BoneMaster™ HA: Nanocrystalline Hydroxyapatite Coating for Metallic Orthopedic Implants

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Introduction: BoneMaster™ is an electrochemical method of depositing hydroxyapatite [HA: $Ca_{10}(PO_4)_6(OH)_2$] coating on metallic orthopedic implants. HA coatings, with composition similar to the mineral content of bone, can enhance the osseo-integration of metallic implants with host bone. Unlike the plasma spray method, BoneMaster™ is not a line-of sight process and can be used to deposit pure, thin and nanocrystalline HA coatings at near physiological pH and temperature conditions. The present study characterizes the HA coatings deposited using the BoneMaster™ process. In addition, a unique application of Focused Ion Beam (Ga ions) technology is demonstrated for analyzing the thickness of thin coatings like those deposited by the BoneMaster™ process.

Methods: BoneMaster™ process was used to deposit the characteristic thin, nanocrystalline HA coating on Ti-6Al-4V substrates. The electrolyte used was a water-based solution containing ammonium phosphate and calcium chloride. The electrolyte was kept at 37 °C and the pH adjusted to 6.4. Moreover, the electro-assisted deposition process was conducted in galvanostatic mode. Scanning Electron Microscopy (SEM, Hitachi S-4700) was used to characterize the microstructure and morphology of the HA coatings. FTIR (Continuum, Thermo Nicolet) was used to confirm the presence of functional groups that characterize HA coating. Atomic force microscopy (PicoForce, Digital Instruments) was used to determine the shear adhesion strength between BoneMaster™ HA coating and metallic substrates. Focused Ion Beam (FEI model 200THP) micromachining was used to determine the thickness of the BoneMaster™ HA coating. The HA coating was first sputter-coated with Pt to protect the general coating surface. Ga^+ ions were subsequently used to micromachine the cross-section of the HA coating, which was then imaged with SEM (Hitachi S-4700).

Results: BoneMaster™ process was used to deposit a thin and continuous HA coating on metallic substrates. SEM analysis showed that numerous individual HA nanocrsytals are stacked together to form a continuous HA coating (Figure 1). FTIR confirmed that the functional groups detected for BoneMaster™ HA coating were typical of those observed for pure crystalline HA. Force spectroscopy analysis using AFM revealed that the average shear strength of HA coating deposited by BoneMaster™ process was 1.28 +/- 0.12 GPa. Figure 2 shows the cross-section of the BoneMaster™ HA coating micro-machined using a focused ion beam (FIB). The FIB analysis showed that the thickness of the coating was between 2 to 3 microns.

Conclusions: BoneMaster™ process can be used to electrochemically deposit a thin, nanocrystalline HA coating on metallic substrates under near physiological conditions. The coating adhesion strength (1.28 GPa) to the substrate was substantially higher than the minimum requirement (20 MPa) listed in FDA guidance document for plasma spray metallic coatings on metallic substrates. FIB is introduced as a unique tool for accurately measuring thickness of thin coatings like BoneMaster™ HA. FIB process preserves the structural features of the coating like porosity, since the coating is not subjected to any shear stresses (in micromachining the cross-section) that may cause delamination of the coating from the substrate. It is of importance to note that since the coating is only a few microns thick, the surface morphology of the substrate is not altered. Thus, BoneMaster™ is a non-line-of-sight technology for coating metallic orthopedic implants with HA for improving osseo-integration while preserving the overall functionality of the device.

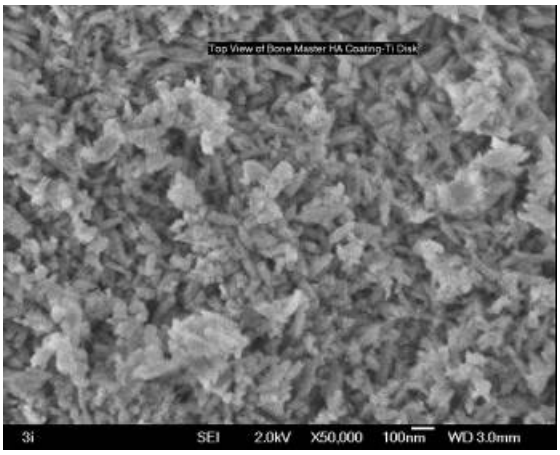

Figure 1. SEM image of nanocrystalline HA coating deposited using BoneMaster™ process

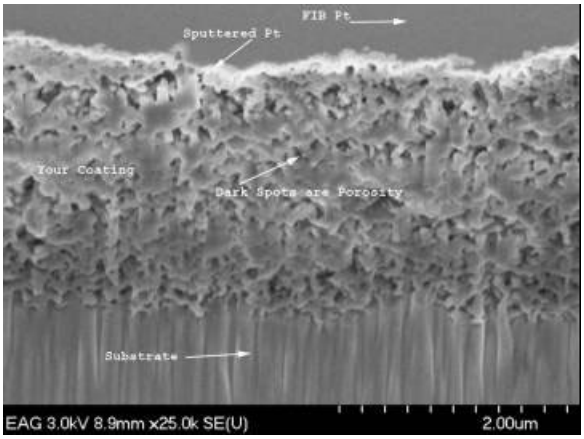

Figure 2. SEM image of cross-section of BoneMaster™ HA coating micromachined using focused ion beam