Microstructural effects and kinetics of high temperature oxidation in Nb-Si base alloys

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INTRODUCTION

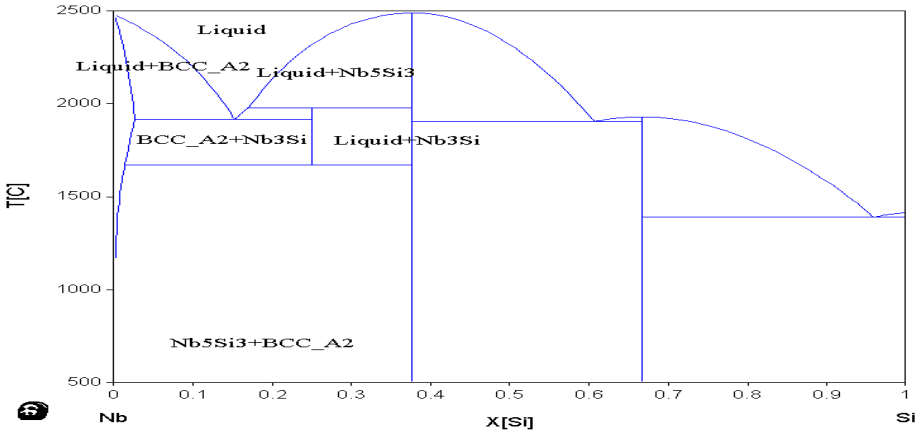
- **Understand the effect of alloying on microstructural modification in Nb-Ti-Si based alloys (phases formed, microstructural distribution)**

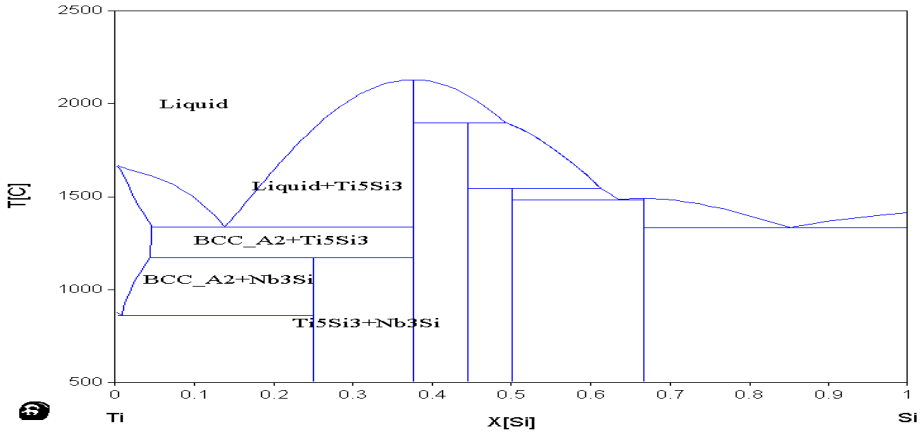
- **Effect of Ti, Al, Cr, C on Nb-Si alloys (as-cast, heat-treated alloys)**

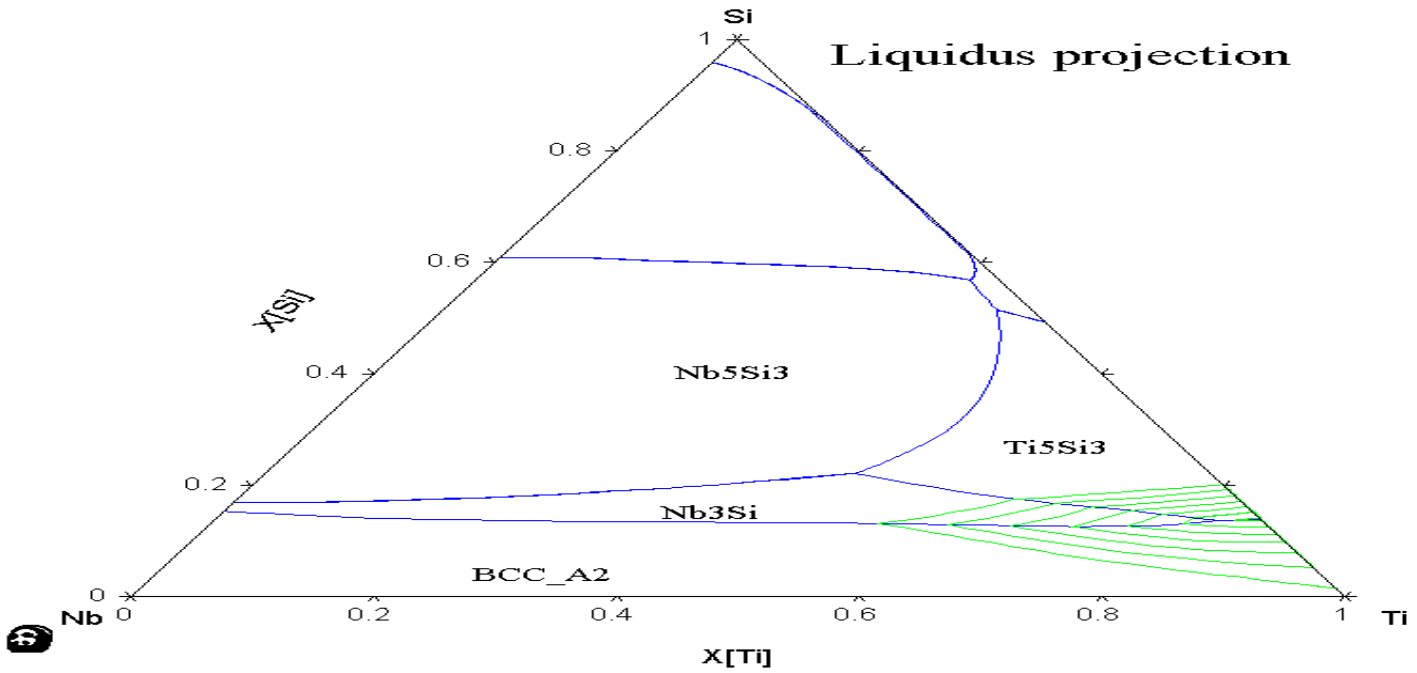
- **Oxidation effects on microstructures**

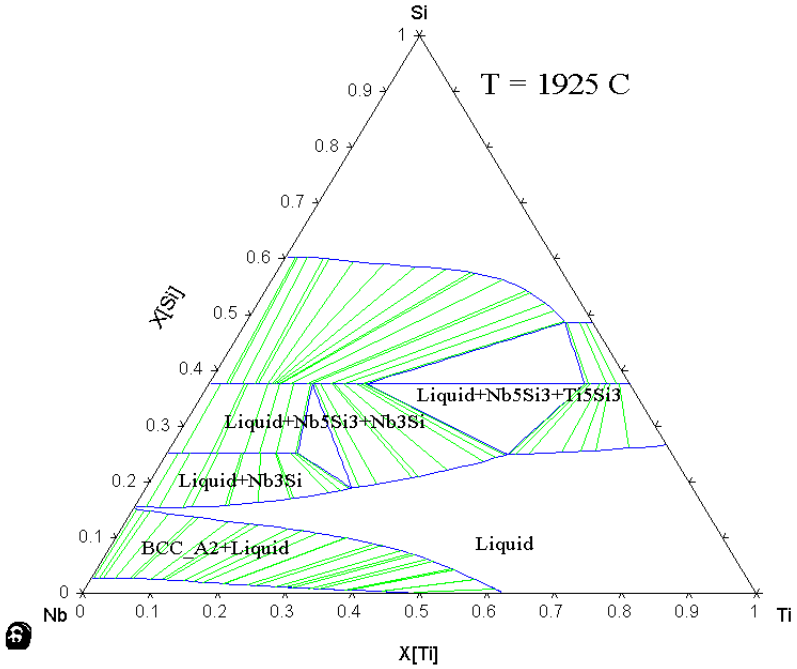
- **Future directions in the study**

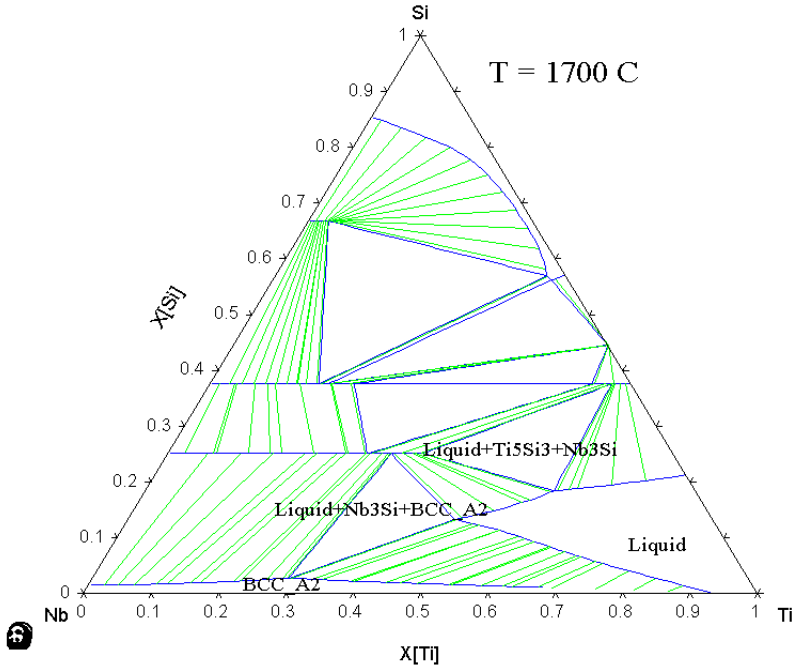
Phase diagrams calculated using PANDAT (Y.A. Chang et al. Computherm, LLC)

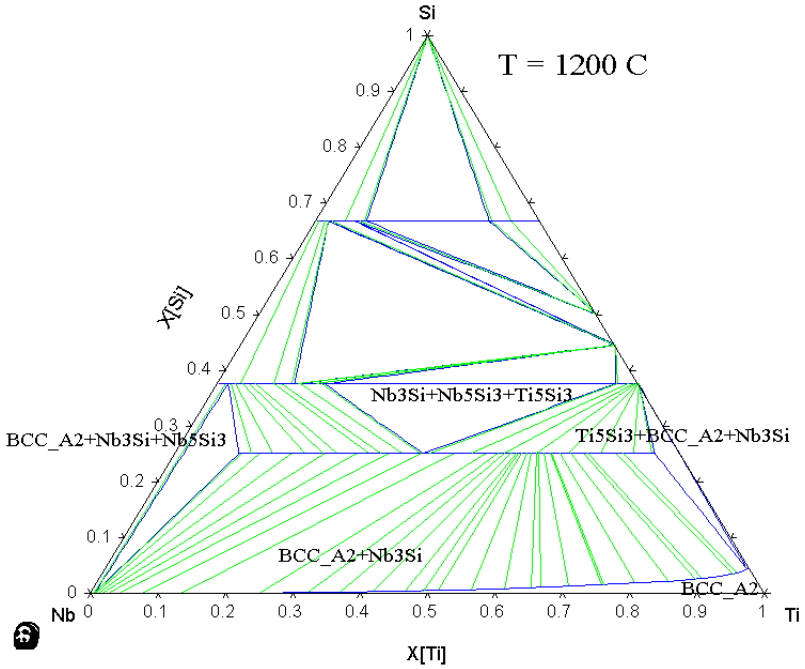


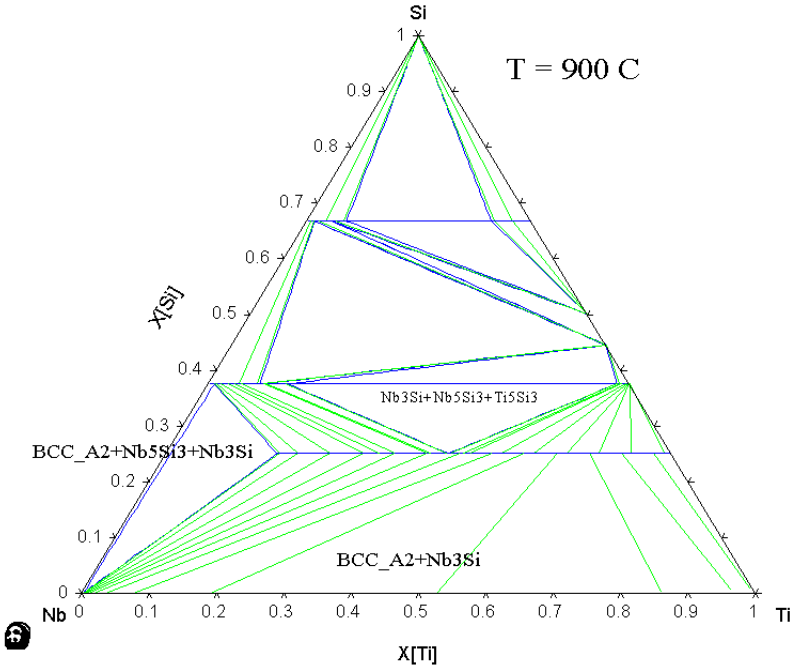




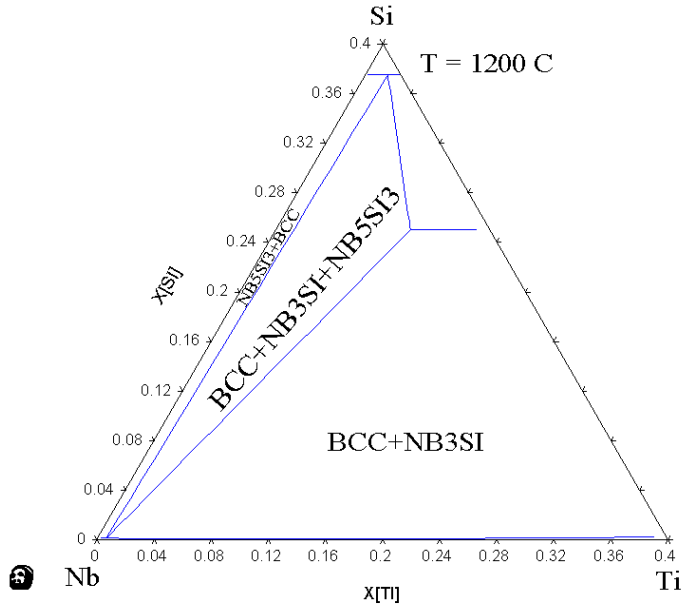

T = 1925 C
Si
Nb
Ti
X[Si]
X[Ti]
Liquid+Nb5Si3+Ti5Si3
Liquid+Nb5Si3+Nb3Si
Liquid+Nb3Si
BCC_A2+Liquid
Liquid

