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A novel titania/calcium silicate hydrate hierarchical coating on titanium

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ABSTRACT

Recently, surface micron/nano-topographical modifications have attracted a great deal of attention because it is capable of mimicking the hierarchical characteristics of bone. In the current work, a novel titania/calcium silicate hydrate (CSH) bi-layer coating with hierarchical surface topography was successfully prepared on titanium substrate through micro-arc oxidation (MAO) and subsequent hydrothermal treatment (HT). MAO treatment could lead to a micron-scale topographical surface with numerous crater-like protuberances. The subsequent HT process enables the *in situ* nucleation and growth of CSH nanoplates on MAO-fabricated titania surface. The nucleation of CSH nanoplates is considered to follow a dissolution–precipitation mechanism. Compared to MAO-fabricated coating with single-scale surface topography, MAO–HT-fabricated coating with hierarchical surface topography exhibits enhanced hydrophilicity, fibronectin adsorption and initial MG-63 cell attachment. The process of cell-material interactions is considered to be triggered by surface properties of the coated layer and indirectly mediated by protein adsorption on coating surface. These results suggest that MAO–HT treatment is an efficient way to prepare coatings with hierarchical surface topography on titanium surface, which is essential for altering protein adsorption and initial cell attachment.

1. Introduction

The establishment of integration between the implant and the surrounding bone is a key factor for successful implants fixation in orthopedic and dental applications [1]. The generally accepted process of osseointegration involves a complex chain of biological events between the implant surface and the physiological environment. These events are likely initiated by protein adsorption and blood clotting at the implant surface, followed by mesenchymal stem cells and osteoblasts adhesion to the surface and finally result in bone matrix formation by those differentiated cells at the interface [2,3]. The surface characteristics of titanium-based implants can significantly influence these interactions that emerge at the interface [4]. Unfavorable surface properties lead to the formation of fibrous layer around the implant and finally result in failure of implantation [5]. Among all the surface properties of titanium-based implants, surface topography and chemistry are considered to be the two critical factors that influence bone response [6].

In order to enhance these surface features of titanium-based implants for successful osseointegration, numerous modification strategies involving chemical, physical and biological tools have been established in the last decades [7–10]. The surface modification of titanium implants with micron/nano-topography has been proven useful to mimic the hierarchical characteristics of the bone [11]. Bone undergoes remodeling consisting of sequential osteoclastic resorption and osteoblastic formation to repair the microdamages and replace old bone with new one [12,13]. The resorpted lacunae created by osteoclastic activity have micron-scale features (pits with a diameter of 30–100 μm) and nanostructure (collagen fibers left on the surface), exhibiting unique hierarchical structure [14,15]. This kind of hierarchical structure could be the signal for osteoblast attachment, proliferation and differentiation [2]. Many dental and orthopedic implants have been improved for better cellular response by modifying their surface topography at micron- and nanoscale [11,16]. Kubo et al.

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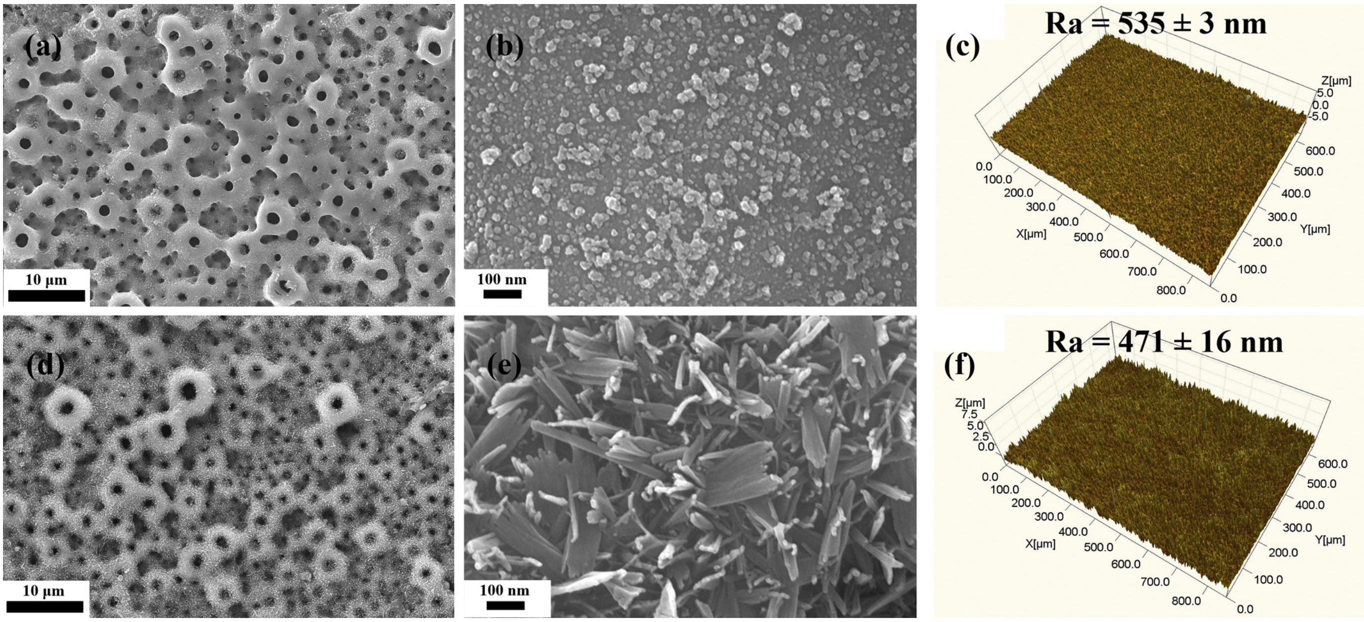

