

# TEM study of Co<sub>3</sub>Ti made amorphous by high pressure torsion

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Amorphous structures can be achieved by a solid state transformation of the crystalline structure using severe plastic deformation. This has been successfully carried out by applying high-pressure torsion (HPT) deformation in the case of L<sub>12</sub> ordered Zr<sub>3</sub>Al [1].

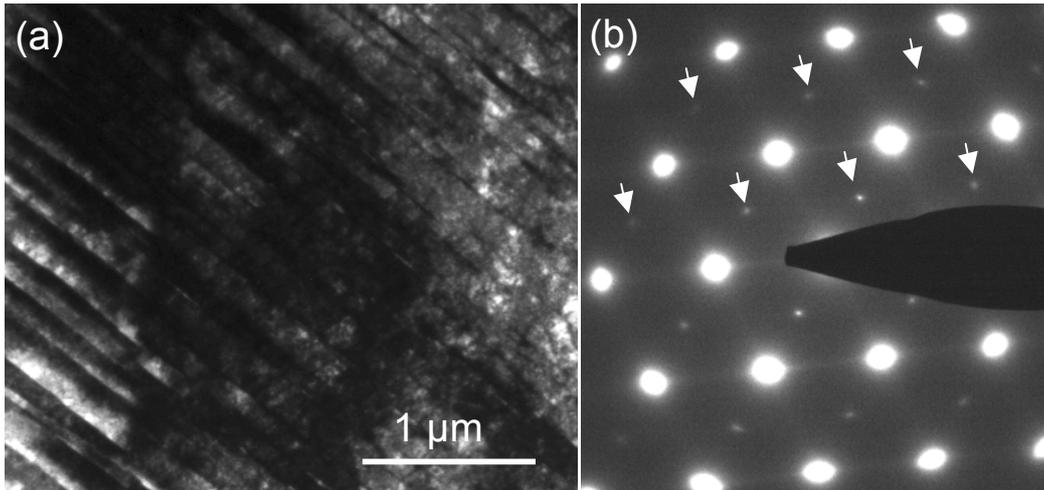
In the present work the structural changes caused by HPT deformation of bulk intermetallic Co<sub>3</sub>Ti is studied on multiple length scales using a combination of scanning (SEM) and transmission electron microscopy (TEM) methods, including high-resolution TEM (HRTEM). Co-23at.%Ti samples were alloyed from high purity elements and deformed by HPT to different degrees of deformation under a pressure of 4 GPa. TEM foils were prepared from different areas of the HPT-discs using electropolishing.

The SEM investigations of the cross-section of the HPT samples using back-scattered electrons reveal that the material deforms very inhomogeneously and shows a tendency to amorphization localized in the form of bands. With increasing deformation the volume fraction of the amorphous phase increases.

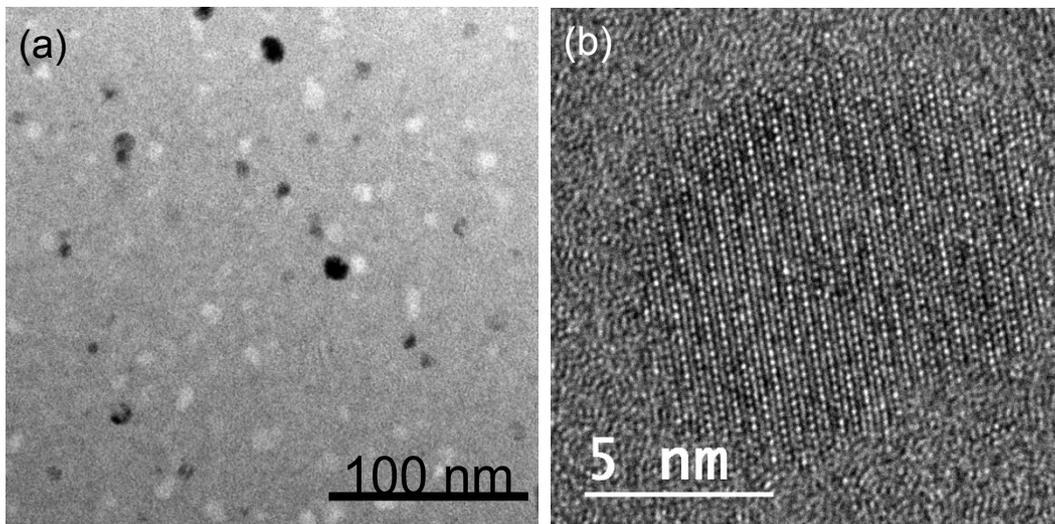
Figure 1a shows a TEM bright-field image from a region corresponding to a low deformation. A high density of stacking faults on {111} planes is observed. The selected area (SA) diffraction pattern (Figure 1b) shows streaking of the fundamental reflections along two different <111> directions but not of the superlattice reflections, thus revealing that the observed faults are stacking faults. During the deformation of L<sub>12</sub> ordered intermetallic compounds superlattice glide dislocations are formed. The glide dislocations can reduce their energy by dissociation; which can be achieved in two different ways: (i) the dissociation into unit dislocations bounding an antiphase boundary fault, as observed in Ni<sub>3</sub>Al and Cu<sub>3</sub>Au or (ii) the dissociation into super-Shockley partials bounding a superlattice intrinsic stacking fault, as observed in Zr<sub>3</sub>Al and in the present work on Co<sub>3</sub>Ti. In a recent paper we demonstrate that a dissociation by scheme (ii) does not lead to chemical disorder but facilitates amorphization [2]. This is in good accordance with the present results. In Co<sub>3</sub>Ti no disordering is observed but amorphization occurs at large deformations.