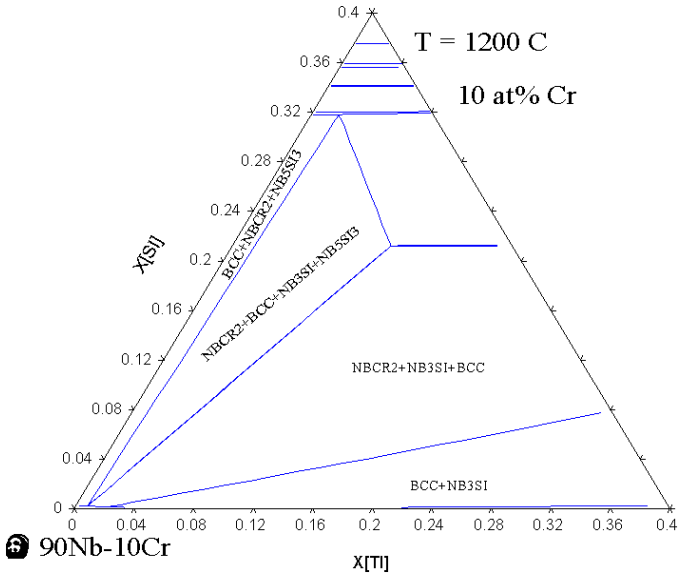

T = 1700 C
Si
Nb
Ti
X[Si]
X[Ti]
Liquid+Ti5Si3+Nb3Si
Liquid+Nb3Si+BCC_A2
Liquid
BCC_A2

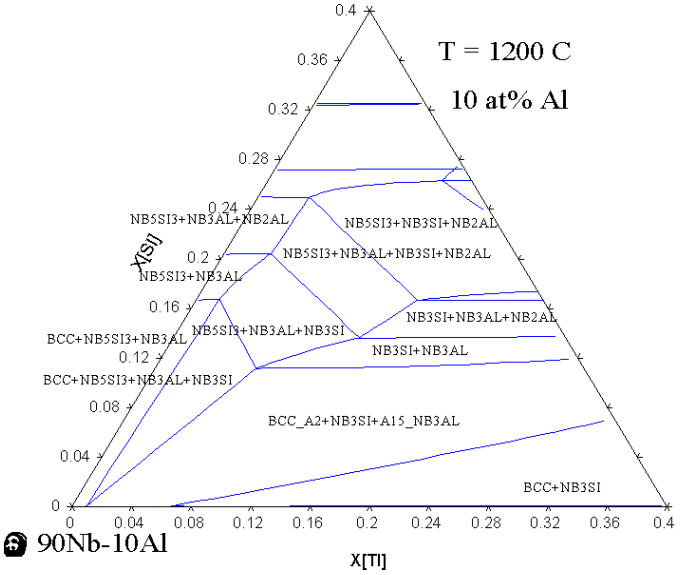

T = 1200 C
Si
Nb
Ti
X[Si]
X[Ti]
Nb3Si+Nb5Si3+Ti5Si3
BCC_A2+Nb3Si+Nb5Si3
Ti5Si3+BCC_A2+Nb3Si
BCC_A2+Nb3Si
BCC_A2

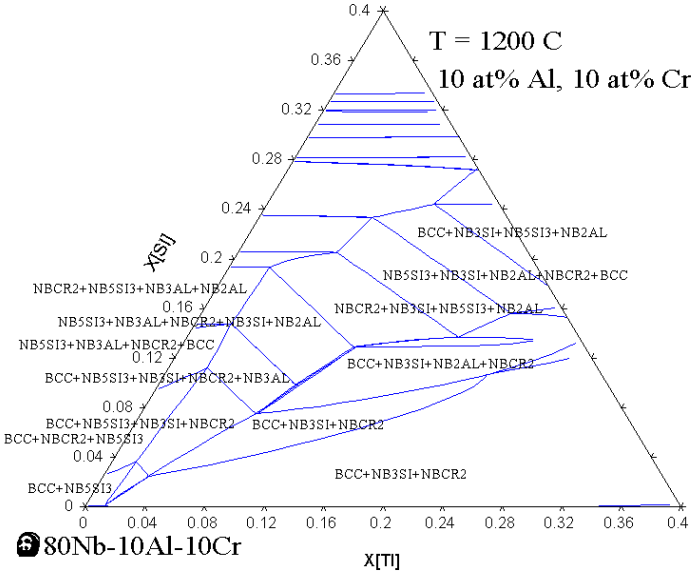

T = 900 C
Si
Nb
Ti
X[Si]
X[Ti]
Nb3Si+Nb5Si3+Ti5Si3
BCC_A2+Nb5Si3+Nb3Si
BCC_A2+Nb3Si

