Innovative pathways in bioactive materials: The role of bioactive glasses in modern science and technology (Part I)

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Abstract

Glasses have evolved over centuries from simple silicate materials used in art and construction to highly engineered biomaterials with tailored properties. During and after the Second World War, the clinical options for bone repair were limited to bioinert materials, which often failed to integrate with living tissue. In response to this limitation, bioactive glasses were first developed by Larry Hench in 1969 to create materials capable of forming a direct chemical bond with bone and promoting tissue regeneration. Based on the original Bioglass® 45S5 composition, bioactive glasses typically consist of a silicate network composed of silicon dioxide (SiO_2), calcium oxide (CaO), sodium oxide (Na2O), and phosphorus pentoxide ($P2O_5$), with proportions carefully optimized to achieve high bioactivity. The amorphous structure of these glasses, characterized by a partially depolymerized silicate network, enables rapid ion exchange at the interface with biological fluids, leading to the formation of a carbonated hydroxyapatite layer chemically analogous to bone mineral. This surface reactivity is strongly influenced by the $SiO_2/Na_2O/CaO$ ratio and network connectivity, which determine the dissolution rates, ion release, and subsequent biological responses. Controlled variation of the chemical composition allows fine-tuning of key physicochemical properties, including biodegradation rate, solubility, local pH, and apatite nucleation potential. Furthermore, the incorporation of modifying or doping oxides, such as MgO, SrO, ZnO, CuO, or $B2O_3$, alters the glass network structure, which in turn influences bioactivity, mechanical behaviour, ion release kinetics, and biological performance. These compositional and structural modifications are fundamental to the versatility of bioactive glasses, making them essential materials for bone grafts, implant coatings, and tissue engineering scaffolds.

About the lecturer

Manuel Pedro Fernandes Graça is an Associate Professor with Habilitation at the Department of Physics of the University of Aveiro, Portugal. He holds a degree in Physics Engineering, a Master's degree in Materials Science and Engineering, and a Ph.D. in Physics jointly from the University of Aveiro and the Federal University of Ceará, Brazil.

He is an expert in solid-state physics, particularly in the electrical and magnetic properties of materials and micro- and nanomaterials processing, with a major dedication to bioactive materials research. He coordinates the Physics of Advanced Materials and Devices (PAMD) group at the i3N — Institute of Nanostructures, Nanomodelling and Nanofabrication — currently involving over 80 researchers. He has authored or co-authored over 300 journal papers, 30 book chapters, and 2 books, with more than 8,000 citations and an h-index of 46. He has delivered over 50 invited talks, including 14 plenary lectures in the past five years, and holds 3 patents. He has been involved in numerous national and international research projects, fostering collaborations across Europe, Africa, Asia, and South America. He has supervised 14 Ph.D. and 40 Master's student projects, coordinated several academic programmes, and served on various university and scientific councils. He has also been recognized as one of the top 2% most influential scientists worldwide by Stanford University since 2021.