materials proceedings

Abstract

Precise Approach for the Surface Functionalization of Poly(Lactic) Acid Coating via Electrical Patterning †

Maxim Ivanov *, **Júlio R. H. Rocha** and **Paula M. Vilarinho**

Department of Materials and Ceramic Engineering, CICECO—Aveiro Institute of Material, University of Aveiro, 3810-193 Aveiro, Portugal; julio.rocha@ua.pt (J.R.H.R.); paula.vilarinho@ua.pt (P.M.V.)
* Correspondence: ivanovmaxim@ua.pt

† Presented at the Materiais 2022, Marinha Grande, Portugal, 10–13 April 2022.

Keywords: Poly(L-lactic) acid (PLLA); surface functionalization; atomic force microscopy

Poly(L-lactic) acid (PLLA) is a biocompatible and biodegradable semicrystalline synthetic polymer that has considerable potential as a scaffold for tissue engineering, especially that related to bone regeneration [1–3]. The functionalization of the surface of medical Stainless Steel 316L (SS316L) by deposition of PLLA coating for its enhanced bioactive properties provides the precise control of the adhesion and proliferation of osteoblasts cells responsible for efficient bone tissue regeneration [1,2].

In this work, thin films of PLLA deposited using the spin coating technique (2.5% *w*/*w* solution) on 316 L SS substrate (previously functionalized with thermal treatment (500 °C for 2 h) and silanization APTES (60 min) procedures) were crystallized (180 °C for 3 min followed by 120 °C for 45 min). The significant potential of the PLLA/SS316L device for pronounced bioactivity was promoted via PLLA-coating functionalization using the application of local electrical field patterns at 1–3 GV/m (Figure 1a). This functionalization relies on the electromechanical stimulation phenomenon to generate the electric potential in response to the mechanical impact induced by skeletal weight and motion, thus allowing the control of the bone tissue cell adhesion, growth, and proliferation [1–3]. The fabricated samples were studied using the scanning probe microscopy technique (SPM) implemented in atomic force (AFM), piezoresponse (PFM), and Kelvin-probe (KPFM) modes. The results of topography and PFM scan images show that the microspherulites are the primary origin of the local piezoelectric response (Figure 1a,b). The correlated out-of-plane PFM response in Figure 1b suggests the ferroelectric nature of the PLLA thin films as measured at the nano- and microscale levels. An application of square-shaped and box-in-box dc bias voltage (BV) patterns gives rise to a work function redistribution measured as a sharp contrast in KPFM response and a substantial impact of both OOP and IP PFM signals (Figure 1b,c). The electrical functionalization of the PLLA coating and the results of PFM, EFM, and KPFM measurements confirm the ability to control in advance the electronic state of the internal fiber structure and manipulate the electrical polarization and surface charges at the micro- and nanometer scales to tailor the adhesion behavior of target bone tissue cells. Along with the biocompatible and biodegradable properties, the main advantage of functionalized PLLA coating is its self-induced electromechanical stimulation phenomena, i.e., enhanced natural healing ability, for all the tissue regeneration-oriented scaffolds.

Citation: Ivanov, M.; Rocha, J.R.H.; Vilarinho, P.M. Precise Approach for the Surface Functionalization of Poly(Lactic) Acid Coating via Electrical Patterning. *Mater. Proc.* **2022**, *8*, 57. https://doi.org/10.3390/materproc2022008057

Academic Editors: Geoffrey Mitchell, Nuno Alves, Carla Moura and Joana Coutinho

Published: 1 June 2022

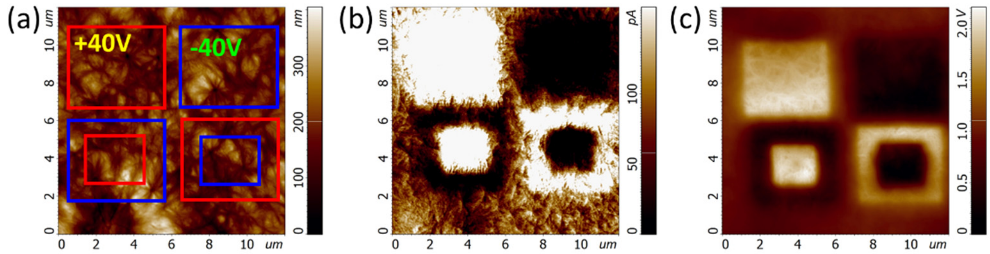

Figure 1. SPM imaging of the PLLA thin film: (**a**) Topography with marked dc BV patterns, (**b**) OOP PFM, and (**c**) KPFM.

Author Contributions: Conceptualization, methodology, formal analysis, investigation, writing—original draft preparation, M.I. and J.R.H.R.; writing—review and editing, supervision, project administration, funding acquisition; P.M.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the project "Advanced BioMEMs for tissue engineering: applications in hard tissue (BioMEMs)", POCI-01-0145- FED-ER-032095, and the RSF (20-79-10223). The authors thank CICECO-Aveiro Institute of Materials, UIDB/50011/2020, UIDP/50011/2020, and LA/P/0006/2020, financed by national funds through the FCT/MEC (PIDDAC).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is available on request from the authors.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Branquinho, M.V.; Ferreira, S.O.; Alvites, R.D.; Magueta, A.F.; Iva-nov, M.; Sousa, A.C.; Amorim, I.; Faria, F.; Fernandes, M.H.V.; Vilarinho, P.M.; et al. In Vitro and In Vivo Characterization of PLLA-316L Stainless Steel Electromechanical Devices for Bone Tissue Engineer-ing—A Preliminary Study. *Int. J. Mol. Sci.* **2021**, *22*, 7655. [CrossRef]
2. Magueta, F.; Fernandes, M.H.; Hortigüela, M.J.; Otero-Irurueta, G.; Vilarinho, P.M. Poly(L-lactic acid) coatings on 316 SS substrates for biomedical devices: The impact of surface silanization. *Prog. Org. Coat.* **2021**, *157*, 106289. [CrossRef]
3. Barroca, N.; Marote, A.; Vieira, S.I.; Almeida, A.; Fer-nandes, M.H.V.; Vilarinho, P.M.; da Cruz e Silva, O.A.B. Electrically polarized PLLA nanofibers as neural tissue engineering scaffolds with improved neuritogenesis. *Colloids Surf. B Biointerfaces* **2018**, *167*, 93. [CrossRef] [PubMed]