Calculated Isothermal sections at 1200°C



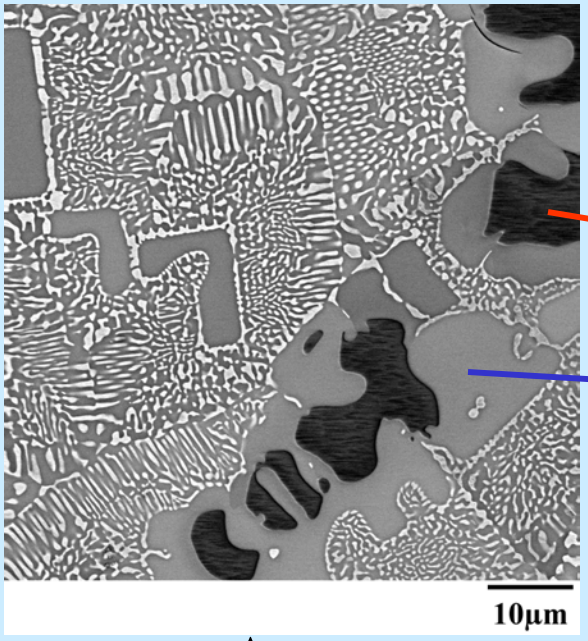






$Nb_3Si \rightarrow \beta + Nb_5Si_3$ eutectoid reaction

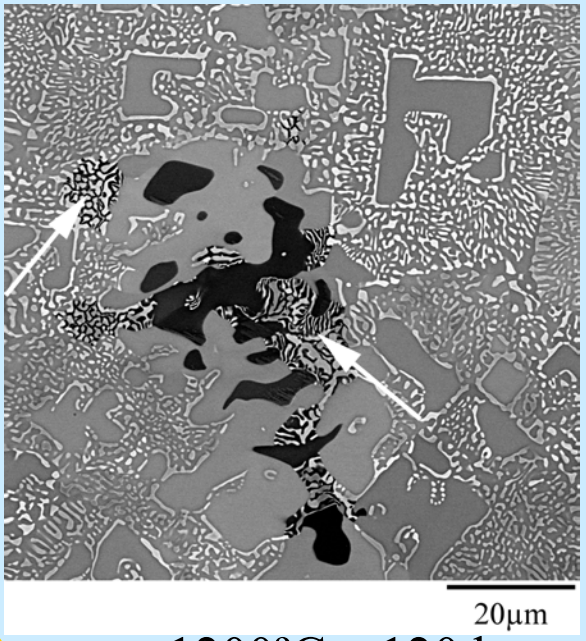
Nb-17.2 at%Si



Nb_5Si_3

Nb_3Si

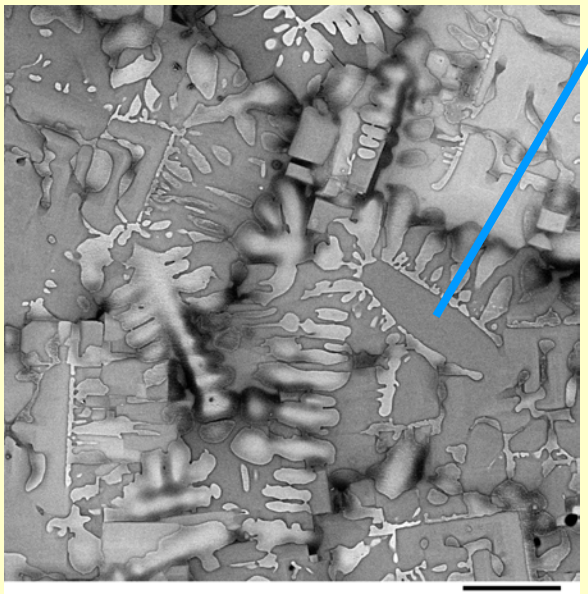
~Nb-22Si-12Ti

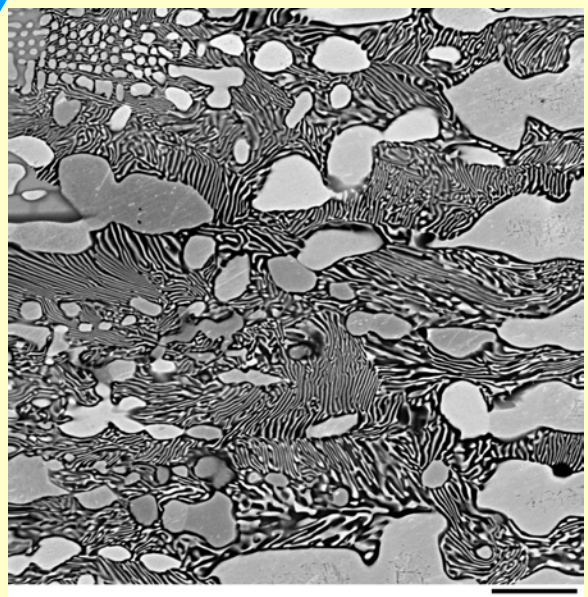


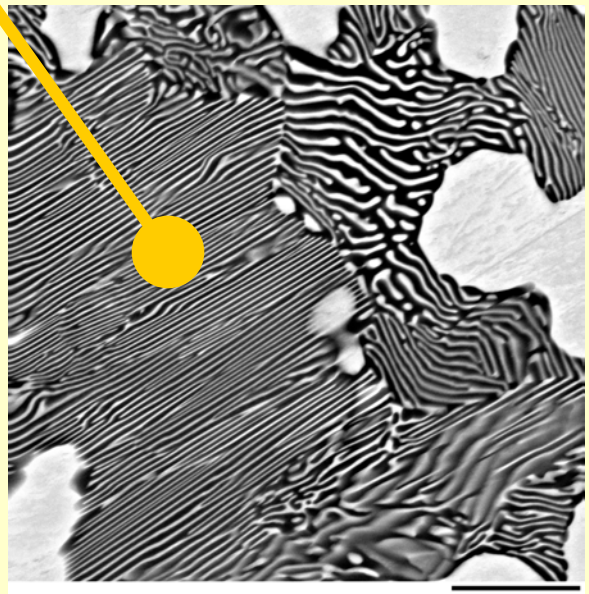
As cast

Nb-15.0Si-12.0Ti

1200ºC – 120 hours

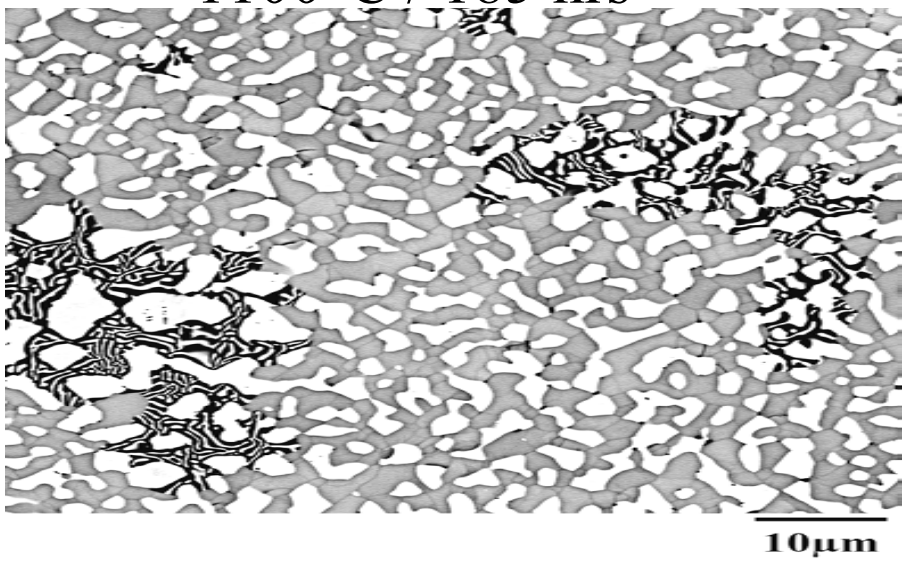




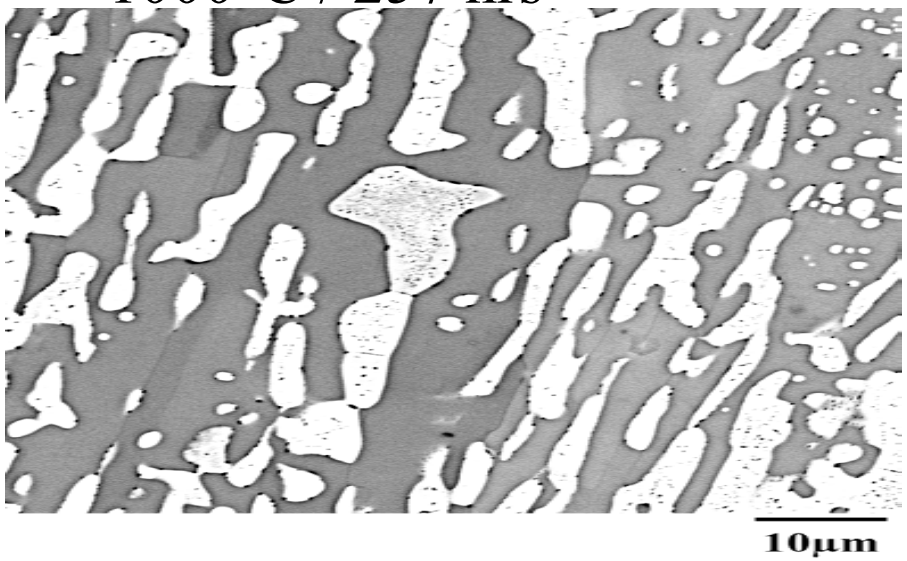


Nb-15.8Ti-16.0Si

1100°C / 185 hrs

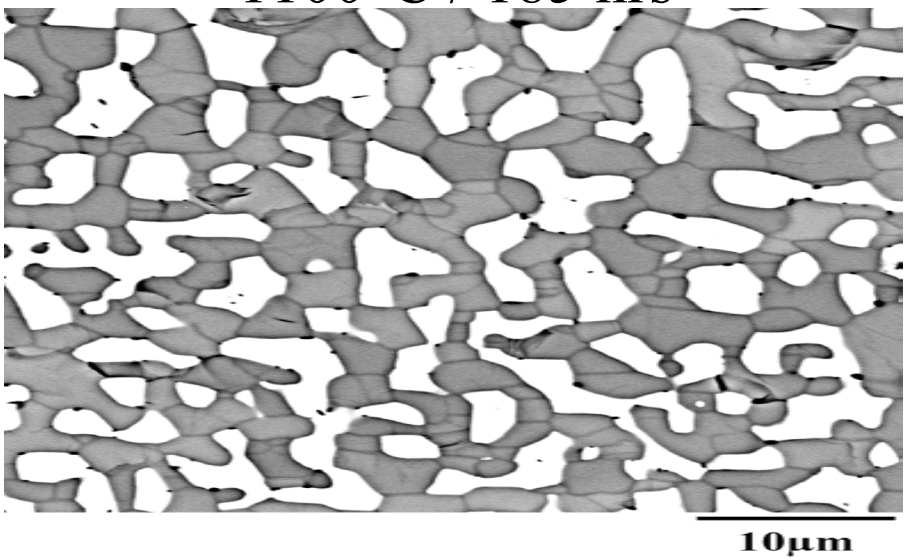


1000°C / 257 hrs

