

# Chapter 8

## Sol–Gel Synthesis of a New Composition of Bioactive Glass

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### ABSTRACT

*Bioactive glasses hold immense promise for tissue engineering and bone regeneration due to their ability to bond with living tissues and stimulate bone growth. This chapter explores the sol-gel method, a versatile technique offering advantages like lower processing temperatures and superior compositional control, for synthesizing a new bioactive glass composition. We discuss the fundamental principles of sol-gel chemistry and precursor selection for achieving the desired elements in the final glass. The chapter details the design rationale behind the new compositions, targeting the effect of therapeutic ions promotion specific antibacterial and angiogenesis properties and enhancement in bioactivity and osteoblast production. Additionally, the chapter offers a brief overview of in vitro bioactivity assessment methods for evaluating the glass's interaction with physiological fluids. Finally, we discuss the potential applications of the newly developed bioactive glass and propose future research directions for further optimization and exploration of its functionalities.*

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## I. INTRODUCTION

Bioactive glasses have emerged as a revolutionary class of biomaterials, offering unprecedented potential in the fields of tissue engineering and regenerative medicine (Owens et al., 2016). These remarkable materials possess the unique ability to form strong bonds with living tissues, particularly bone, making them invaluable in various medical applications (Deshmukh et al., 2020). The development of bioactive glasses represents a significant advancement in biomaterials science, bridging the gap between inert implants and the body's natural healing processes (Lepry and Nazhat, 2021a). Bioglass® 45S5, a melt-quenched bioactive glass with the composition 46.1% SiO<sub>2</sub>-26.9% CaO-24.4% Na<sub>2</sub>O-2.6% P<sub>2</sub>O<sub>5</sub> (in mol %), stands out as the most thoroughly researched bioactive glass (Hench, 1991). It has been utilized in clinical settings for more than 20 years, owing to its remarkable ability to integrate with both hard and soft tissues (Kokubo and Takadama, 2006). The key to its effectiveness lies in its capacity to release ions when exposed to physiological environments, which subsequently leads to the formation of a hydroxy-carbonated apatite (HCA) layer on its surface (Jones et al., 2001; Kokubo and Takadama, 2006; Hench and Jones, 2015). This unique property enables Bioglass® 45S5 to create strong bonds with bone and surrounding tissues (Hench and Thompson, 2010).

At the forefront of bioactive glass synthesis is the sol-gel method, a versatile and powerful technique that offers several advantages over traditional melt-quench processes (Deshmukh et al., 2020). This method allows for the production of glasses with higher purity, larger surface areas, and inherent porosity, all of which contribute to enhanced bioactivity and degradability (Owens et al., 2016). The sol-gel approach opens up new possibilities for tailoring the composition and properties of bioactive glasses, enabling researchers to optimize these materials for specific medical applications (Drago et al., 2018; Kunwong et al., 2021; Ebrahimi et al., 2023; Kaou et al., 2023; El Bouami et al., 2024).

This document explores the intricacies of the sol-gel method for bioactive glass synthesis, delving into the fundamental chemistry, advantages, and various modifications of this technique. It also examines the design considerations for new bioactive glass compositions, including the incorporation of therapeutic ions to enhance functionality. Furthermore, it discusses the mechanisms of bioactivity, methods for assessing it, and the potential applications of these innovative materials in tissue engineering and bone regeneration.

As we continue to push the boundaries of biomaterials science, bioactive glasses synthesized through sol-gel methods stand at the forefront of medical innovation, promising to revolutionize treatments for bone defects, tissue regeneration, and beyond.

## II. SOL-GEL METHOD FOR BIOACTIVE GLASS SYNTHESIS

### 2.1. Fundamentals of Sol-Gel Chemistry

The conventional sol-gel method, at its core, involves two primary stages: solution and gelation, where a “sol” refers to a colloidal suspension of solid particles, while a “gel” is an interconnected network of these solid particles that spans a secondary phase, typically a liquid (Owens et al., 2016). This sol-gel process chemistry fundamentally requires the transformation of alkoxide precursors, like tetraethyl orthosilicate (TEOS) and the triethylphosphate (TEP), through hydrolysis and condensation reactions. (Bokov et al., 2021) The hydrolysis reaction is the substitution of alkoxide groups (-OR) with hydroxyl

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