Figure 2a shows a TEM bright-field image of a sample deformed to a nominal shear strain of 100,000% having an amorphous structure containing a large number of crystallites (5 to 20 nm in size). The morphology of the crystals is mainly round with some faceting. The SA diffraction pattern contains diffraction spots in addition to the amorphous rings caused by crystallites embedded in the amorphous material. The analysis of the diffraction rings indicates that crystallites containing Laves phases (cubic Co<sub>2</sub>Ti and double hexagonal Co<sub>2.1</sub>Ti<sub>0.9</sub>) occur, not encountered in the initial material. Therefore, it is concluded that the crystallites are formed during severe plastic deformation. To analyse the crystallites in more detail HRTEM images (cf. Fig. 2b and Fig. 3) were taken. Fig. 2b shows a nanocrystal with the hcp structure similar to that of pure Co. In contrast, Fig. 3 reveals that several nanocrystals have a Laves phase structure with a heavily faulted stacking sequence.

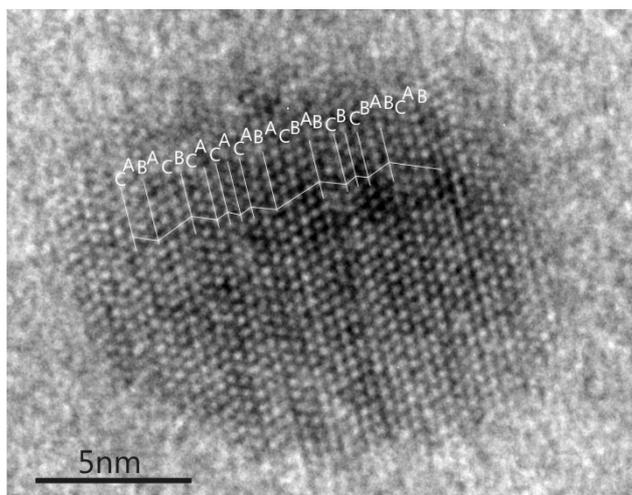
1. D. Geist, C. Rentenberger, H. P. Karnthaler. *Acta Mater.* 59 (2011) 4578.
2. D. Geist, C. Gammer, C. Mangler, C. Rentenberger, H.P. Karnthaler. *Phil. Mag.* 90 (2010) 4635.
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**Figure 1.**  $\text{Co}_3\text{Ti}$  deformed by high pressure torsion; initial stage of deformation. (a) TEM bright-field image showing a high density of stacking faults. (b) The corresponding diffraction shows both fundamental and superlattice spots (some of them marked by arrows) as the material is still ordered. The high density of stacking faults leads to streaking in the fundamental reflections.



**Figure 2.**  $\text{Co}_3\text{Ti}$  deformed by high pressure torsion. (a) TEM bright-field image showing amorphous material containing a large number of nanocrystals. (b) HRTEM of a nanocrystal with hcp structure.



**Figure 3.**  $\text{Co}_3\text{Ti}$  deformed by high pressure torsion. HRTEM image showing a nanocrystal embedded in the amorphous matrix (cf. Figure 2a). A closer inspection of the HRTEM image reveals that the nanocrystal shows a highly faulted structure, comprising an alternation of the cubic and hexagonal Laves phase. The cubic Laves phase ( $\text{Co}_2\text{Ti}$ ) has the stacking sequence ABCABC and the double hexagonal Laves phase ( $\text{Co}_{2.1}\text{Ti}_{0.9}$ ) the stacking sequence ABACABAC. The stacking sequence of the nanocrystal is indicated in the figure.