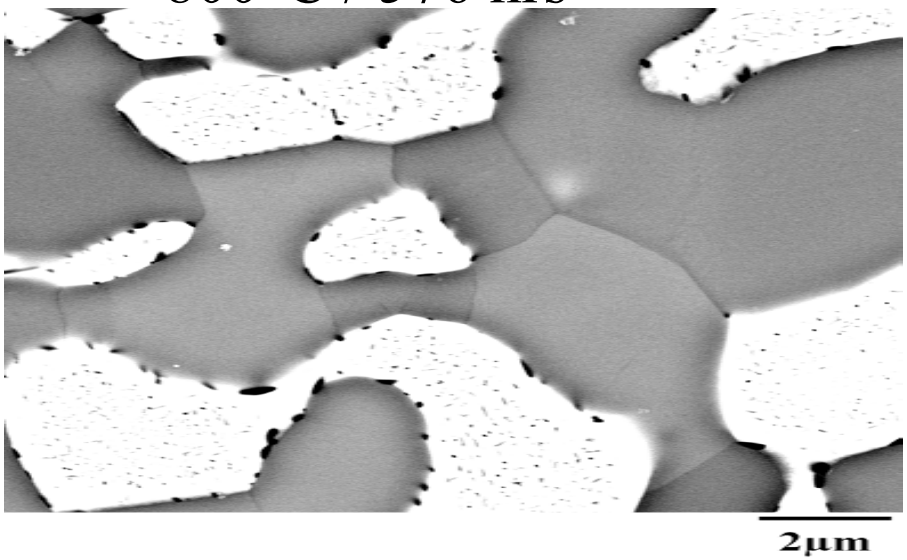


Nb-20.8Ti-15.8Si

1100°C / 185 hrs

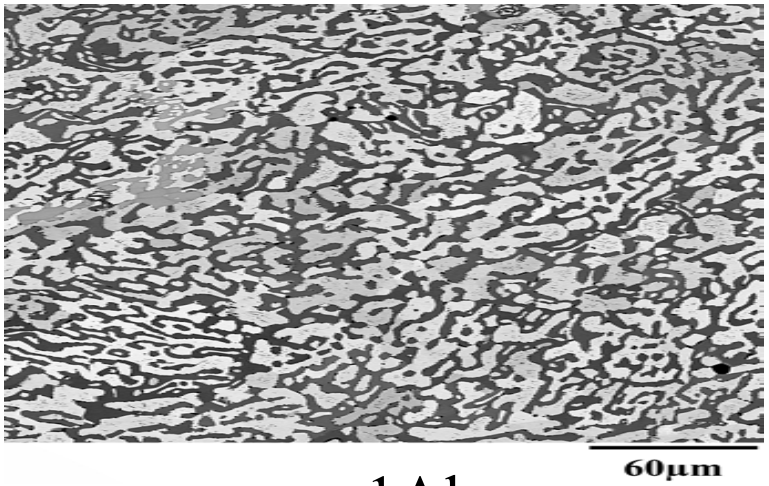


800°C / 576 hrs

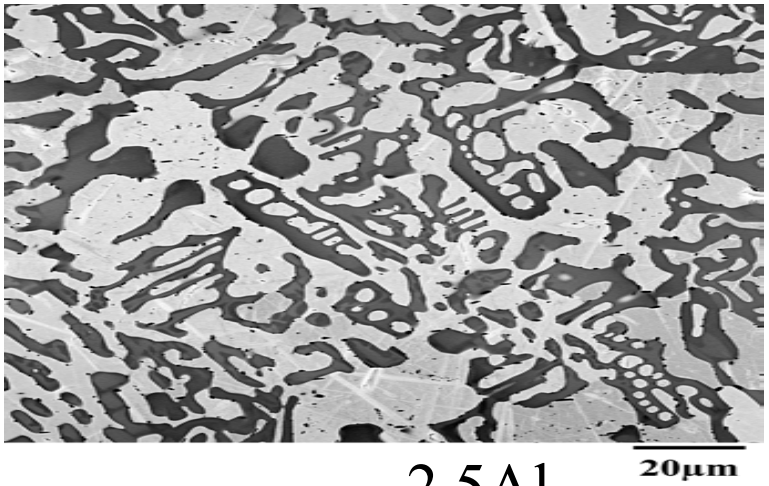


Nb-16.5Si-20Ti-xAl

1500ºC 100 hours

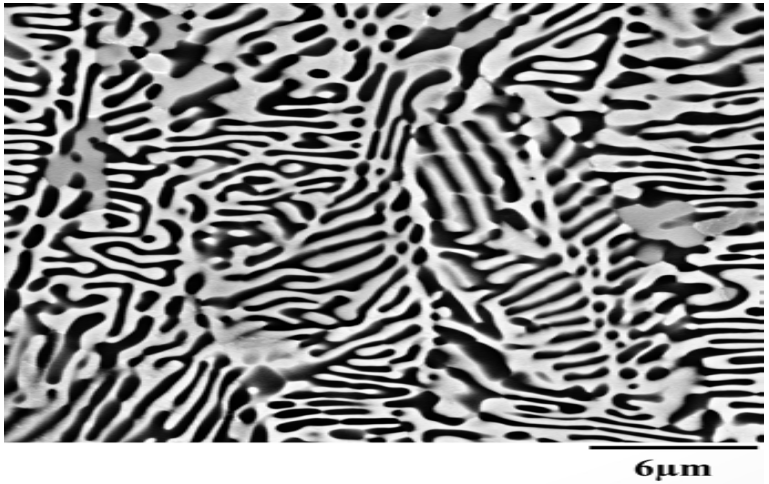


1Al



2.5Al

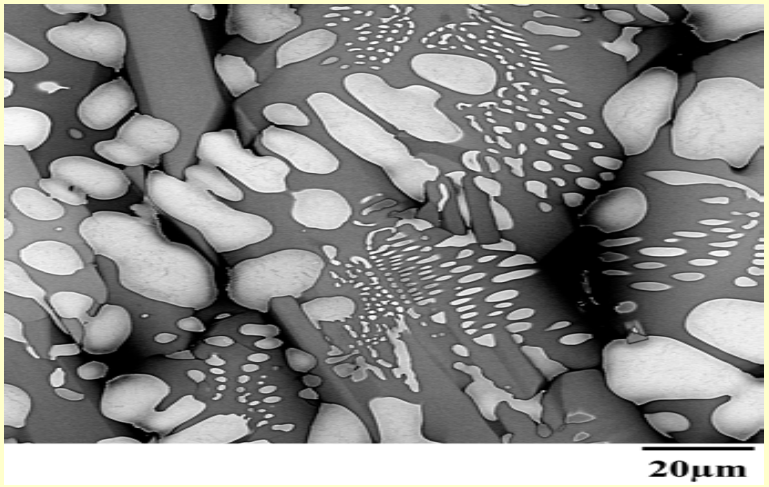
5Al

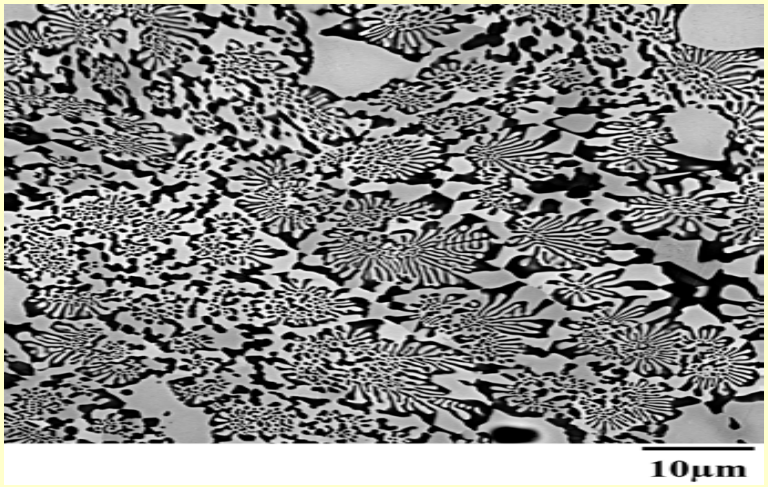


Nb-16.5Si-5Al

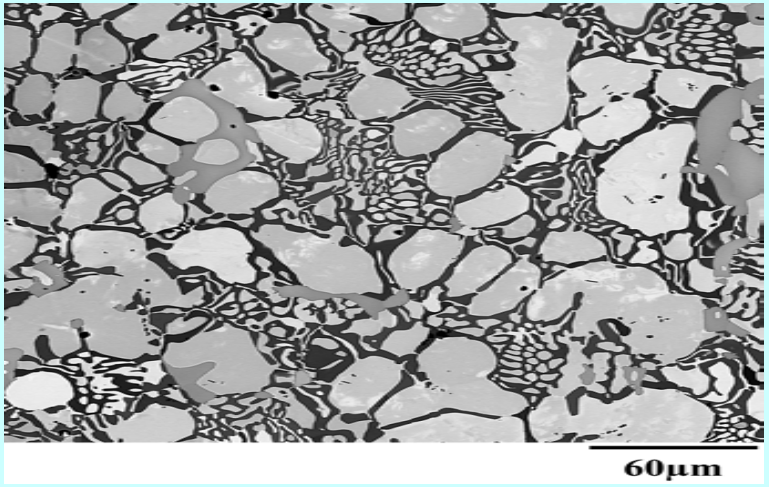
Nb-14Si-12.5Ti	Nb-14Si-12.5Ti-2C

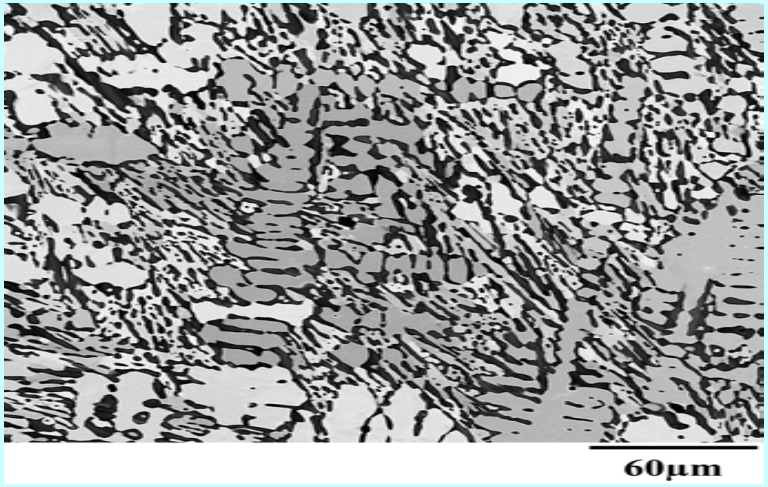
As cast



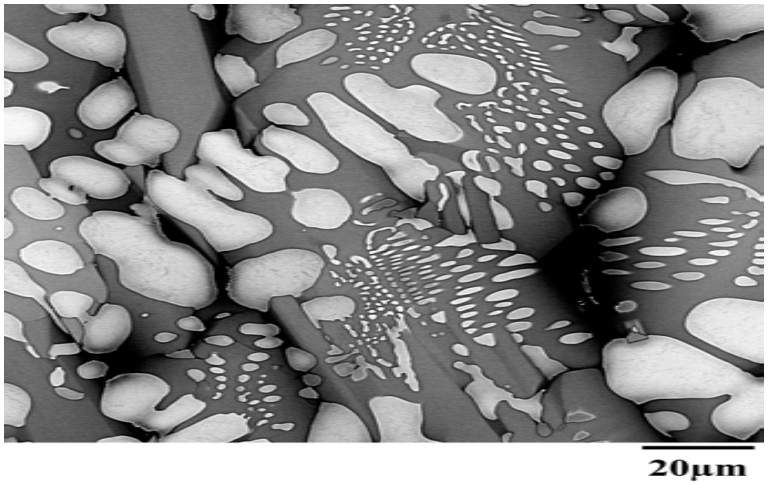


1500°C 100 hours

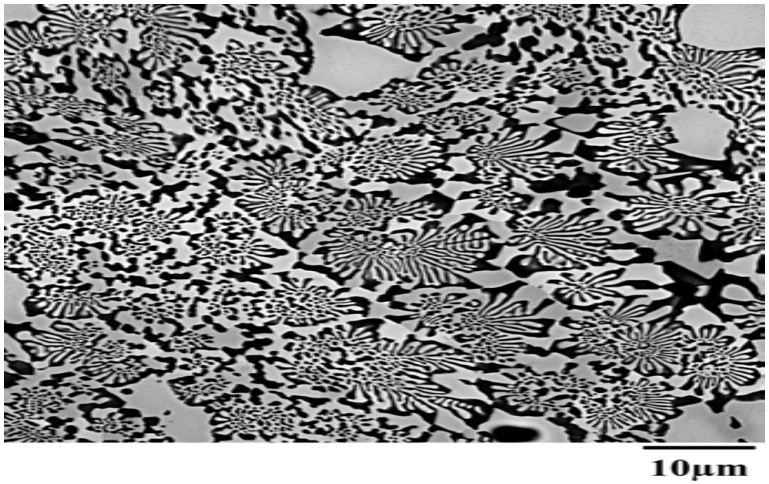




