Smart Luminescent Pyridinium-Based Epoxy Coatings for Early-Stage Structural Damage and Ice Detection in Wind Turbine Blades

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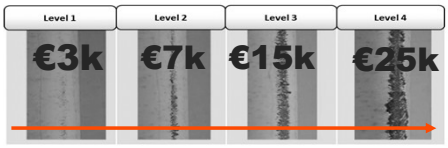
Summary

In this work, we report on the synthesis of PyL and the subsequent fabrication of PyL-functionalized anti-icing coatings. The chemical composition, structural integration, and matrix homogeneity of the PyL-epoxy system were comprehensively evaluated using Fourier-transform infrared (FTIR) spectroscopy. Photoluminescence spectroscopy was deployed to characterize the coating's optical properties and evaluate its performance under simulated real-world degradation in the range of -60 - +60 ºC. In the next step, freeze-thaw cycle testing combined with photoluminescence analysis demonstrated excellent phase separation capabilities during ice formation on the surface, highlighting the coating's dual-functionality in ice detection and mitigation. Mechanical testing of the functionalized coating revealed only a minimal 10% deviation in mechanical properties compared to the pristine, baseline NEINICE epoxy resin, successfully preserving the structural performance required for wind energy applications. These results successfully advance the technology from Technology Readiness Level (TRL) 3 to TRL 4. Developed in close collaboration with industry end-users (PhazeBreak and Aerones), this technology offers a highly promising pathway for commercial non-destructive surface monitoring and lifetime extension of wind energy infrastructure.

Nature factors of blade degradation



Solution: early stage detection by optical methods

Results and discussion

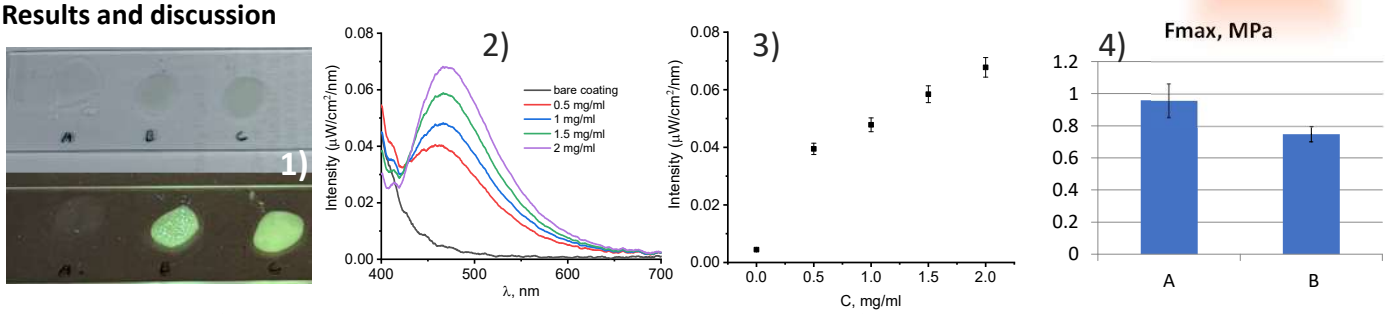


Figure 1. Fabrication of composites: 1) On glass; 2) PL spectra; 3) Thickness effect; 4) Mechanical properties

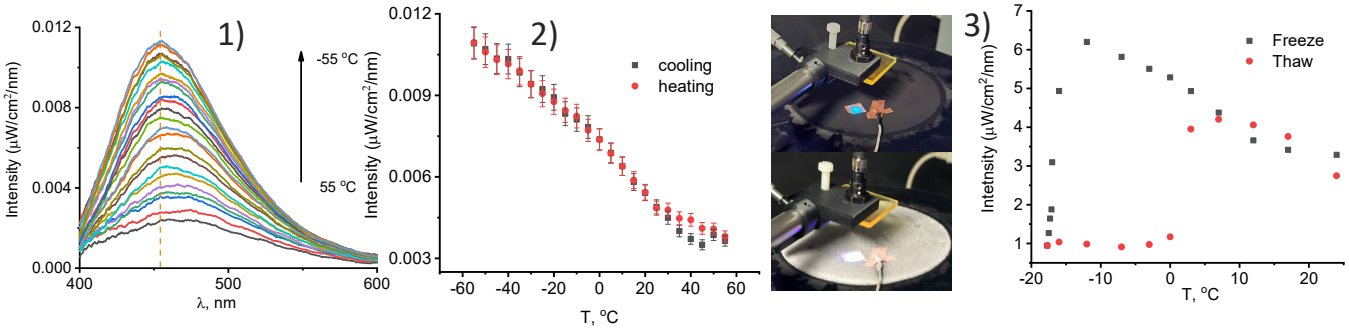


Figure 2. Temperature properties: 1) Temperature dependence in N_2; 2) Signal stability; 3) Anti-icing testing

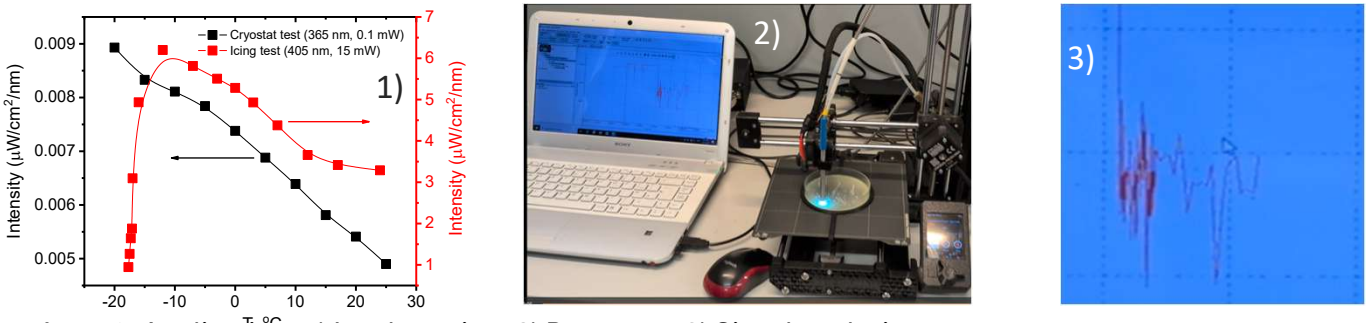


Figure 3. Application: 1) Ice detection; 2) Prototype; 3) Signal analysis

Conclusions: New optical composite materials have been fabricated and integrated with anti-icing coatings. The proposed optical detection showed promising results for detection of ice presence. Developed prototype could recognize surface defects. Transfer to wind blade surface and integration with drone detection methods are foreseen in future

Acknowledgement:
Increase wind turbine life time by early detection of blade erosion, OSI_PIP_BioPhoT-2025/1-0014 / VPP2024/51-1-8