Fig. 1. SEM micrographs of MAOed (a and b) and MAO–HTed coatings (d and e) at different magnifications; 3D toughness profile of MAOed (c) and MAO–HTed (f) coatings.

reported that micron- and nano-hybrid topographies enhanced both osteoblast proliferation and differentiation compared to only micron-scale topography [17]. An investigation conducted by Gittens et al. reported that the surface with both micron-scale roughness and nano-scale features promoted osteoblast differentiation as well as local factor production more significantly than surfaces with only micron-scale roughness or nano-scale features [18]. Zhou et al. developed a hierarchical structure by patterning Sr-doped hydroxyapatite (HA) nanorods on micro-arc oxidized TiO_2 layer and found that the inter-rod spacing played an important role in mediating cell adhesion [19]. These findings suggest that the modification of surface topography of titanium-based implants in both micron/nano-scale might have a great potential for successful osseointegration with host bone.

The modification process of titanium surface with micron/nano-topography is usually achieved by two steps. It starts with the development of micron-scale topography on titanium-based substrate, followed by the superposition of nanostructure to the former modified surface. To create a surface with micron-scale topography on titanium, several techniques are commonly used, such as acid

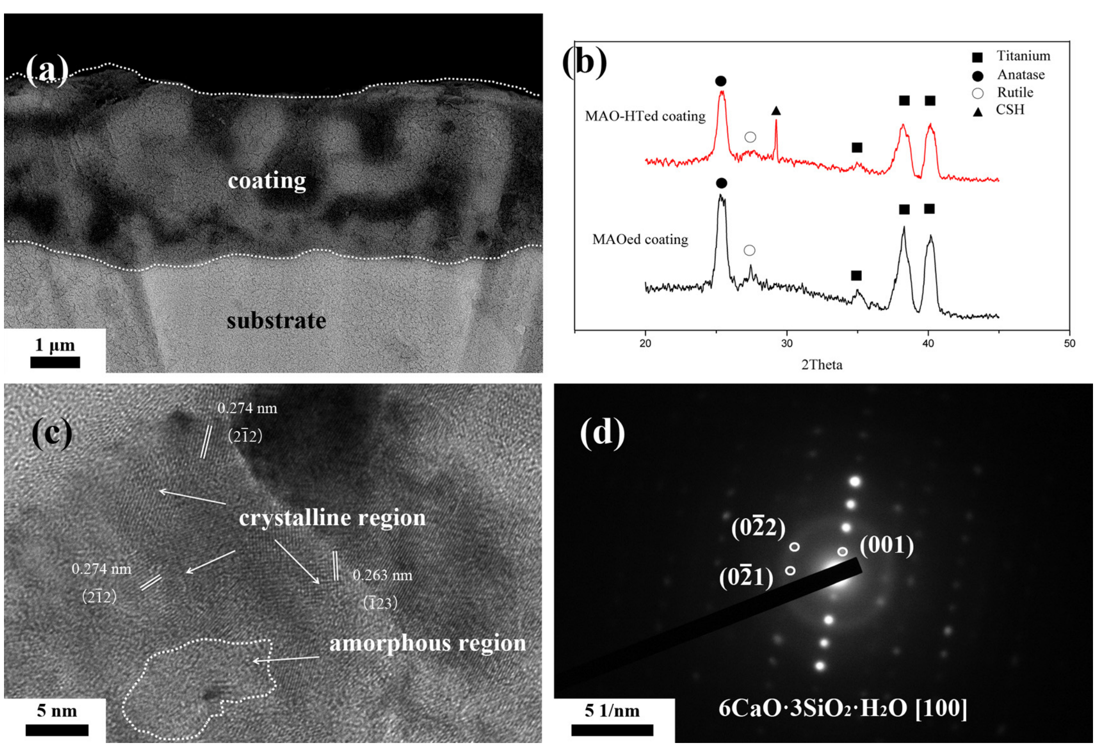

Fig. 2. SEM–BSI of the cross-sectional morphology of MAO–HTed coating (a); TF-XRD patterns of MAO and MAO–HTed coatings (b); HRTEM image (c) and SAED pattern of scratched crystal plates of MAO–HTed coating.