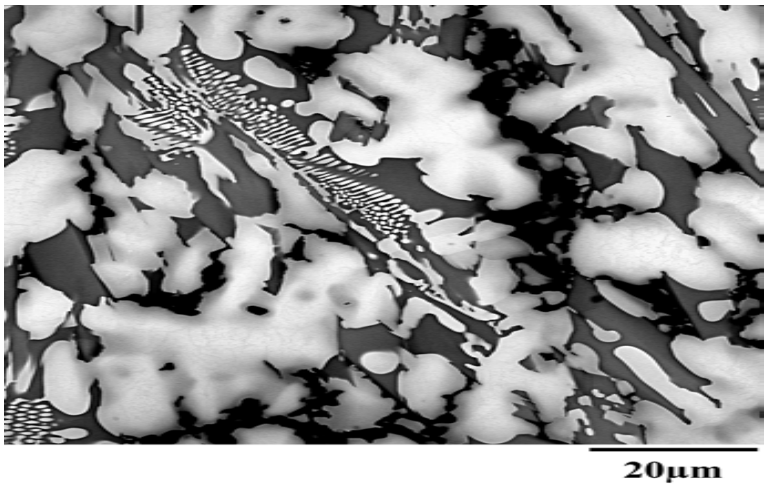
As cast microstructures



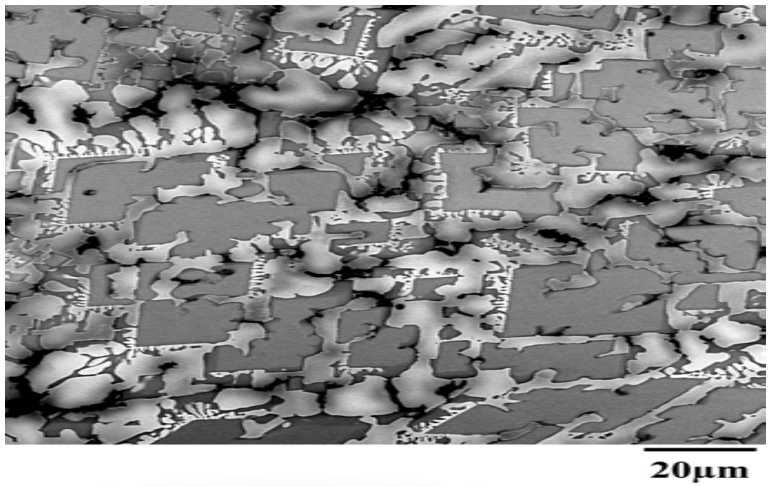
Nb-14Si-12.5Ti



Nb-14Si-12.5Ti-2C



Nb-14Si-12.5Ti-10Cr



Nb-14Si-12.5Ti-10Cr
-10Al

Equilibrium Phases and their Compositions at 1200°C

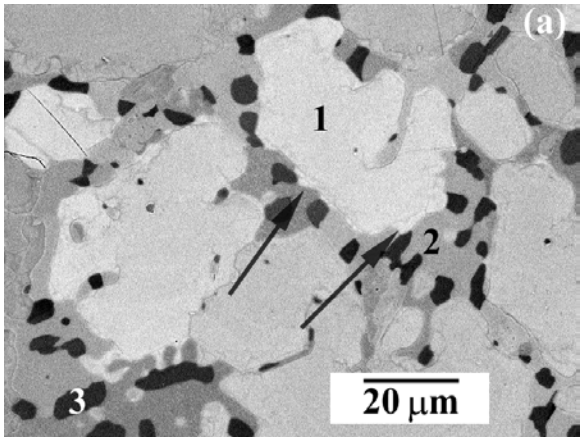


Fig. 1 (a) Nb-19.86Ti-19.74Si-4.21Ge-3.26Al-4.21Hf-9.90Cr

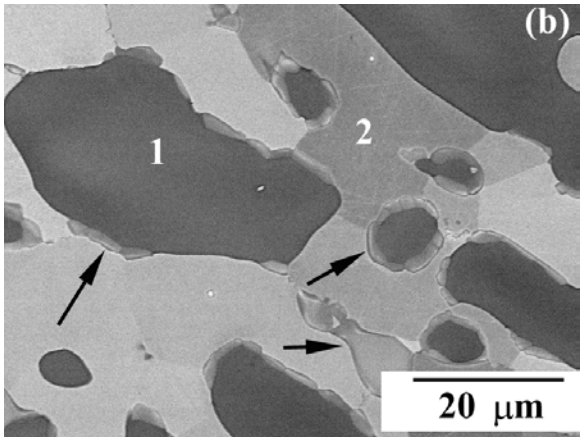
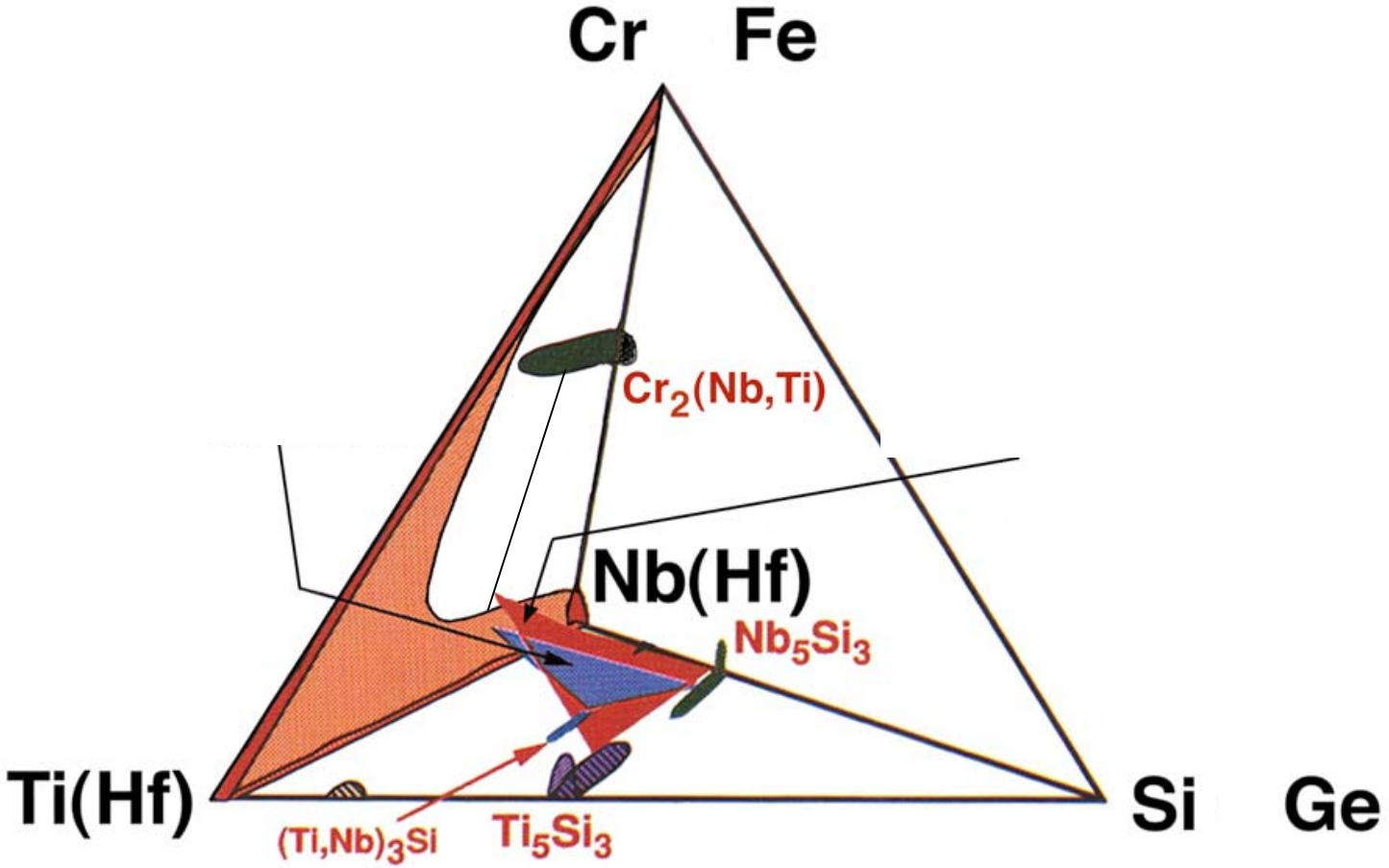


Fig. 1(b) Nb-25.99Ti-12.61Si-4.94Ge-1.92Al-1.90Hf-6.73Cr-0.43Sn.

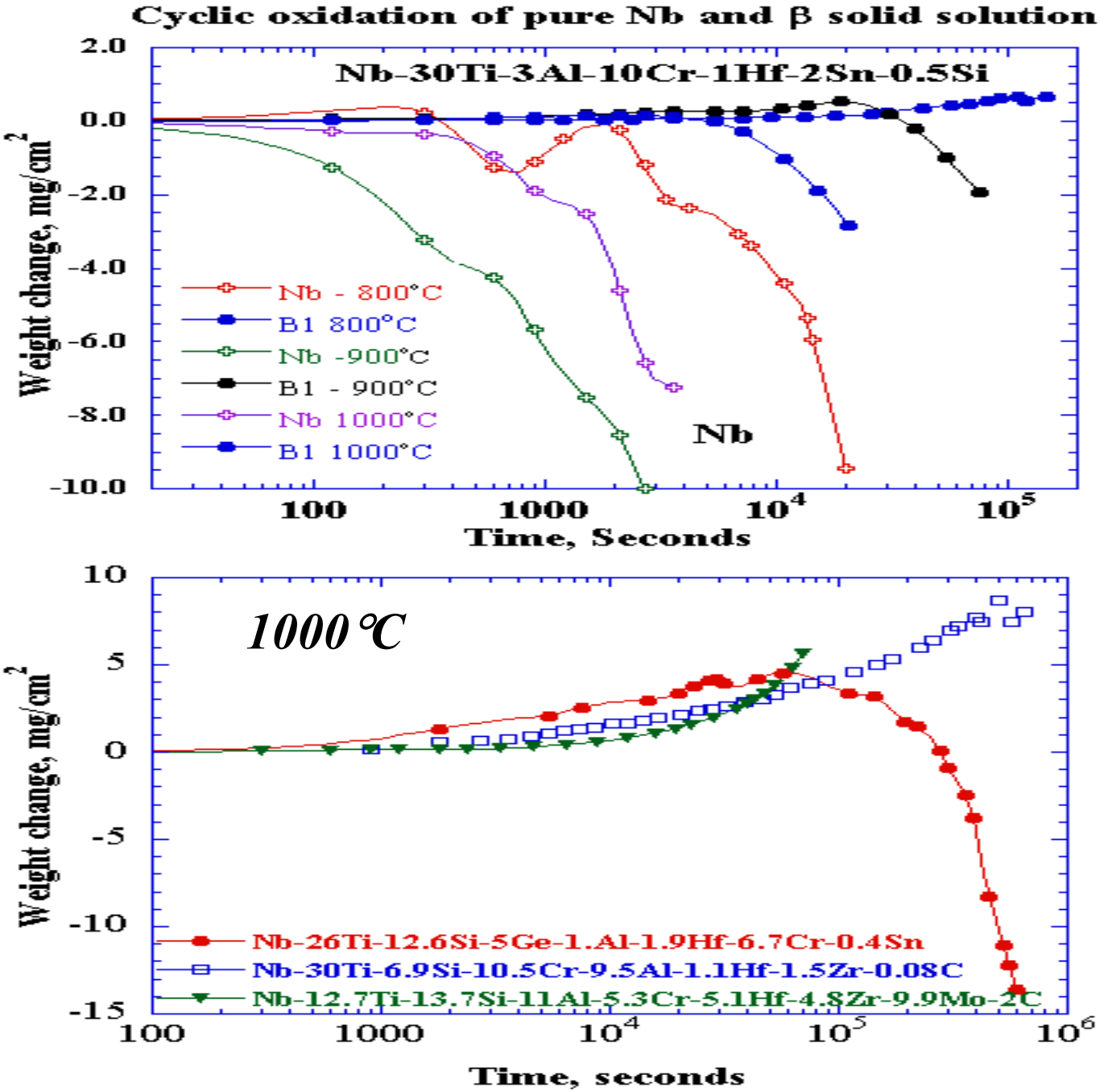
1 : Nb_5Si_3 ; 2 : β solid solution phase; 3: Cr_2Nb; Arrows : Ti_5Si_3

