

First and Second Harmonic Generation Study on Porous Bacterial Cellulose-ZnO composites

Fernando G. Sá¹, Anna Laromaine², Brian J. Rodriguez³, Paula M. Vilarinho¹, Paula Ferreira¹

¹CICECO – Aveiro Institute of Material, University of Aveiro, Department of Materials and Ceramic Engineering, 3810-193 Aveiro, Portugal

²ICMAB – Institute of Materials Science of Barcelona, Campus de la University Autonomous of Barcelona, 08193 Bellaterra, Barcelona, Spain

³School of Physics and Conway Institute of Biomolecular and Biomedical Research, University College Dublin, Belfield, Dublin, D04 V1W8, Ireland

fernandosa@ua.pt

Advancing technology demands a balance between miniaturization and sustainable electronics where, beyond recyclability, energy self-sufficiency is desired. A promising route integrates energy harvesting with biopolymers to create nanosensors and nanogenerators [1]. Cellulose, Earth's most abundant polymer, is a strong candidate, with bacterial nanocellulose (BC) offering a more sustainable, biosynthesized alternative to wood-derived cellulose. BC is highly pure and is reported to exhibit the piezoelectric behaviour, with increased performance when combined with inorganic materials [2]. However, as a biopolymer, BC can show diverse electromechanical behaviours, requiring differentiation between piezoelectricity, electrostriction and other possible phenomena. Atomic force microscopy (AFM) and piezoresponse force microscopy (PFM) help to characterize these by analysing first and second harmonic signals: a linear first harmonic indicates piezoelectricity, while an exponential second harmonic suggests a non-piezoelectric response.

In this study, we investigated the electromechanical properties of porous BC (*Komagataeibacter xylinus*) thin films and BC-ZnO composites synthesized via in-situ growth of the nanoparticles within the matrix porosity. We also analysed Nata de Coco (NC), a commercial BC-based material, and its ZnO composite. Structural and morphological characterization was conducted using X-ray diffraction, scanning electron microscopy, and nuclear magnetic resonance. Electromechanical responses were assessed through shaker-induced signal generation, with AFM and PFM used to evaluate surface topography and voltage-dependent harmonic behaviour. We present a detailed discussion on the origins of electromechanical mechanisms in BC-based materials and their potential in functional bioelectronics.

Acknowledgements: This work was developed within the scope of the project CICECO-Aveiro Institute of Materials, UIDB/50011/2020 (DOI 10.54499/UIDB/50011/2020), UIDP/50011/2020 (DOI 10.54499/UIDP/50011/2020) & LA/P/0006/2020 (DOI 10.54499/LA/P/0006/2020), financed by national funds through the FCT/MCTES (PIDDAC). FGS thanks the FCT for the grant SFRH/BD/150787/2020, as well as the funding of the COST Action NETPORE, CA20126, supported by COST (European Cooperation in Science and Technology).

References

- [1] A. S. M. Zahid Kausar, A. W. Reza, M.U. Saleh, and H. Ramiah, *Renewable and Sustainable Energy Reviews*, 38 (2014) 973-989
- [2] S. Roig-Sanchez, E. Jungstedt, I. Anton-sales, D.C Malaspina, J. Faraudo, and L. A. Berglund, *Nanoscale Horizons*, 4 (2019) 634-641

Figures

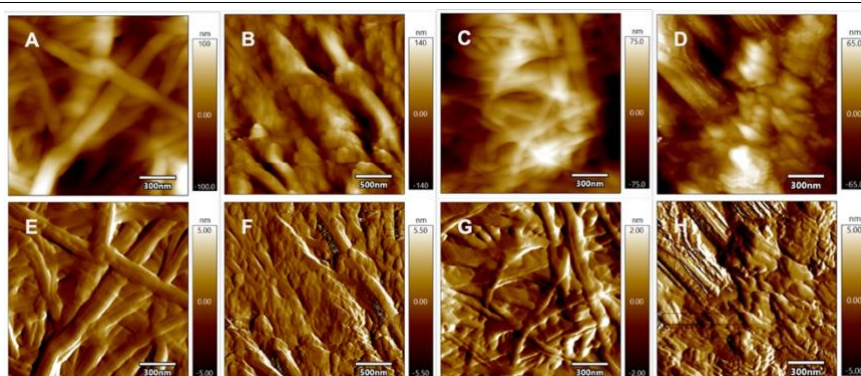


Figure 1: AFM tapping mode height scans of BC (A), BC ZnO (B), NC (C) and NC ZnO (D) and respective deflections (E, F, G, H).