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Fe-Ni-Si (Iron-Nickel-Silicon)

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The review of this system by [1988Ray] presented a tentative liquidus projection, partial isothermal sections at 1000, 800, 600, and 450 °C for Ni-rich alloys, two computed isothermal sections at 1127 and 427 °C and a reaction sequence. This was followed by several brief updates by [1994Rag, 2003Rag, 2008Rag]. The first update [1994Rag] reviewed the work of [1985Ans], who computed a number of isothermal sections between 1127 and 427 °C. The second update [2003Rag] summarized the experimental phase equilibria reported by [1998Ike] in the order-disorder region of Fe-rich alloys and the computed results of [1999Mie]. The recent update by [2008Rag] reviewed the isothermal section in Ni-rich alloys 900, 800, and 700 °C from [2005Him]. Very recently, an isothermal section at 850 °C was determined by [2009Zha] over the entire composition range. The phase equilibria were also investigated by [2009Ack].

Binary Systems

In the Fe-Ni phase diagram, a continuous face-centered cubic solid solution (denoted γ) forms between γFe and Ni and is stable over a wide range of temperature. At 517 °C, an ordered phase $FeNi_3$ ($L1_2$, $AuCu_3$-type cubic) forms congruently from γ. In the Fe-Si system [Massalski2], the Fe-based face-centered cubic phase γ is enclosed by a loop. The intermediate phases are: α_2 (*B*2, CsCl-type cubic), α_1 ($D0_3$, BiF_3-type cubic), Fe_2Si (stable between 1212 and 1040 °C; hexagonal), Fe_5Si_3 ($D8_8$, Mn_5Si_3-type hexagonal), FeSi (*B*20-type cubic), $\beta FeSi_2$ (tetragonal) and $\alpha FeSi_2$ (orthorhombic). There are a number of intermediate phases in the Ni-Si system [1999Du, Massalski2]. The phases found stable at 850 °C by [2009Zha] are: Ni_3Si (denoted β_1; $L1_2$, $AuCu_3$-type cubic), Ni_5Si_2 or $Ni_{31}Si_{12}$ (Ni_5Si_2-type, hexagonal, space group *P*321), θNi_2Si ($B8_2$, Ni_2In-type hexagonal), δNi_2Si (*C*37, Co_2Si-type orthorhombic), Ni_3Si_2 (Ni_3Si_2-type orthorhombic, space group $Cmc2_1$), NiSi (*B*31, MnP-type orthorhombic), and $NiSi_2$ (*C*1, CaF_2-type cubic).

Ternary Phase Equilibria

With starting metals of 99.99% Fe, 99.99% Ni, and 99.95% Si, [2009Zha] arc-melted under Ar atm 24 ternary alloys. The alloys were annealed at 850 °C for 28 days and quenched in water. The phase equilibria were studied with

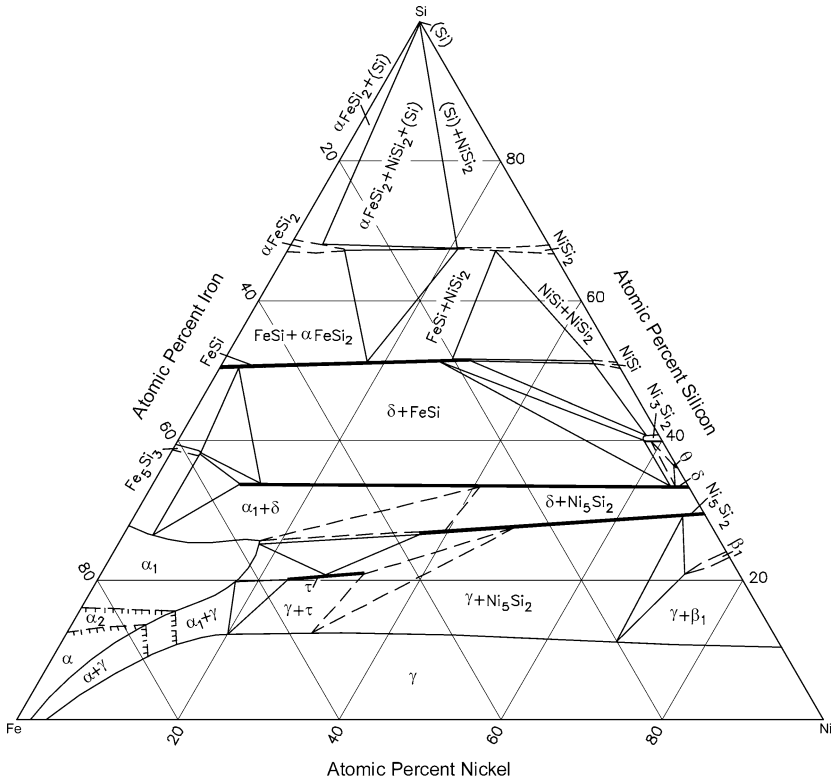

Fig. 1 Fe-Ni-Si isothermal section at 850 °C [2009Zha]

optical and scanning electron metallography, x-ray powder diffraction, and energy dispersive x-ray analysis/electron probe microanalysis. The identified phases, their composition and lattice parameters were listed. The isothermal section at 850 °C constructed by [2009Zha] is shown in Fig. 1. The previously known ternary phase of nominal formula $Fe_5Ni_3Si_2$ (denoted τ here) is present with a homogeneity range of 46.5-56.3 at.% Fe and 32.5-23.6 at.% Ni. Its crystal structure was confirmed to be Au_4Al-type cubic, with the lattice parameter a = 0.61322-0.61420 nm [2009Zha]. The solubility of Fe in Ni_3Si (β_1), Ni_5Si_2, δNi_2Si, NiSi and $NiSi_2$ is up to 7.6, 38.3, 55.9, 3.3, and 11.5 at.%, respectively. The solubility of Ni in Fe_3Si (α_1), Fe_5Si_3, FeSi, and $FeSi_2$ is up to 17.0, 5.0, 31.5, and 9.6 at.%, respectively.

With starting metals of 99.99% purity, [2009Ack] arc-melted 25 ternary alloys under Ar atm. The alloys were annealed at 700 °C for 2 weeks and quenched in water. The phase equilibria were studied with x-ray powder diffraction, energy dispersive x-ray analysis on a scanning electron microscope and differential thermal analysis at a heating/cooling rate of 5 °C per min. Using their results and the literature data, [2009Ack] constructed an isothermal section at 700 °C, a vertical section along the Fe_2Si-Ni_2Si join and a liquidus projection. For the composition range of 20-67 at.% Ni along the above join, [2009Ack] postulated that θNi_2Si is stable at higher temperatures and transforms on cooling to δNi_2Si in a diffusionless manner without any thermal hysteresis and without an intervening two-phase field. Further, [2009Ack] assumed that θNi_2Si (Ni_2In-type hexagonal, $P6_3/mmc$) and Fe_2Si (hexagonal, $P\bar{3}m1$) form a continuous solid solution, which was justified on the basis of the close structural similarity between them. Additional experimental support is needed to confirm the findings of [2009Ack].

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