At. %	β		Nb_5Si_3 -type		Ti_5Si_3 -type		Cr_2Nb -type
	Fig 1(a)	Fig. 1(b)	Fig. 1(a)	Fig. 1(b)	Fig. 1(a)	Fig. 1(b)	Fig. 1(a)
Nb	53.07	57.99	38.04	38.59	28.28	26.80	21.78
Ti	30.23	26.58	18.04	22.23	26.22	29.18	12.65
Si	0.45	0.50	30.83	25.78	27.67	26.47	6.05
Ge	0.16	0.06	5.72	7.34	7.80	9.19	0.34
Hf	1.03	0.72	4.74	1.71	6.73	6.10	4.74
Al	3.35	2.60	1.19	1.54	2.13	1.22	0.98
Cr	11.72	10.06	1.43	2.41	1.17	0.90	54.81
Sn	-	1.51	-	0.41	-	0.14	-

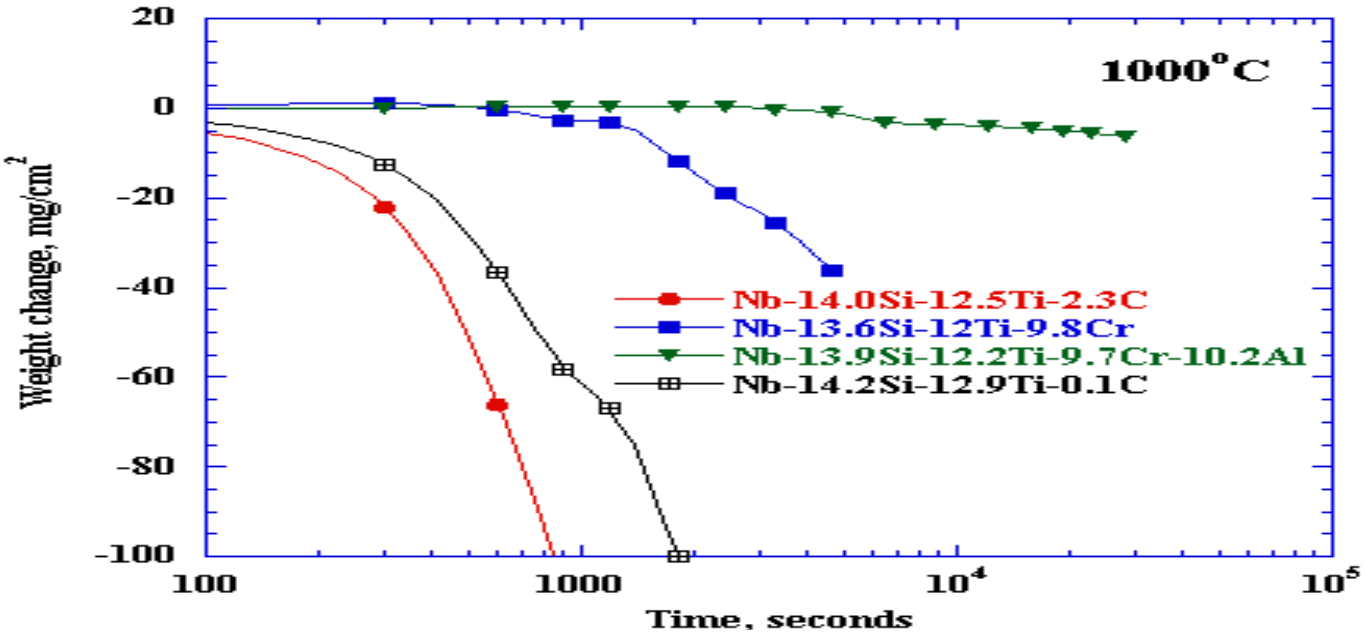
Schematic Phase Diagram

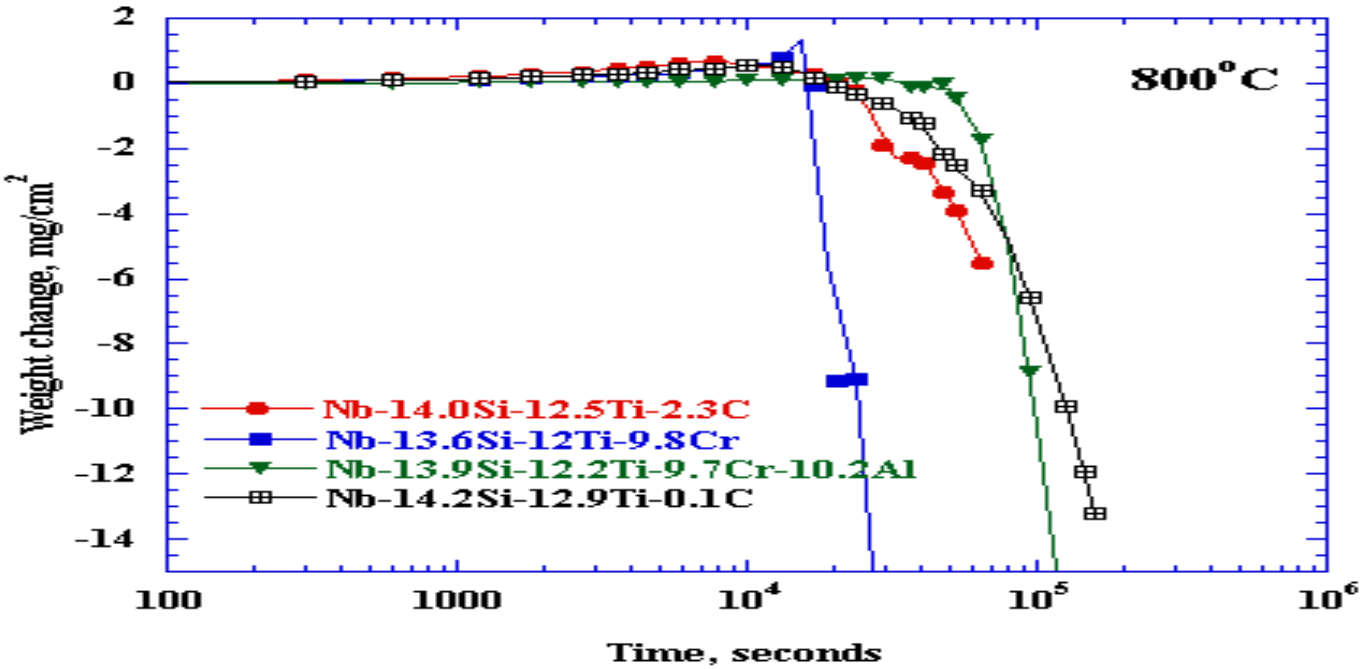


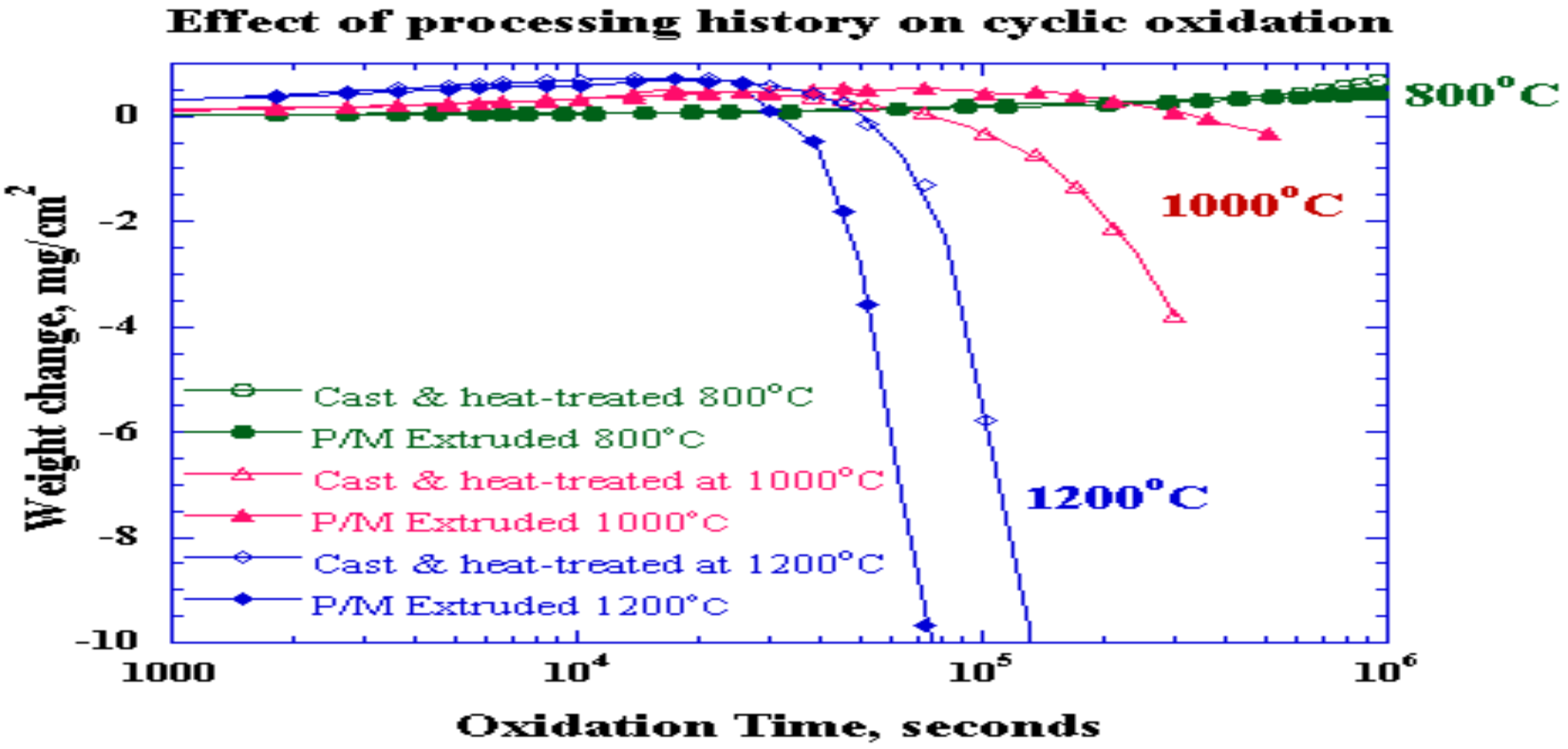
Oxidation resistance of Nb alloys



Effects of alloying on cyclic oxidation

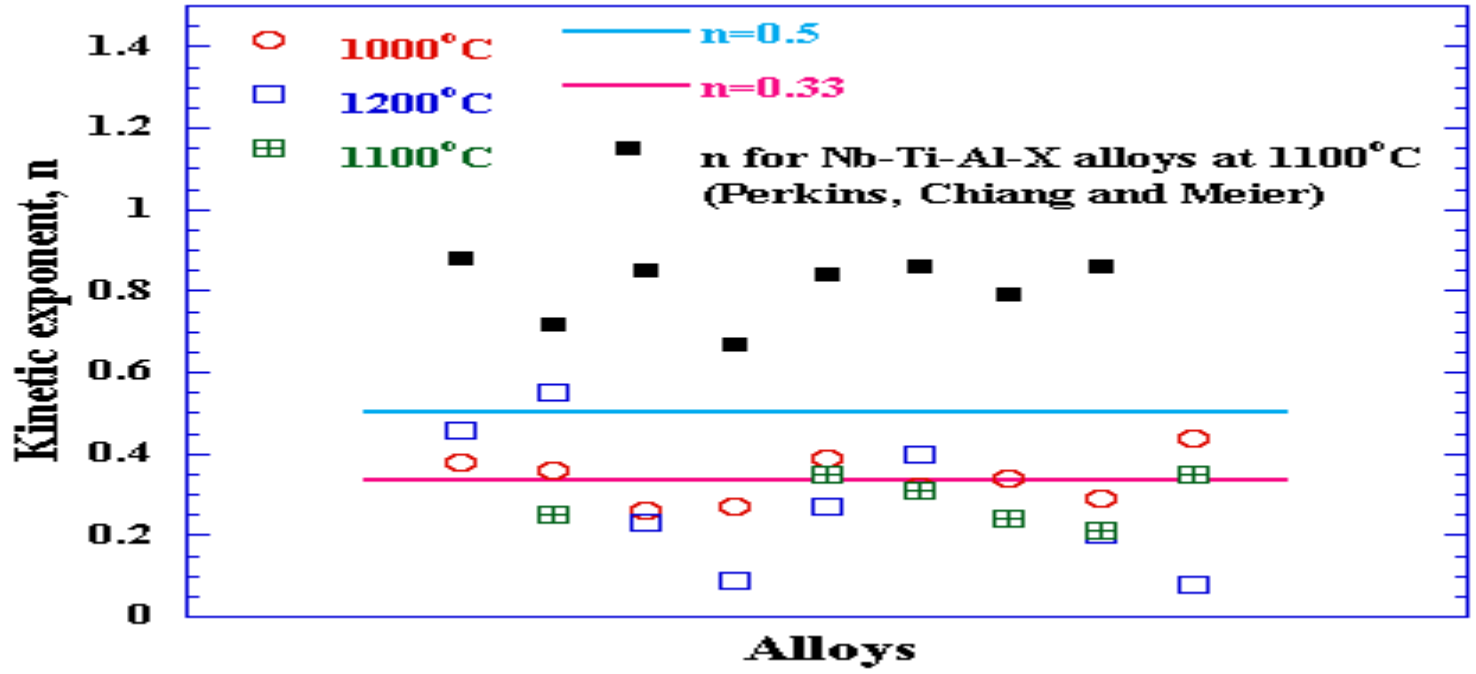


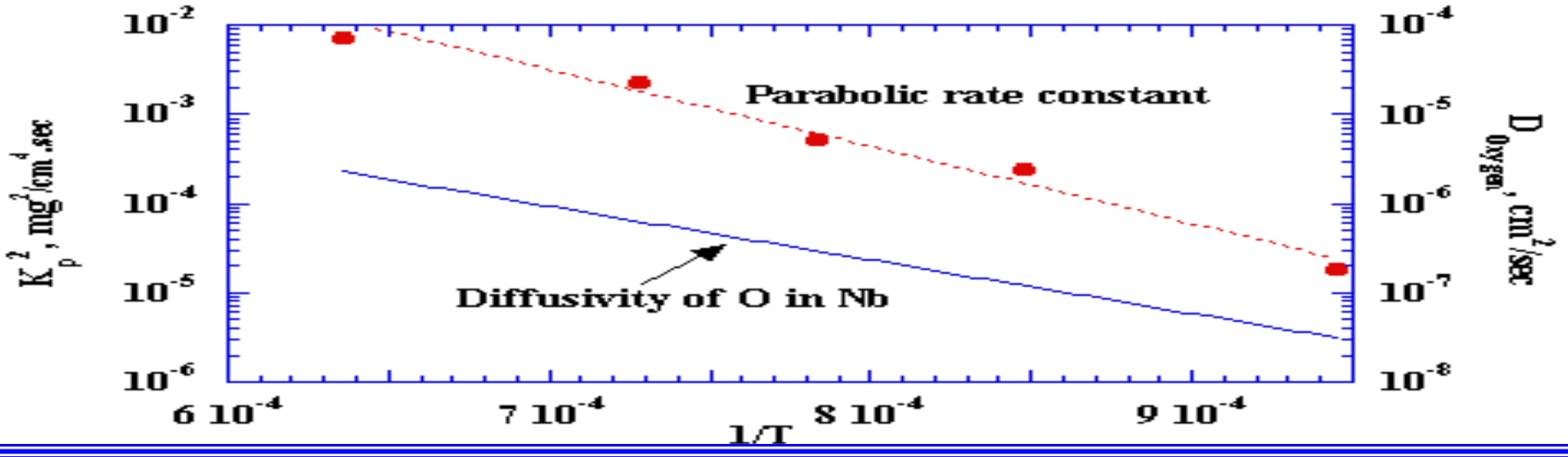



Effect of processing history on cyclic oxidation
Weight change, mg/cm^2
0
-2
-4
-6
-8
-10
1000
10^4
10^5
10^6
Oxidation Time, seconds
Cast & heat-treated 800°C
P/M Extruded 800°C
Cast & heat-treated at 1000°C
P/M Extruded 1000°C
Cast & heat-treated at 1200°C
P/M Extruded 1200°C
800°C
1000°C
1200°C

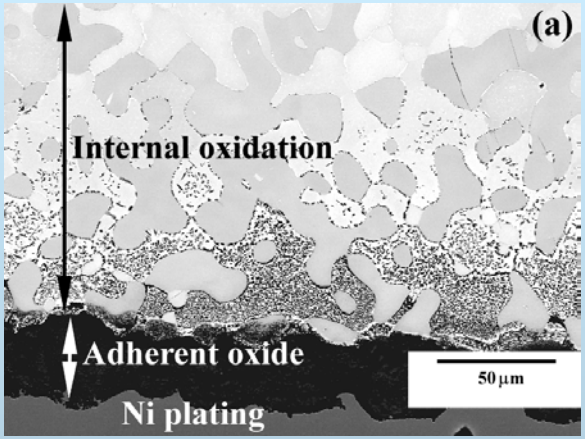
Initial stages of oxidation

$$\Delta w = Kt^{n}$$

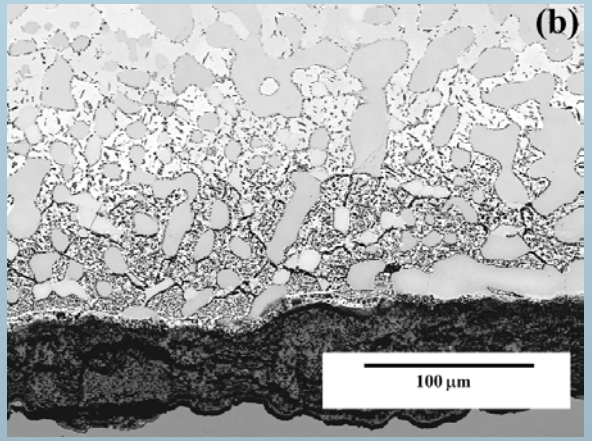




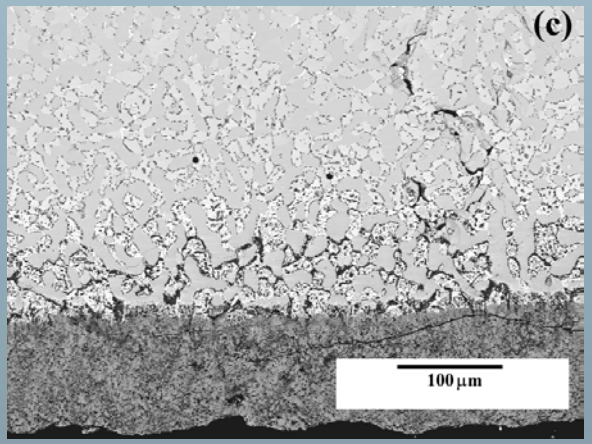
Oxidation of a Nb-26Ti-13Si-5Ge-7Cr-2Al -2Hf-0.5Sn alloy at 1200°C



