9 Sol-Gel Coatings on Titanium

Laurent–Dominique Piveteau

Massachusetts Institute of Technology,
Department of Chemical Engineering, Cambridge, MA 02139, USA

Introduction ................................................... 268
The Sol-Gel Process ............................................. 269
Film Formation ................................................ 271
Spin and Dip Coating ......................................... 271
Drying Stresses and Cracking ............................... 272
Control of Microstructure ................................. 273
Sol-Gel Routes to Titanium Oxide ....................... 274
Calcium-Phosphate Coatings ............................ 276
TiO$_2$–CaP Composites .................................. 278
Outlook ....................................................... 279
Abbreviations and Symbols ............................... 281
References ..................................................... 281
9.1 Introduction

Thin ceramic films or coatings over metallic bone-interfacing implant surfaces have the potential to improve the *in vivo* implant performance with respect to implant fixation, wear and corrosion. For example, the coating of a stainless steel or titanium implant with a calcium phosphate ceramic noticeably increases its integration into the bone tissue. A faster growth of the natural tissue and an increase of the contact surface between bone and implant have been observed. Other examples are implants having articulating surfaces (knee, hip) for which wear and oxidation resistance of the surface are of crucial importance for the long-term performance of the device. It can be improved by the presence of a hard coating, thus combining the advantageous mechanical properties of the bulk metal with the enhanced bioactivity (e.g. calcium phosphate, bioglasses) or the higher hardness of the ceramic material such as titanium nitride or zirconia. However, coatings on biomedical implants also bear some risks, which have to be judged in comparison to the potential benefit of the surface coating. The introduction of an additional interface can reduce the lifetime of an implant, in particular if the adhesion strength of the coating is low. In addition, the method that is used to deposit the coating can have a negative impact on the properties of the substrate (e.g. the elevated temperatures needed to densify ceramic may be deleterious to the mechanical properties of the substrate) or of the coating itself (a change in crystallinity can induce an increase in solubility and reduce its stability *in vivo*). Thus, if one would like to take advantage of the inherent benefits of ceramic coatings for metallic implants, the deposition technique as well as the pretreatment and potential posttreatment steps have to be chosen and controlled carefully.

The sol-gel process is exclusively aimed at the deposition of thin (< 10 μm) ceramic coatings. Compared to conventional thin film forming processing, it offers several advantages: it allows a better control of the chemical composition of the coating, the preparation of homogeneous films, a reduction of the densification temperature of the ceramic and the control of the film microstructure, and finally it requires considerably less equipment and is potentially less expensive than many of the alternative coating techniques. The precursors used in the sol-gel process are solutions. It is thus especially easy to purify them by distillation or crystallization or, taking the opposite approach, to introduce trace elements. In addition, these precursors are mixed at the molecular level in the solution. A high degree of homogeneity in the film can be expected. This intimate mixture of the coating components allows lower processing temperatures to be applied during sintering. This can be important for coating compositions, which easily decompose or otherwise undergo undesired phase transitions or possess volatile components. The resulting microstructure depends mostly on the treatment applied to the precursor as well as the relative rates of condensation and evaporation during film deposition. For example, the pore volume may be varied from 0 to 65%; the pore size from < 0.4 nm to > 5.0 nm; and the surface area from < 1 to > 250 m²/g. Control of these factors enables