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Exploration of Novel Ordering Mechanism in Titanium Alloys Using Atom Probe Tomography and Aberration-corrected Scanning Transmission Electron Microscopy

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Microstructural evolution and phase transformations in titanium alloys are closely related to the beta phase stability. With the development of advanced characterization techniques, e.g. atom probe tomography (APT) and aberration-corrected scanning transmission electron microscopy (STEM), various novel nano-scaled structural and/or compositional instabilities in beta phase have been explored in titanium alloys recently, including athermal and isothermal omega phase [1], incommensurate nano-domains [2], O' phase [3] and nano-scaled solute segregation via spinodal decomposition [4]. For example, in our recent studies, the structure and composition of nano-scaled isothermal omega phase has been systematically explored in a metastable beta titanium alloy, Ti-5Al-5Mo-5V-3Cr (Ti-5553, wt.%), through coupling APT and aberration-corrected STEM data [1]. Via these atomic resolution characterizations, it has been clearly shown that the hexagonal structure of nano-scaled isothermal omega phase is formed via the collapse of every two of three adjacent {111} plane where solutes including Al, Mo, V and Cr are all rejected from the isothermal omega phase into the beta phase by diffusion. In this presentation, the latest investigation of novel nano-scaled ordered orthorhombic structure phase in titanium alloy, named as O'' phase, as studied using APT, transmission electron microscopy (TEM) and aberration-corrected STEM will be introduced [5-6].

In the first part of this work, novel O'' phase was investigated using ex-situ TEM (FEI CM200) and aberration-corrected STEM (FEI Titan™ 80-300) in Ti-5553 [5]. For the first time, the nano-scaled particles of ellipsoidal morphology and ordered orthorhombic structure were observed in the aged Ti-5553, shown in Fig. 1(a-b) [5]. The structure of the O'' phase was characterized using Z-contrast HAADF-STEM imaging, revealing ordering of every third {011} beta planes by the periodic intensity change of the atom columns, shown in the Fig. 1(c) [6].

The second part of the work to be presented focuses on the exploration of the compositional information of the O'' phase using APT (LEAP 5000XR) [6]. For the first time, conclusive experimental evidence showing that the Al segregation plays an important role in the nano-scaled ordering is provided. Fig. 2(a) shows a representative 3D reconstruction where only Ti ions as well as an 85 at.% Ti and 6.5 at.% Al iso-concentration surfaces are shown, revealing the presence of nano-scaled O'' phase (green colored particles) together with nano-scaled isothermal omega phase (red colored particles). The compositional profile in Fig. 2(d) across the beta/O'' phase interface shows that Al slightly segregates into O'' phase compared with the composition of isothermal omega phase (although still lower than in the parent beta phase). During heating, significant amounts of V, Mo and Cr together with Al partition to the beta phase from the incipient nano-scaled domains, generating the heating-induced ordered orthorhombic structure of O'' phase [6].

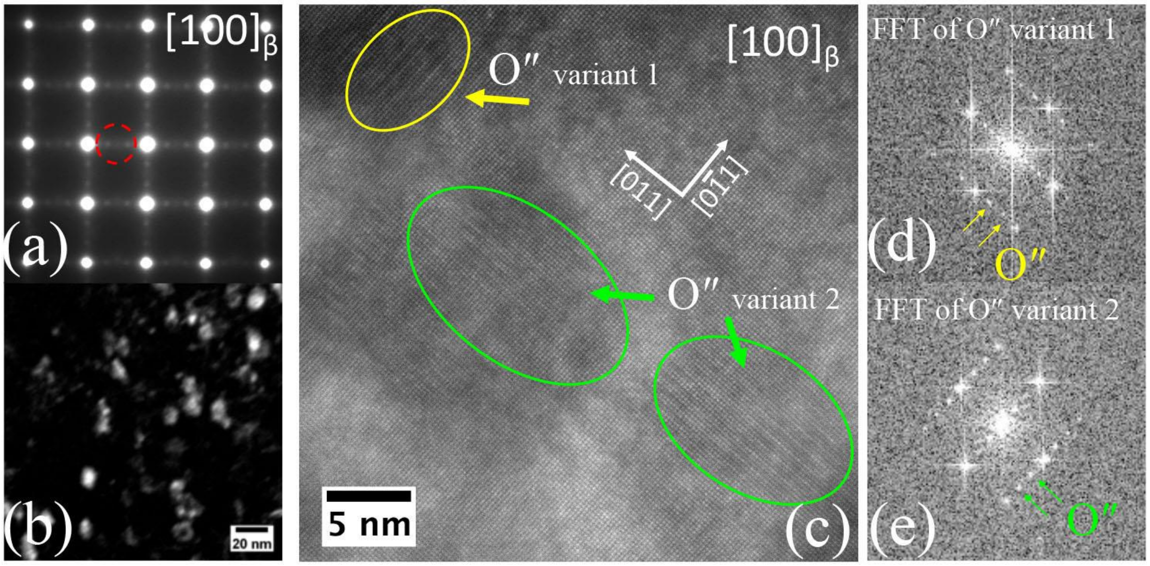

Figure 1. TEM and aberration-corrected STEM results showing the nano-scaled O" phase particles: (a) Selected area diffraction pattern and (b) corresponding dark field image showing the morphology of O" phase particles [5]; (c) HAADF-STEM image and corresponding Fast Fourier Transformations showing the ordered structure of O" phase [6].

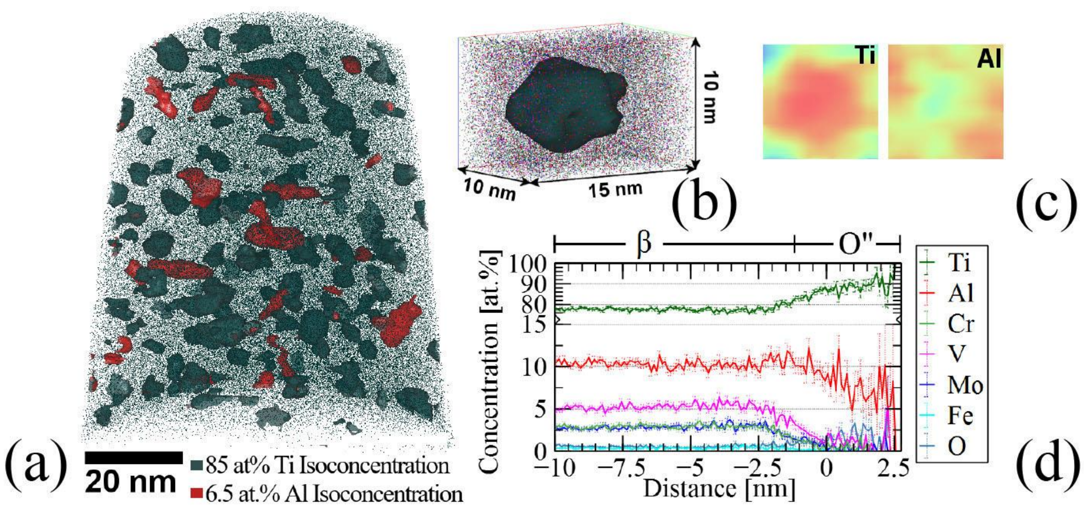

Figure 2. APT results showing nano-scaled O² phase particles: (a) 3D reconstruction showing the morphology of O" phase particles (green) and isothermal omega phase particles (red); (b-c) selected 3D reconstruction of an O" phase particle and 2D composition slices from that particle; (d) composition profile across beta/O" interface showing the composition of O" phase [6].

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