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Intermetallics

Intermetallics 15 (2007) 783–790

www.elsevier.com/locate/intermet

Microstructural control of Nb–Si alloy for large Nb grain formation through eutectic and eutectoid reactions

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Available online 20 December 2006

Abstract

Alloys based on Nb-silicides exhibit superior high temperature strength than the commercial nickel based superalloys. In order to improve the low-temperature ductility by microstructural control, authors have attempted to understand the nature of the eutectic and eutectoid reactions in Nb-rich portion of the Nb–Si binary system, especially the crystallographic orientation relationship among the phases using FESEM-EBSD. During the eutectic reaction it was found that Nb rods of about 1 μm in diameter having a certain crystallographic orientation disperse in Nb_3Si matrix in a eutectic cell. Then, during the following heat treatment Nb_3Si decomposes into a lamellar structure composed of Nb and α-Nb_5Si_3 in a manner of eutectoid reaction. It is observed that eutectoid Nb plates tend to nucleate at the eutectic Nb rod because both of them have a similar crystallographic orientation, resulting in a network of Nb phase with fine α-Nb_5Si_3 dispersoids. The Nb network may act as a large Nb grain which is expected to show better mechanical properties at both low and high temperatures. Both the reaction kinetics of the eutectoid decomposition of Nb_3Si and the tendency of the Nb network formation are significantly affected by doping elements, which are attributed to the control of the interfacial energies among phases.

Keywords: A. Silicides, various; B. Alloy design; B. Grain growth; B. Phase transformations; F. Electron microscopy, scanning

1. Introduction

Among various refractory materials, alloys based on Mo- and Nb-silicide have attracted many investigations because they exhibit superior high temperature strength than the commercial nickel based superalloys [1–8]. In order to overcome their deficits, lack of room temperature ductility and high temperature oxidation resistance, both microstructural control techniques and coating technologies have been developed. As the interfacial condition for fine coatings also strongly depends on the bulk microstructure, it is inevitable to improve the microstructure which fulfills both requirements for further development of the high performance alloys.

Because of the good density–melting point ratio, Nb-silicide is one of the most promising materials. According to the advanced microstructural control of Ni-based superalloys, both larger ductile matrix grains and higher volume fraction of thermally and mechanically stable dispersoids are most desirable microstructure for high temperature use. Fig. 1 shows the Nb–Si binary phase diagram [9]. The melting point of Nb is as high as 2469 °C, which is very attractive for high temperature application, but is a barrier to apply conventional grain growth techniques for single crystal production from its melt. Moreover, the maximum solid solubility of Si in Nb terminal solid solution is as small as 3.5 at% which is much smaller than the Al solid solubility in Ni of about 20 at%. High Al solubility in Ni solid solution enables one to introduce large amount of precipitates (γ′-Ni_3Al) into Ni-based superalloys, but it is not the case for the Nb–Si system. Another processing route is required for the development of Nb–Si alloys which provides much lower processing temperature and allows one to introduce larger amount of thermodynamically stable dispersoids.

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doi:10.1016/j.intermet.2006.10.041

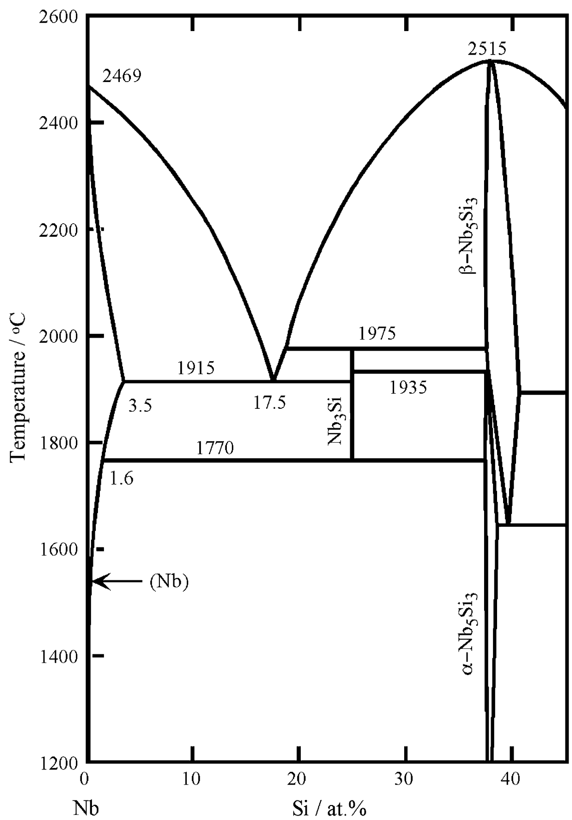

Fig. 1. Phase diagram of the Nb–Si binary system [9].

