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Order-disorder morphologies in rapidly solidified ε/ε'-Ni_5Ge_3 intermetallic

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Abstract

Congruently melting, single-phase Ni_5Ge_3 (T_m = 1185 °C) has been rapidly solidified via drop-tube processing wherein powders, with diameters between 850 – 53 μm, are produced. At low cooling rates (850 – 150 μm diameter particles, 700 – 7800 K s^{-1}) the dominant solidification morphology, revealed after etching, is that of isolated plate & lath microstructure in an otherwise featureless matrix. At higher cooling rates (150 – 53 μm diameter particles, 7800 – 42000 K s^{-1}) the dominant solidification morphology is that of isolated faceted hexagonal crystallites, again imbedded within a featureless matrix. Selected area diffraction analysis in the TEM reveals the plate & lath, and isolated hexagonal crystallites, are a disordered variant of ε-Ni_5Ge_3, whilst the featureless matrix is the ordered variant of the same compound. Thermal analysis and *in situ* heating in the TEM indicate a reversible solid-state order-disorder transformation between 470 - 485 °C.

1. Introduction

Intermetallic compounds have been of widespread and enduring interest within Materials Science over the last 30 years or so. Such compounds are characterised by strong internal order and mixed covalent/ionic and metallic bonding, which gives rise to mechanical behaviour intermediate between ceramics and metals. A range of potential applications as high temperature structural materials have been proposed for these materials due to good chemical stability and high hardness at elevated temperatures. However, poor room temperature ductility limits formability. Such limitations can be overcome by controlling the degree of chemical ordering present within the intermetallic, with the disordered form typically showing behaviour which is more metallic in character (higher ductility, lower hardness, and lower chemical resistance) than the fully ordered form. Rapid solidification of intermetallics is therefore an important area of study as high cooling rates are one means of suppressing ordering. Subsequent annealing of the formed part can then be utilised to restore chemical ordering, and hence the desirable properties of the intermetallic.

In this paper we consider the rapid solidification of the intermetallic Ni_5Ge_3. This is an interesting model system as, being congruently melting, the ordering reaction can be studied without any complicating solute effects. That is, we can be certain that solute partitioning, and hence also solute trapping, is absent.

The phase diagram for the Ni-Ge system has been studied extensively by Ellner et al. [1] and by Nash and Nash [2], in 1971 and 1987 respectively. More recently, further work has been also reported by Liu *et al.* [3] and by Jin *et al.* [4]. Ni_5Ge_3 is a congruently melting compound with a homogeneity range for the single phase compound of 34.6 – 44.5 at. % Ge. The congruent point is towards the Ge-deficient end of this range at 37.2 at.% Ge and 1458 K. Ni_5Ge_3 displays two equilibrium crystalline forms, ε and ε' [2] [4]. The high temperature ε-phase has the $P6_3/mmc$ crystal structure (Hexagonal, space group 194), while the low temperature ε'-phase has the C2 crystal structure (Monoclinic, space group 5) [4]. The transition between the two occurs either