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Development of Cr-Si-Ge Alloys for High Temperature Structural Applications

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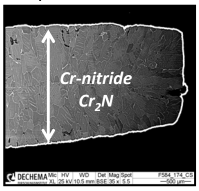
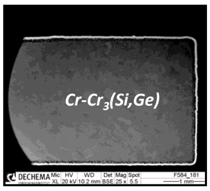
Highlights

- Novel oxidation and nitridation resistant chromium alloys are developed
- Synergic addition of Si and Ge to chromium shows significant oxidation protection
- Chromium silicide (Cr_3Si) A15 structure shows high temperature stability in N_2-containing atmospheres
- Addition of Ge enhances the stability of an A15 silicide layer at metal-oxide interface which provokes internal nitridation at high temperatures



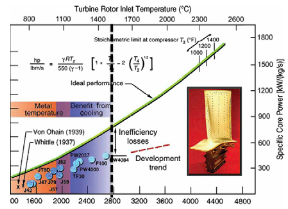
Pure chromium coupon after 1000 hours oxidation in air at 1200°C



Cr-Cr_3(Si,Ge) alloy after 1000 hours oxidation in air at 1200°C

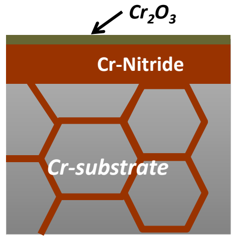
Motivation

Higher efficiencies require higher temperatures



Core power versus turbine inlet temperature for selected gas turbine engines, state of the art [1].

- At temperatures above 1150°C Ni-base superalloys start to soften
- Refractory alloys (Nb, Mo, W, Cr) are candidates beyond Ni-base superalloys
- Challenges are the intrinsic brittleness and lack of environmental resistance of reffractory alloys at high temperatures

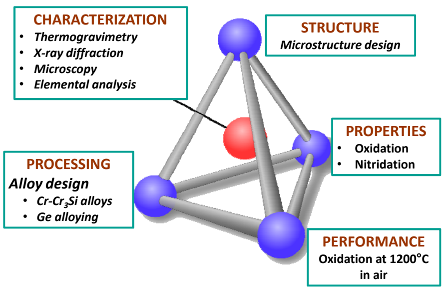


The schematic morphology of chromium after exposure to nitrogen containing atmosphere at high temperatures

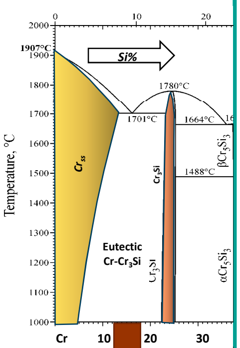
Chromium and its alloys

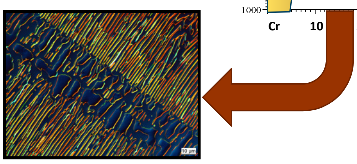
- At high temperatures common Cr-alloys develop an internally grown brittle nitride which hinders the applicability of such alloys
- In this work, the nitridation behavior of the Cr-silicide system is studied using high temperature exposures in synthetic air (at T> 1200°C). The effect of Ge alloying on nitridation resistance is discussed

Materials and Methods



The targeted part of the Cr-Si phase diagram in this work.





- Cr-Si alloys have been arc-melted in the 0-25 at% Si range
- Single phase Cr_{ss} and two phase Cr-Cr_3Si eutectics are studied
- Up to 2 at% Ge is added to the two phase eutectic alloys providing a quasi-eutectic microstructure [2]

References

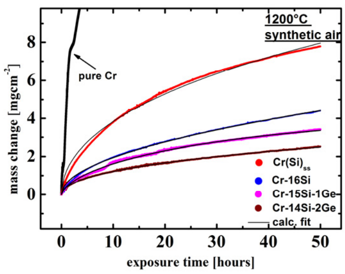
1. D. M. Dimiduk, J. H. Perepezko, MRS Bulletin, 2003, vol. 28, p. 639.
2. A. Soleimani-Dorcheh, M. C. Galetz, Metall and Mat Trans A, 2014,45,P1639.
3. A. Soleimani-Dorcheh, W. Donner, M. C. Galetz, Materials and Corrosion, 2014

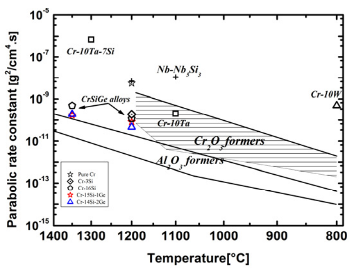
Results

Oxidation Kinetics

$$(\Delta W/A) = (k_p t)^{0.5} - k_v t$$

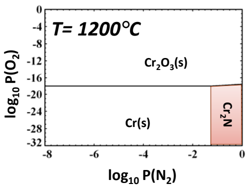
- *Parabolic growth*
- *Linear evaporation*

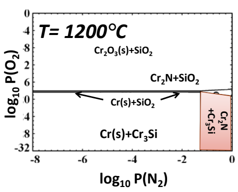




- Pure chromium severely oxidizes at temperatures higher than 1000°C
- Addition of Si reduces both vaporization and growth kinetics
- Synergic addition of Si and Ge further reduces the growth kinetics
- Cr-Si-Ge alloys as the most protective amongst other Cr-base alloys [3]

Thermodynamics





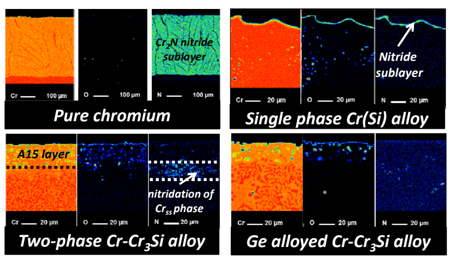
Cr_2N is only stable at low $P(O_2)$ pressure and high $P(N_2)$

with Si addition:

- SiO_2 is stable at lower PO_2
- The Cr_3Si silicide phase is stable in the whole $P(N_2)$ range, while solid solution chromium is selectively nitrided

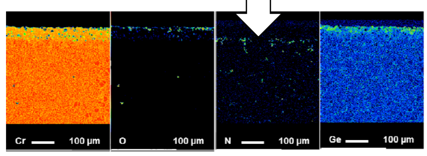
Subscale Nitridation

after 50h in air at 1200°C



Ge-alloying enhances the stability of the A15 layer at oxide-substrate interface which slows inward nitrogen transport

Nitridation is inhibited even after 1000h exposure at 1200°C



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