According to the Nb–Si binary system, there are two invariant reactions. One is the eutectic reaction,

$$L \rightarrow Nb + Nb_3Si, \tag{1}$$

and the other is the eutectoid reaction,

$$Nb_3Si \rightarrow Nb + \alpha - Nb_5Si_3(LT) \tag{2}$$

It is quite easy to figure out a processing route to form Nb/Nb_5Si_3 two-phase alloys from the melt by combining these two reactions. The expected microstructure evolution is summarized in Fig. 2. Once a eutectic microstructure composed of Nb and Nb_3Si phases is attained from the melt as shown in Fig. 2(b), then the following eutectoid reaction initiated from the Nb phase drives the decomposition of Nb_3Si phase and Nb_5Si_3 phase remains as small particles among Nb network as shown in Fig. 2(c). Traditionally the eutectoid reaction in the Fe–C system, called pearlite formation, has been utilized to control the microstructure of steel. However, the eutectoid decomposition from Nb_3Si to Nb/Nb_5Si_3 two-phase structure was reported to be so sluggish that it takes about 100 h for completion of the decomposition even at the nose temperature of about 1500 °C [3]. Hence, the reaction has not been considered as a candidate for the technique for microstructural control of Nb–Si based alloys. This slow kinetics may be relevant to its high melting point.

Recently Sekido et al. found that the addition of 10 at% of Ti increases the decomposition rate of the Nb_3Si [10–14]. The present authors also found that Zr accelerates the decomposition of Nb_3Si [15–17]. Fig. 3 shows the time–temperature transformation (TTT) diagram for various Nb–Si alloys [3,10–14,16]. Although the details are still not fully understood [10–14,16], these findings motivate us to realize the combination of the eutectic and eutectoid reactions for

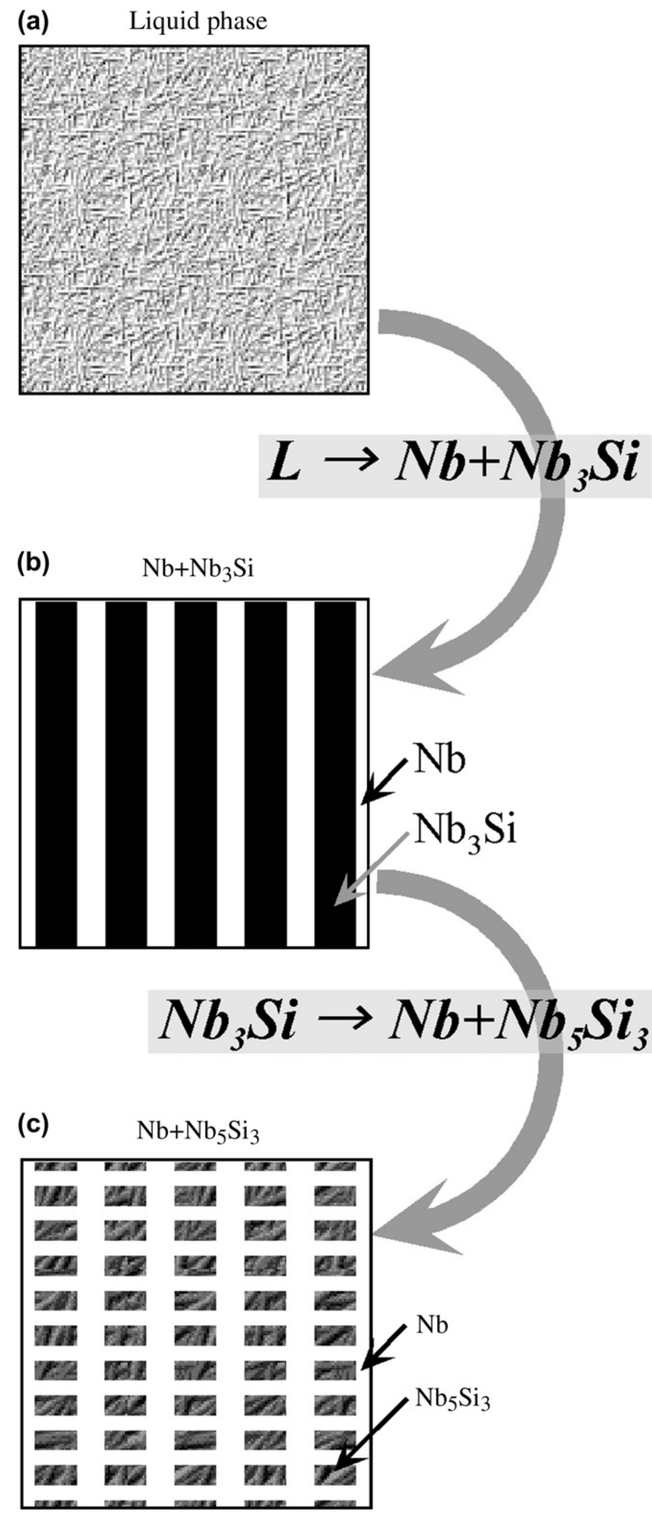

Fig. 2. A schematic representation of the microstructural evolution during two invariant reactions.