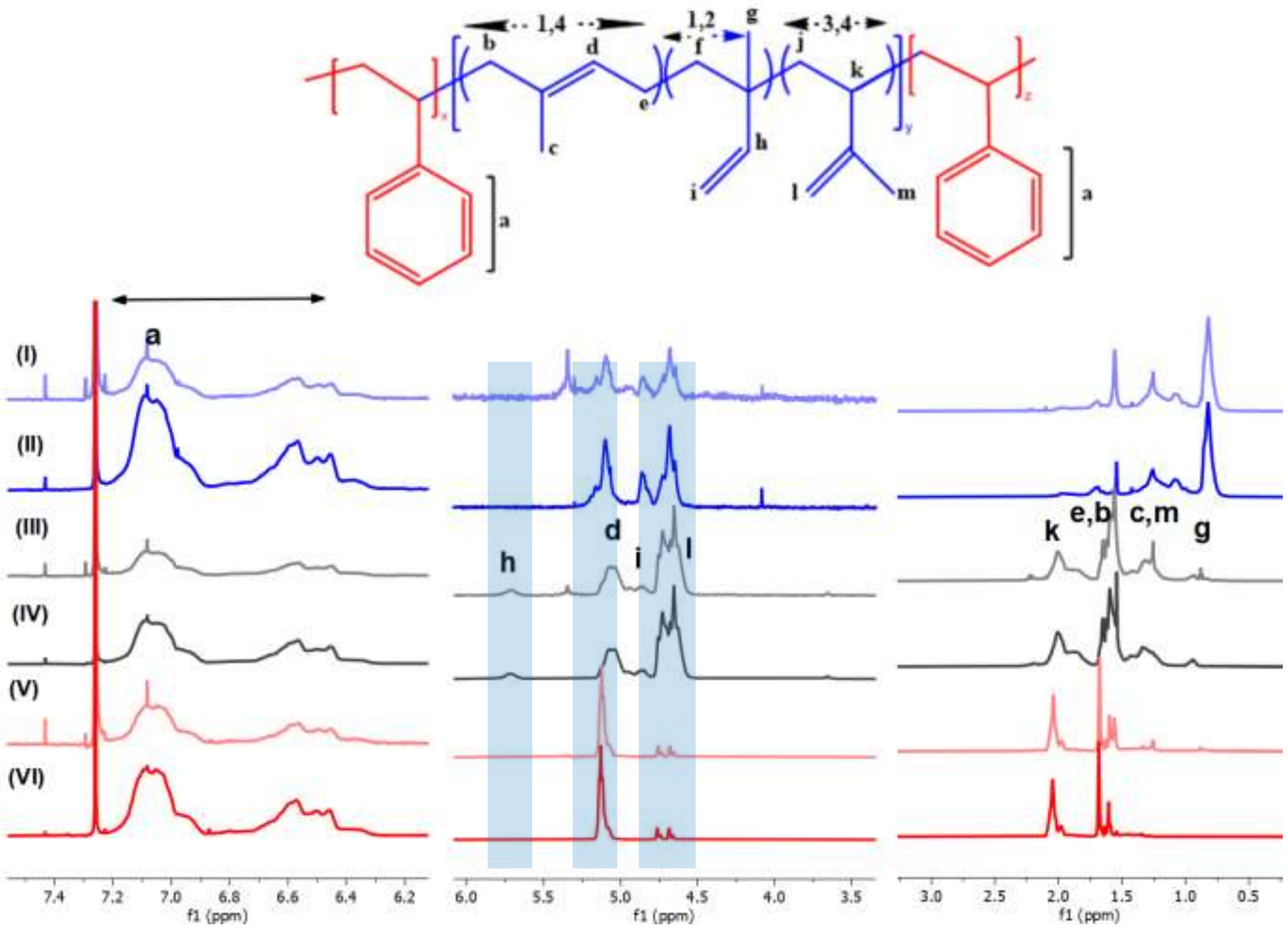

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