Nanocomposites: next generation capacitor materials for the green transition

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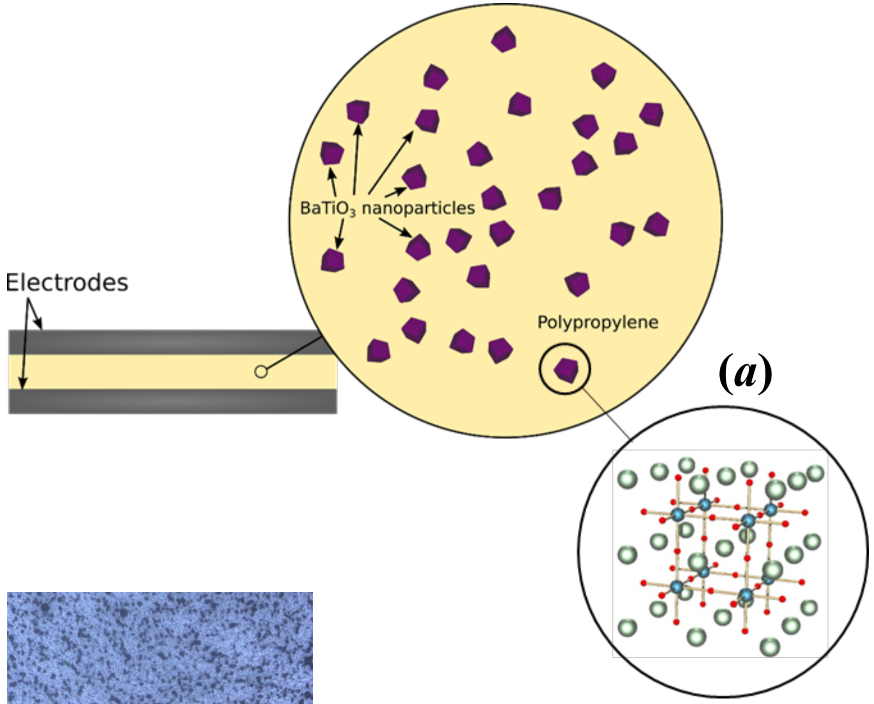
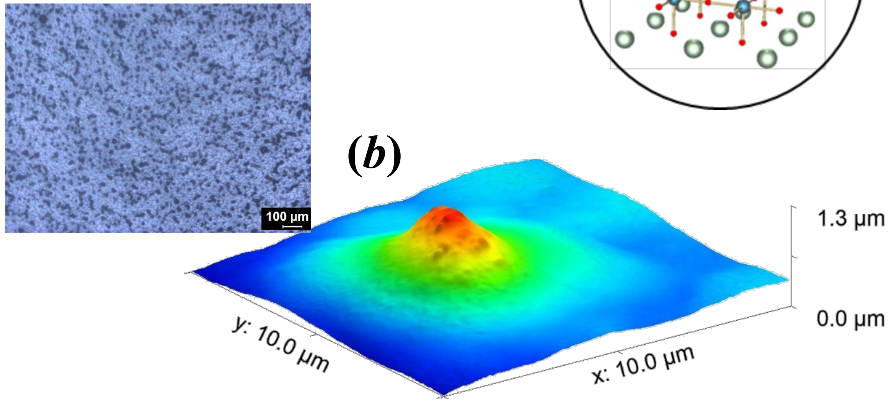
With the green transition to a carbon-zero society, never before has power electronics taken such an important role in shaping our future. Efficient power electronics requires capacitors that are reliable, can tolerate high temperatures, and are more space efficient – particularly in applications such as electric vehicle motor drives. Unfortunately, no single class of commercial dielectric materials can currently deliver this in a single material. Metallised polymer film capacitors exhibit excellent reliability due to their ability to self-heal, but have poor volumetric capacitance and rarely can tolerate temperatures over 100°C. On the other hand, ceramic capacitors have excellent volumetric capacitance and temperature stability, but are less reliable. The ideal dielectric, therefore, would exhibit characteristics of both ceramics and polymers. Nanocomposites (ceramic nanostructures dispersed in polymers) may be the answer (***a***).

Nanocomposites present a number of new fabrication challenges compared to more established dielectric materials. In particular, ensuring proper dispersion of the nanostructures to avoid clustering (***b***) is critical, as such clusters can compromise the breakdown performance of the devices and decrease device reliability/lifetime. Furthermore, nanocomposites function best in structured morphologies where layers with different dielectric properties/nanostructures are layered in a sandwich structure (***c***). Whilst relatively easily achievable in a laboratory, this is extremely difficult to do reproducibly using extrusion-based fabrication techniques (such as in polypropylene film production).

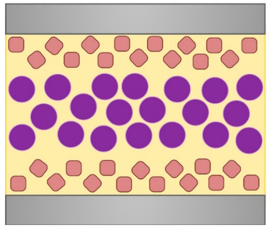
At the University of Southern Denmark Centre for Industrial Electronics, we have developed a new bottom-up approach to nanocomposite capacitor fabrication via layer-by-layer printing using polymer gel inks (***d***). Akin to 3D printing on the 100 nm length scale, this technique allows the easy fabrication of complex dielectric morphologies and is fully scalable to commercial-scale roll-to-roll printing. Printed polymer films perform similar to commercial films, and by adding nanoparticles with special surface treatments, we are able to demonstrate significant performance improvements with very low volume fractions of ceramic, due to decreased clustering. We believe that this technique offers a pathway towards the commercial adoption of nanocomposite capacitors in power electronics.



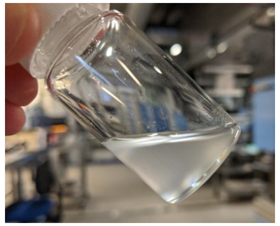
(***a***)



(***b***)



(***c***)



(***d***)

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Professional experience:

- Postdoctoral researcher, University of Southern Denmark, Denmark
- PhD student, Université de Bordeaux, France
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Research areas:

- Nanocomposite capacitor dielectric materials
- High-temperature polymer dielectrics
- Thin-film polymer electronic device fabrication

Background:

Dr Greenbank is a young materials scientist working at the University of Southern Denmark Centre for Industrial Electronics capacitor group, led by Professor Thomas Ebel. Originally from Wellington, New Zealand, Dr Greenbank has had a highly multidisciplinary career with research ranging from macromolecular and supramolecular chemistry to charge dynamics and degradation mechanics in organic photovoltaics. His current work aims to combine lessons from nanoscience and advance polymer chemistry research into the development of novel dielectric materials for capacitors in power electronics applications.

University of Southern Denmark Centre for Industrial Electronics

The SDU Centre for Industrial Electronics is part of the Faculty of Engineering and the Department of Mechanical and Electrical Engineering at the University of Southern Denmark. The CIE is located in Sønderborg, Southern Denmark – approximately 30 km from the German border, placing it in a unique position to take advantage of cross-border collaboration with German and Danish industry. The centre was initiated by a unique public-private partnership between the university, the region and municipality as well as leading industrial partners.

CIE has a strong mission to advance electrification, digitalisation and energy efficiency bridging between applied research, technology development for sustainable development and innovation. A strong focus is put on the development of next generation electronics, such as active and passive components, power electronic devices, EMC and intelligent systems.

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