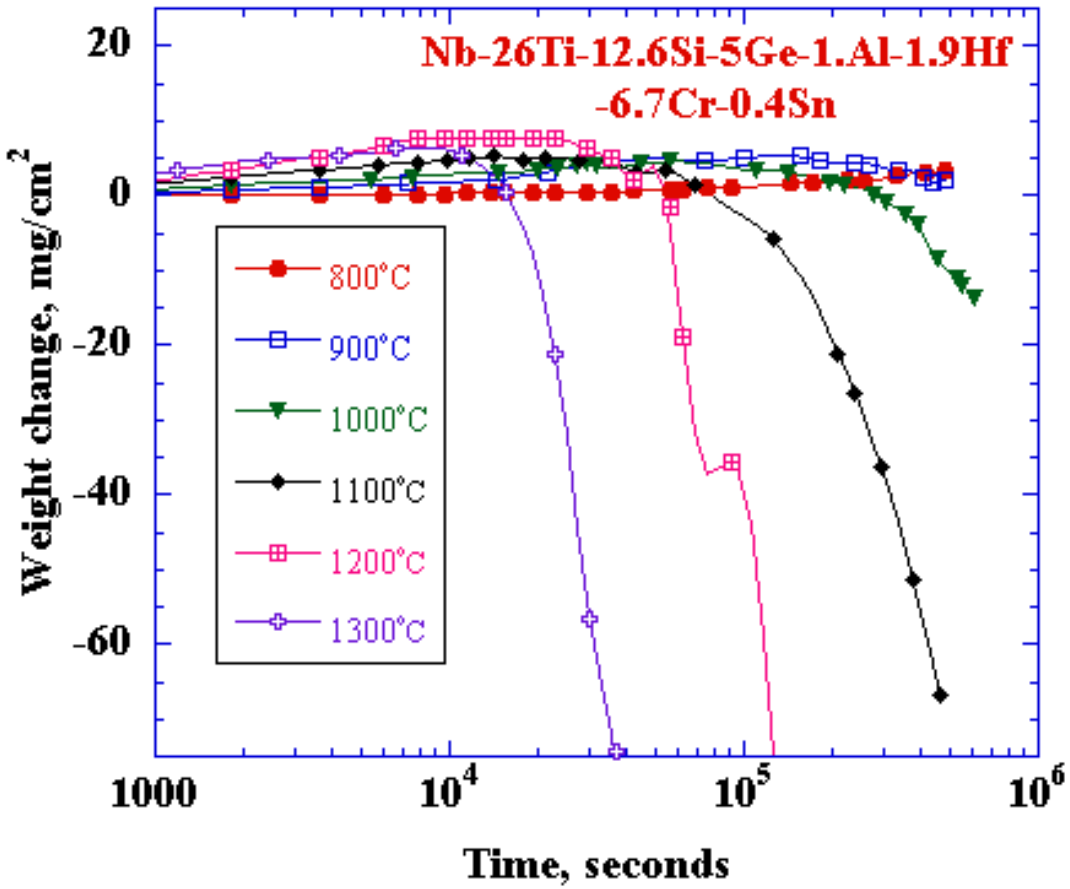
1 hour

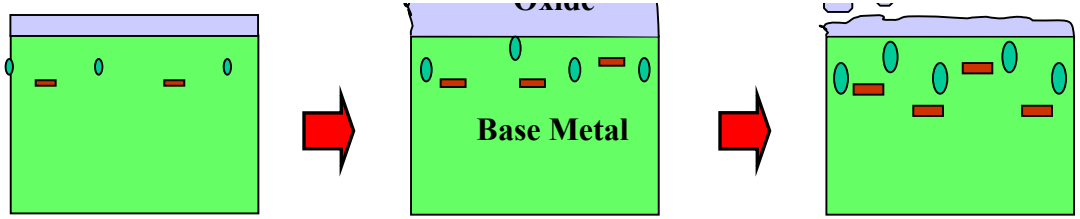


5 Hours



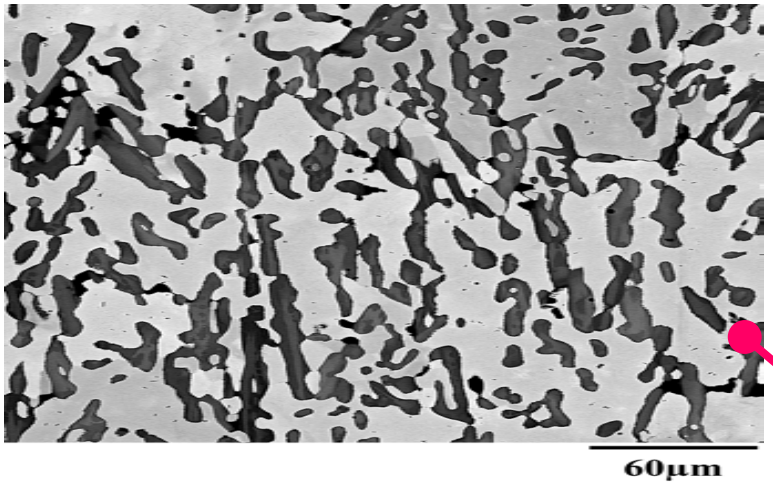
24 hours



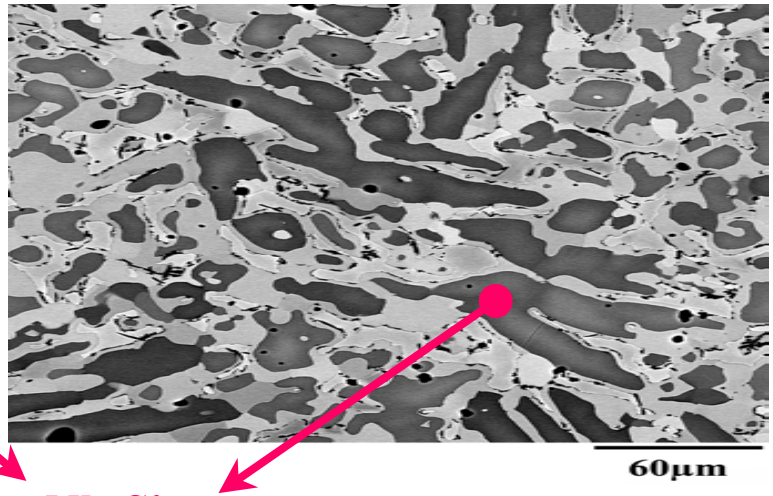


Internal Oxidation

Effect of complex alloying

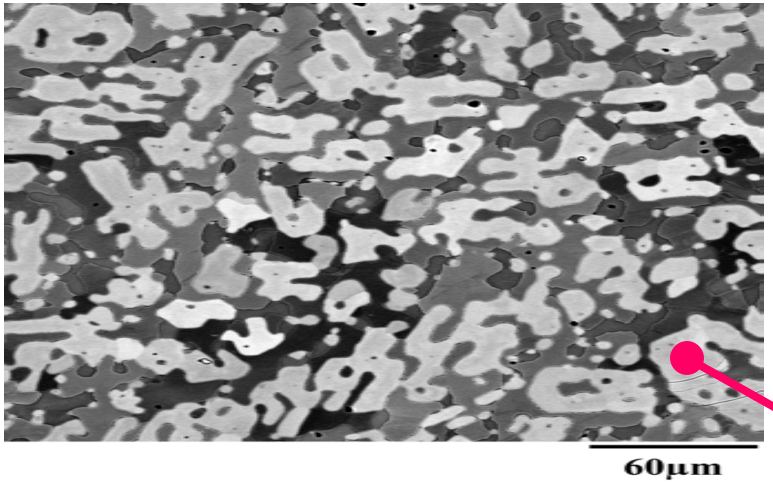


Nb-14Si-12.5Ti-10Cr

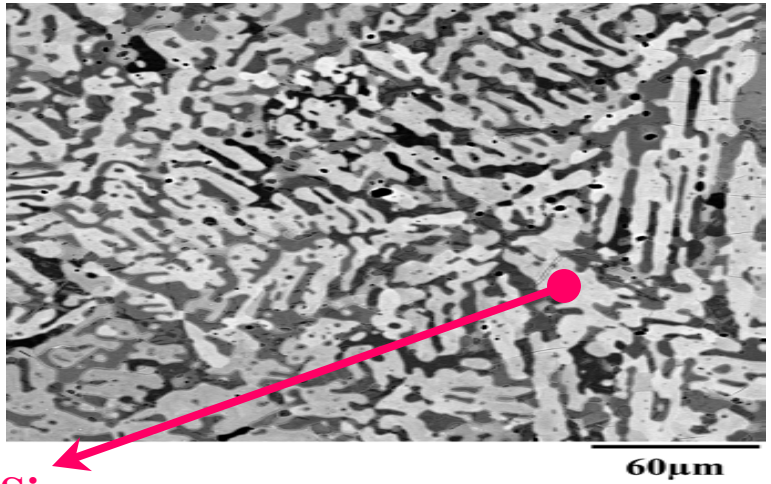


Nb_5Si_3

Nb-14Si-12.5Ti-10Cr-10Al



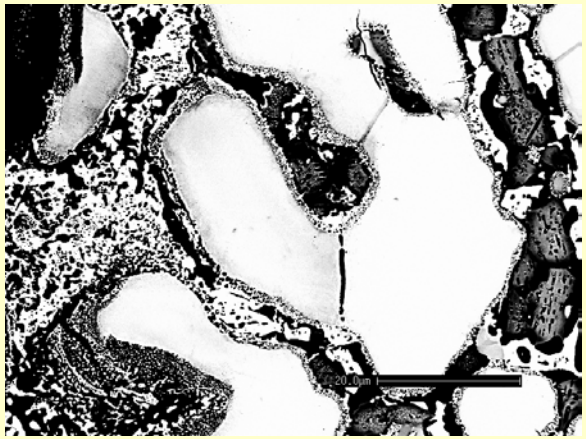
Nb-12.5Ti-14Si-10Mo-10Al
-5Cr-5Hf-5Zr

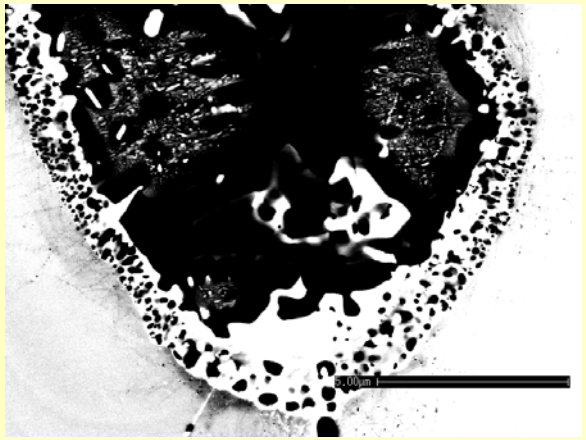


Nb_5Si_3

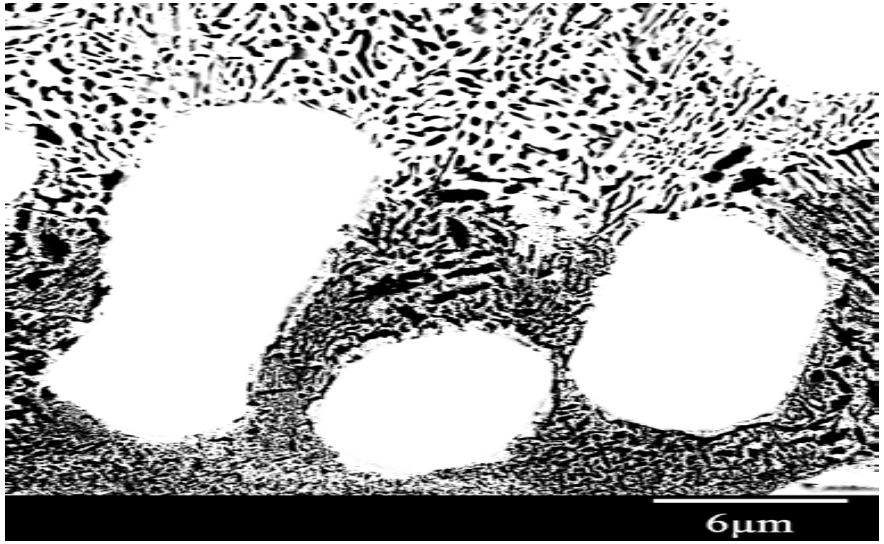
Nb-12.5Ti-14Si-20Mo-10Al
-9Cr-5Hf-5Zr

Preferential oxidation of phases in Nb-20Ti-20Si-4Ge-10Cr-3Al-4Hf-3B Oxidized at 1200°C for 48 hrs

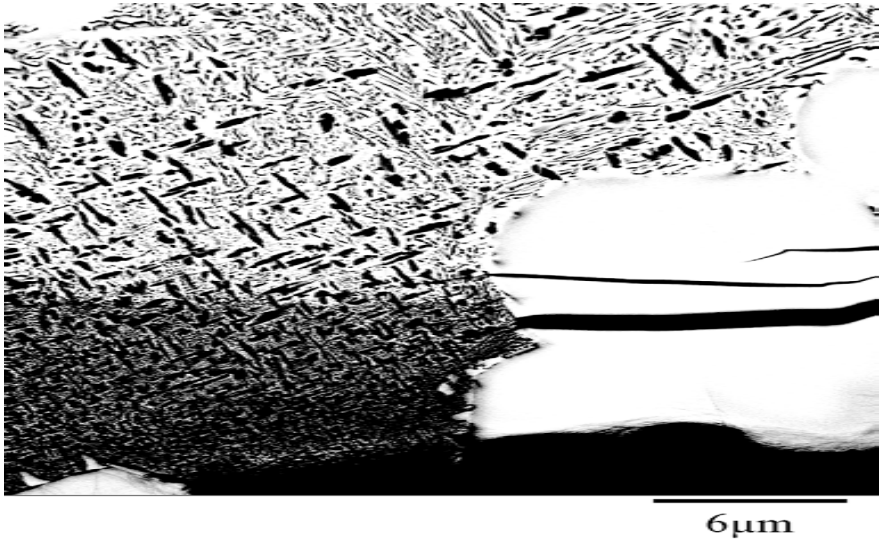




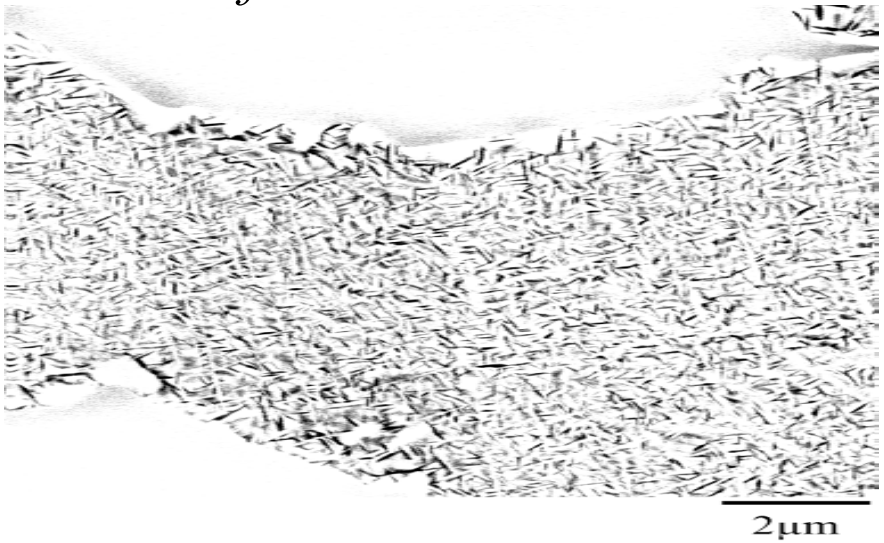
Oxidation of Nb-30Ti-7Si-10.5Cr-9.5Al -1.1Hf-1.5Zr-0.08C



