V-based High Entropy Alloys for Fusion Blanket Applications

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Introduction

The blanket of a fusion reactor (see Fig. 1) has many functions, necessitating the following properties in any material used:

- Good mechanical performance
- Resistance to radiation damage
- Wide operating temperature range to maximise thermodynamic efficiency
- Compatibility with coolant and tritium breeding system

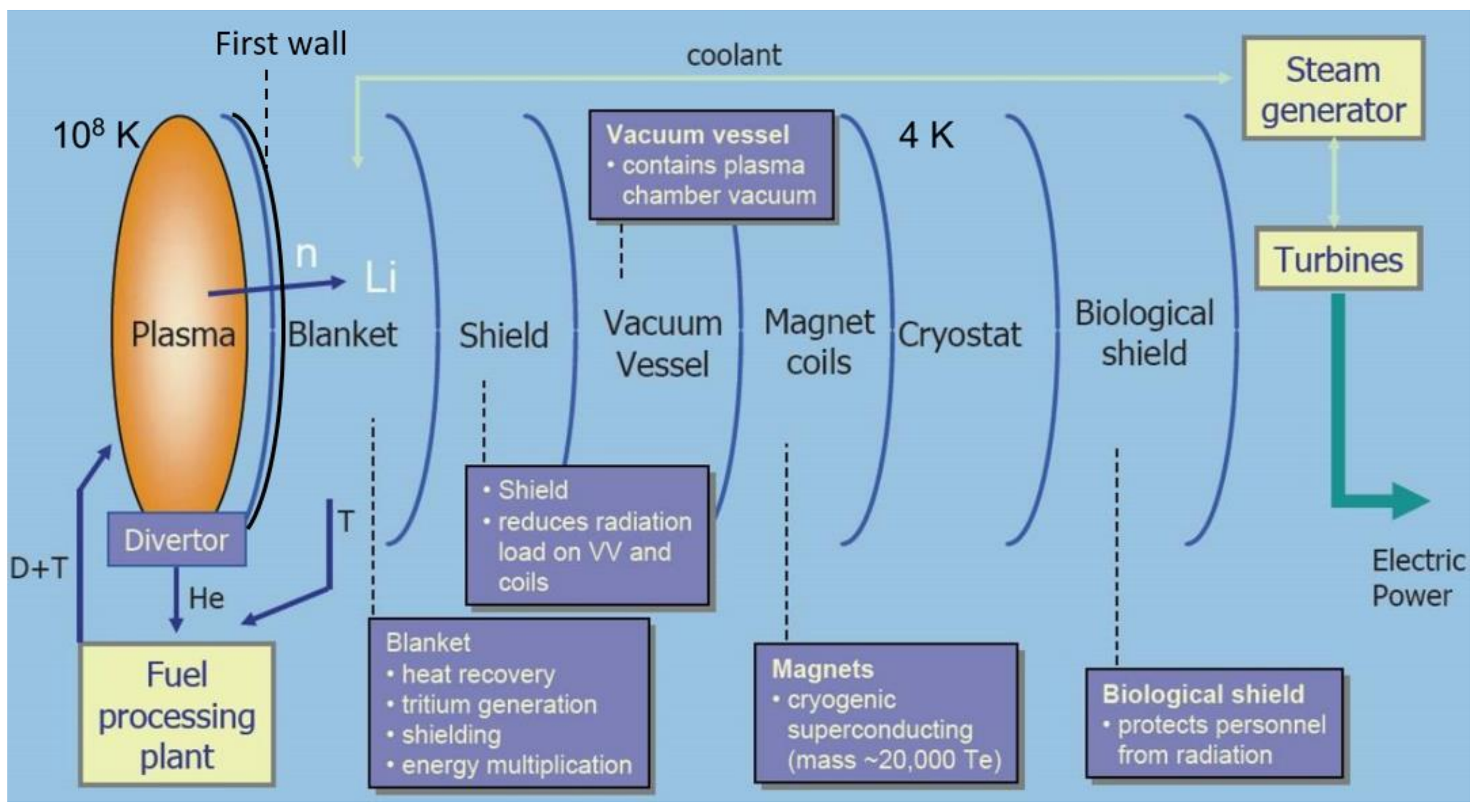

Figure 1. Schematic of a fusion reactor (from ITER organisation).

