Guest Editorial: Thermally conductive but electrically insulating materials for high voltage applications

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In this High Voltage Special Issue the invited review and research articles cover the topic of thermally conductive but electrically insulating materials for high voltage applications. The review paper summarises the research progress on the development of epoxy resins with high pristine thermal conductivity, while the five research articles report different strategies for enhancing the thermal conductivity of polymer composites or polymer blends. The authors have a diverse range of experience across all fields of materials science, thus providing interdisciplinary perspectives to readers of the journal.

The following topics relating to high voltage applications are addressed by the papers in this Special Issue:

- Enhancing thermal management
- Bottlenecks and material limitations
- High pristine thermal conductivity

Enhancing thermal management: High voltage electrical equipment (e.g. generators, converter transformers and saturable reactors located in valve modules) and high power electronic devices (e.g. high-performance central processing units, insulated gate bipolar transistor, light emitting diodes) give a high dissipation of electrical energy, which leads to the production of excess heat. This heat passes through an insulation layer to the coolant to ensure the maintenance and long-term reliability of the equipment and devices. Enhancing the thermal management capability of the electrical insulating materials for high voltage and/or high power applications is therefore essential.

Organic polymers, such as epoxy thermosts, are excellent electrical insulation materials in electronic equipment and devices due to their facile processing procedures, lightweight, and low cost. However, their thermal conductivity is 1 to 3 orders of magnitude lower than inorganic and metallic materials. Low thermal conductivity is one of the bottlenecks limiting the performance and reliability of electric power systems. As a result, the development of polymers with high pristine thermal conductivity has attracted researcher's attention [1]. Taking turbo generators with indirect air cooling systems as an example, increasing the thermal conductivity of groundwall insulation can improve the thermal transfer of heat from the conductor to air. As a consequence the power density is increased whilst the operating temperature is maintained.

Bottlenecks and material limitations: Turbo generator groundwall insulation usually consists of barrier materials (e.g. mica paper or flakes) for preventing partial discharge and electrical treeing, supporting materials (e.g. polyethylene terephthalate film, glass fibre, or polyester fleecy) and binder materials (e.g. polyester or epoxy resin) [2]. Amongst these three components, the binder resin has the lowest thermal conductivity, which currently limits the overall thermal management capability of the insulation. In this case, substitution of these binder resins with resins with a high pristine thermal conductivity will result in more efficient thermal management capabilities of groundwall insulation.

Vacuum pressure impregnation (Fig. 1) is a process used to cover electrical components for high voltage applications in impregnating resin, which is the right solution for manufacturing turbo generator groundwall insulation with high-quality and long-term reliability. One challenge of developing advanced epoxy resins for vacuum pressure impregnation of materials for high voltage applications (a general procedure of which is given in Fig. 1), is being able to maintain their low viscosity whilst increasing their thermal conductivity.

High pristine thermal conductivity: Although polymers with high pristine thermal conductivity are highly desirable in high voltage electrical insulation, the thermal conductivity enhancement, particularly for amorphous thermoset resins, is usually limited. So far, the reported maximum thermal conductivity is approximately 1.0 W/m·K for epoxy resins, which is not high enough for insulating high power components. Therefore, polymer composites with much higher thermal conductivity have been widely used instead. However, the thermal conductivity enhancement of epoxy resins is not apparent until the conductive filler loading is high. A highly filled epoxy composite (60 vol%}

Fig. 1 Global vacuum pressure impregnation of a complete 300 MW generator stator in a resin tank (left). Manufacture of a stator bar covered by an epoxy resin (right) by vacuum pressure impregnation, printed with permission from [3]
AlN, as shown in the scanning electron microscope image (Fig. 2), has a thermal conductivity of around 4.0 W/m·K, which demonstrates the increase in thermal conductivity with composite loading [4]. At such a high concentrations of filler loading, however, the bulk processing, mechanical and dielectric properties of the composite materials may not fulfill the requirements for engineering applications. The current research focus is to improve the thermal conductivity enhancement and address the described material limitations [5].

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Fig. 2 Scanning electron microscope image showing the cross-section of epoxy composite with 60 vol% AlN. Printed with permission from [4]