1000℃ for 24 hours

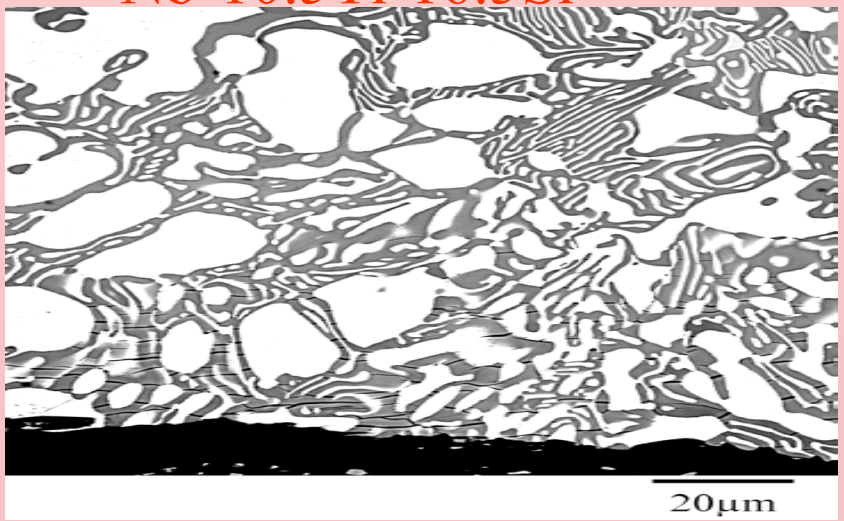


900℃ for 16 hours

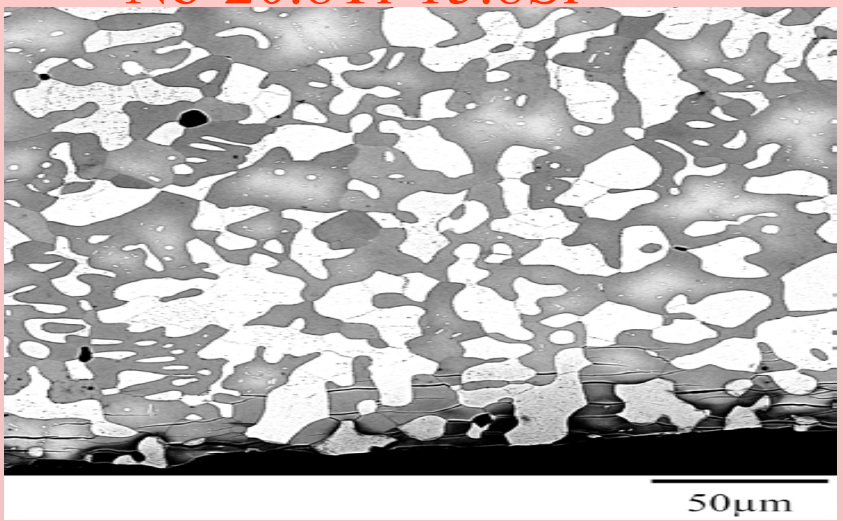


Oxidation of Nb_3Si and lamellar $\beta+Nb_5Si_3$

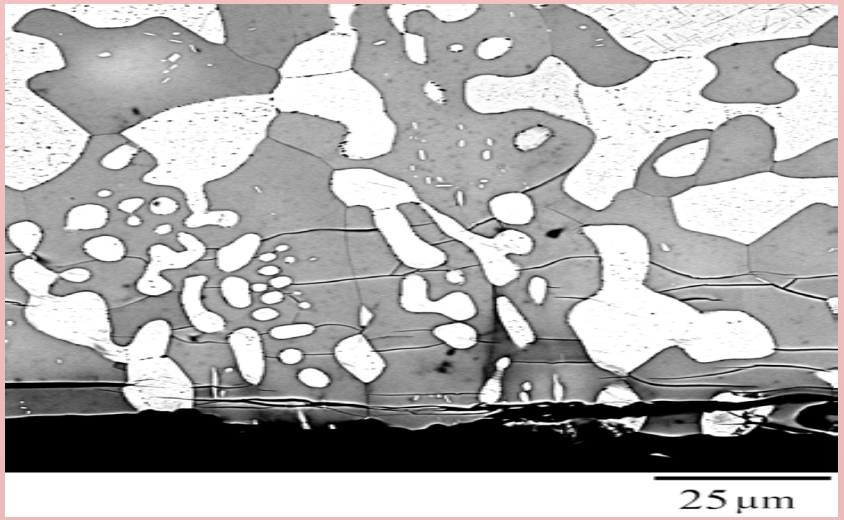
Nb-10.5Ti-16.5Si



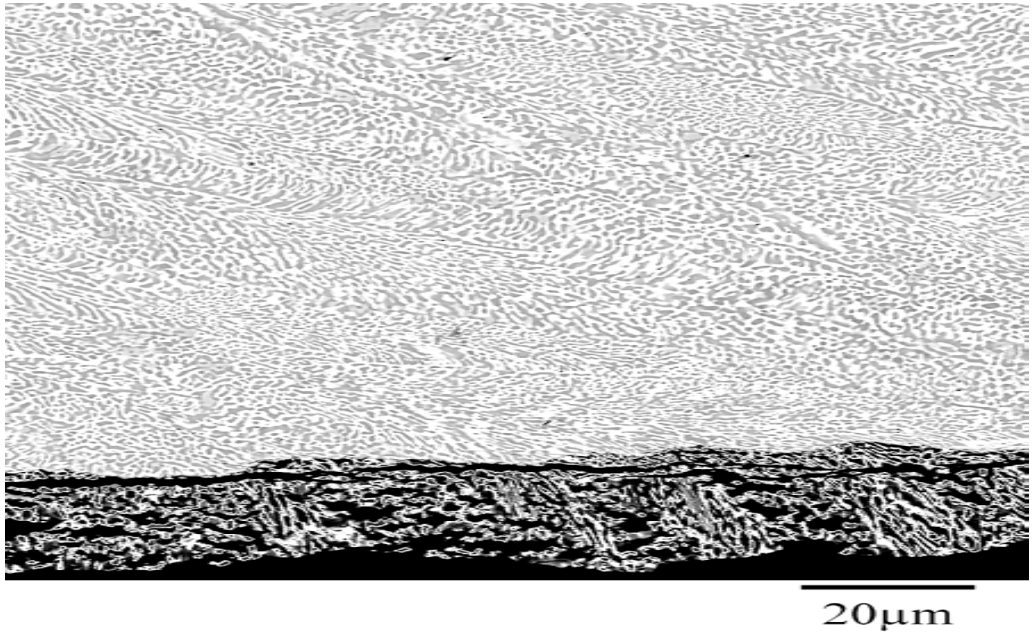
Nb-20.8Ti-15.8Si



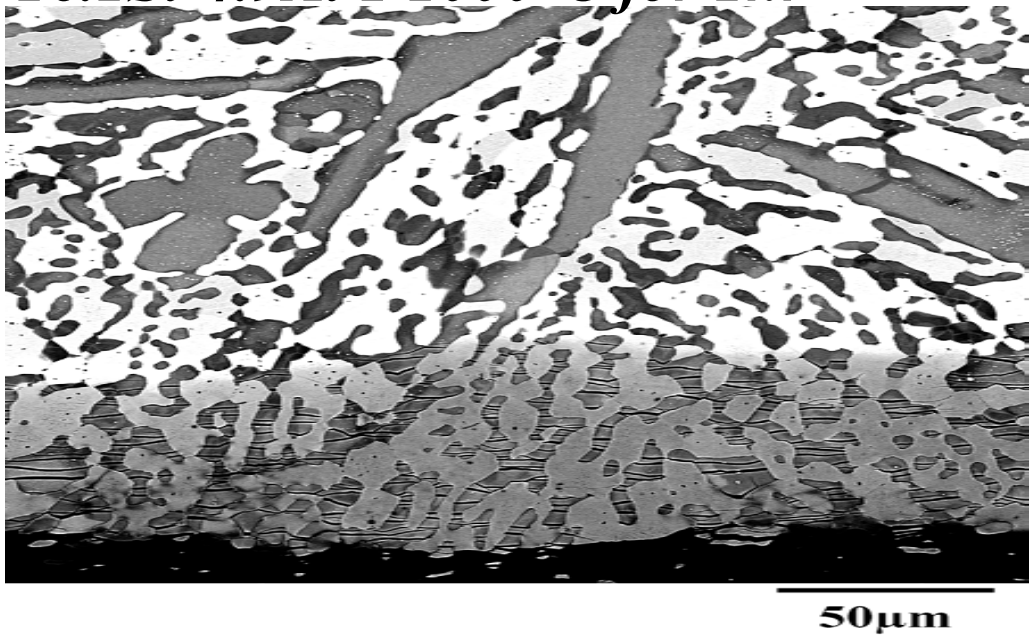
Oxidized at 1000℃ for 1 hr



Oxidized at 800℃ for 4 hrs

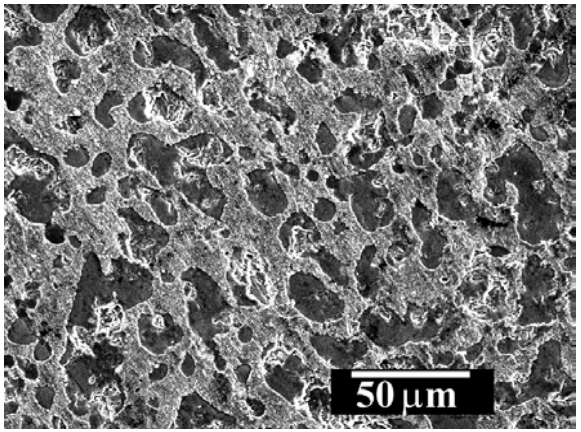


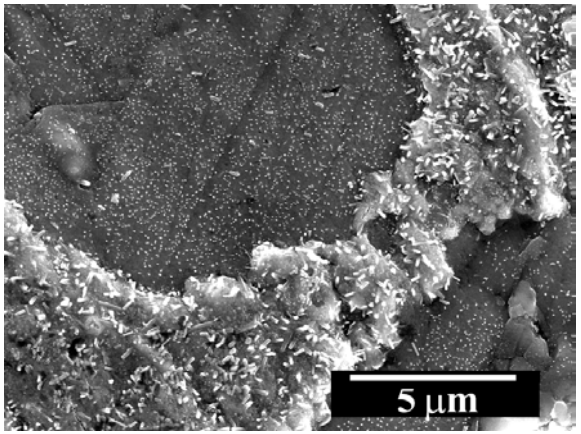
Nb-16.1Si-4.9Al 1 1000℃ for 1hr

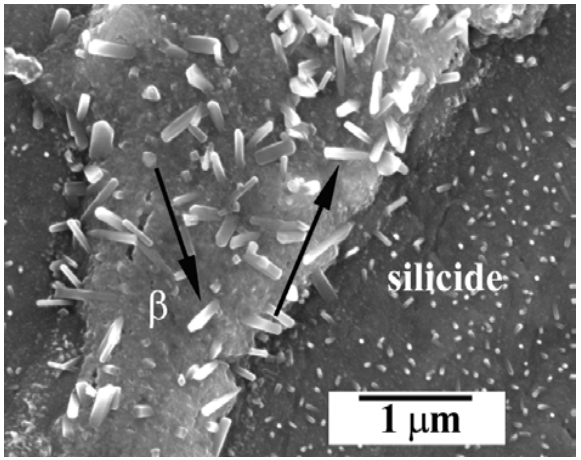


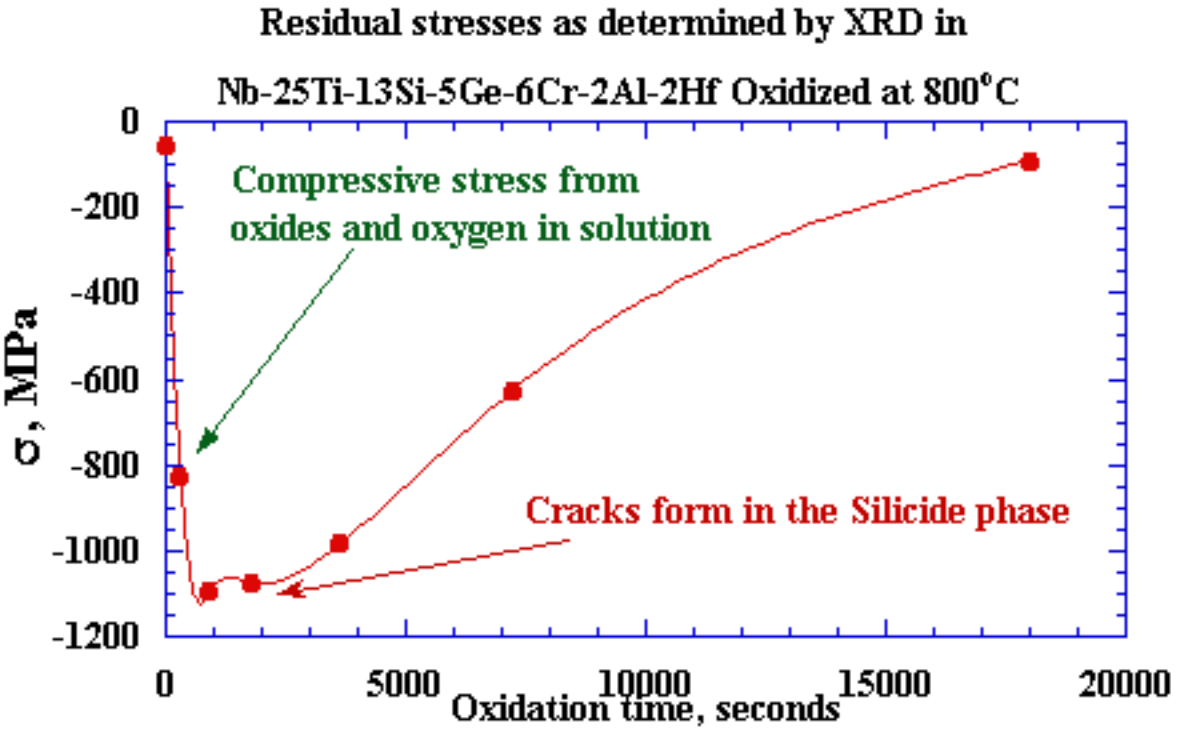
Nb-20.8Ti-15.7Si-4.3Al 800℃ for 4hrs

Growth of surface oxide in Nb-26Ti-13Si-5Ge-7Cr-2Al-2Hf-0.5Sn alloy after oxidation at 800°C/ 5 hrs.

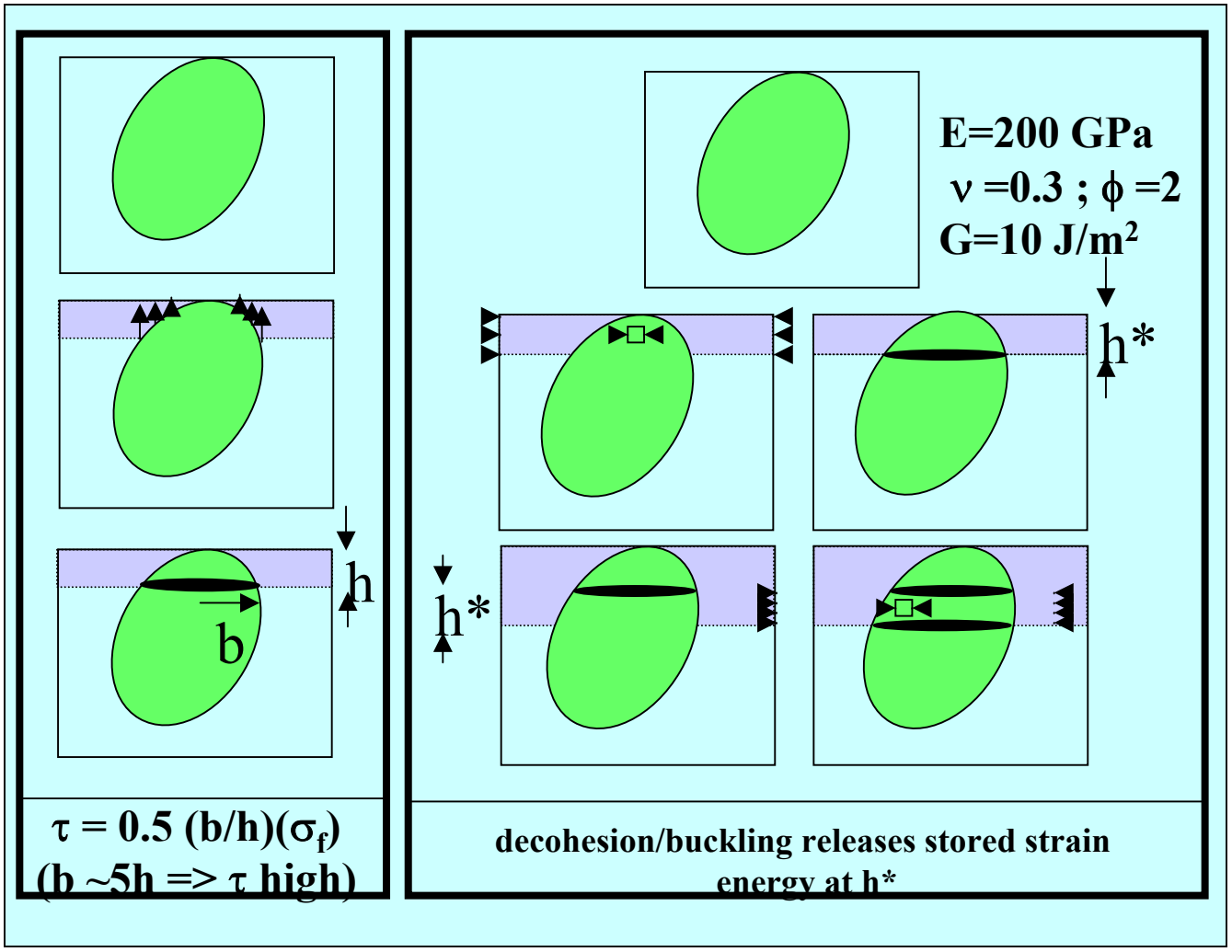




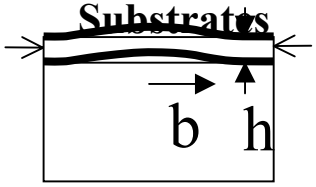




Mechanism of low temperature cracking



Compression Buckling of Thin Films on Substrates

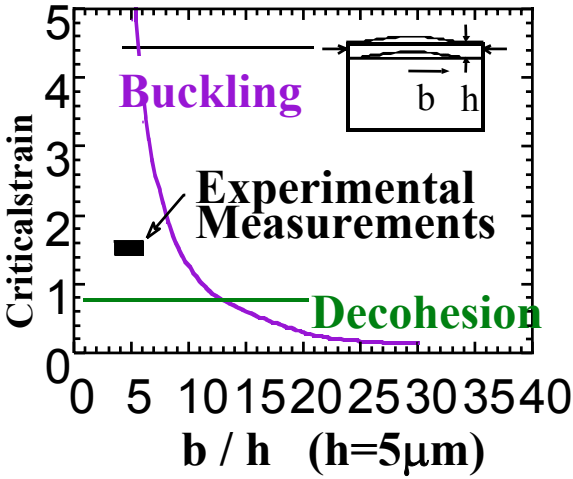


Energy Balance

$$\sigma_{decoh} = \phi\sqrt{\frac{E\Gamma_i}{(1-\nu)h}}$$

Buckling

$$\frac{b}{h} = 1.1\sqrt{\frac{E}{\sigma_b}}$$



Conclusions

- It is possible to significantly modify the microstructural distribution of the phases in Nb alloys.
- Stability of Nb_3Si & Nb_5Si_3 is strongly influenced by alloying additions : Thermodynamic parameters associated with multicomponent systems must be modified.
- Oxidation resistance of Nb alloys can be increased by alloying.
- Oxidation behavior is affected by phase distribution in the material.
- It maybe possible to control the low temperature cracking by microstructural control.