Low activation alloys

- Fusion reactors should aim to minimise long-lived radioactive waste produced
- Desirable elements are only active for <50 years (see Fig. 2)
- **Alloy design rationale 1: use only low activation elements**

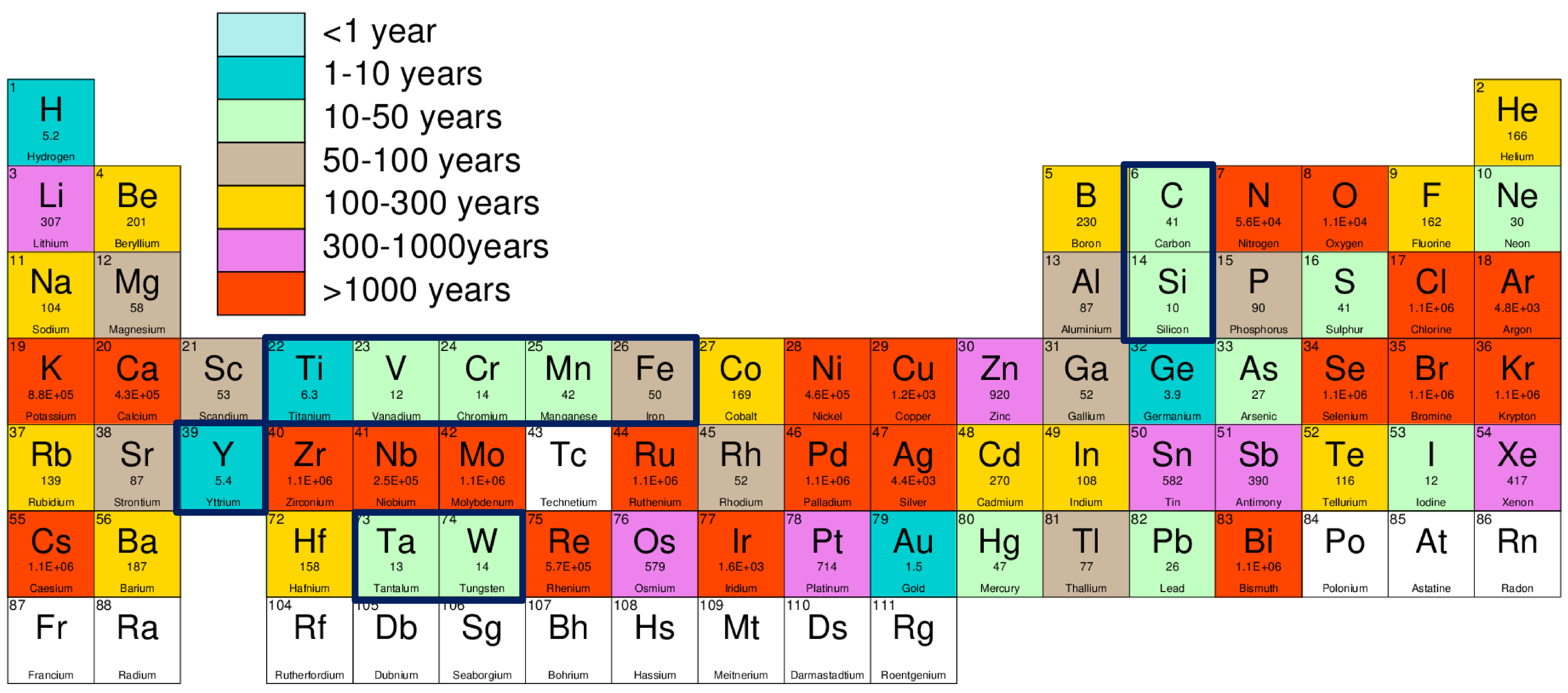

Figure 2. Time taken to reach low-level waste after 14 years of pulsed operation in the DEMO blanket shield.[1] Elements used in fusion reactors have been highlighted.

High entropy alloys (HEAs)

- Relatively new class of alloys
- Characterised by multiple principle alloying elements
- Often (near-)equiatomic concentrations
- Certain HEAs confer radiation resistance[2] and unique tensile properties[3]
- **Alloy design rationale 2: Develop HEAs based on low-activation elements**

Exploring the ternary space

- A suite of **ternary V-Cr-Mn alloys** has been fabricated (see Fig. 3 for compositions)
- **V** for creep properties, high T_m
- **Cr** for corrosion resistance, good solubility with V (both bcc)
- **Mn** for solution strengthening and to build towards an HEA-like system
- **Ti** has also been added in small amounts to act as an interstitial getter (as in V-4Cr-4Ti, another fusion alloy [4])

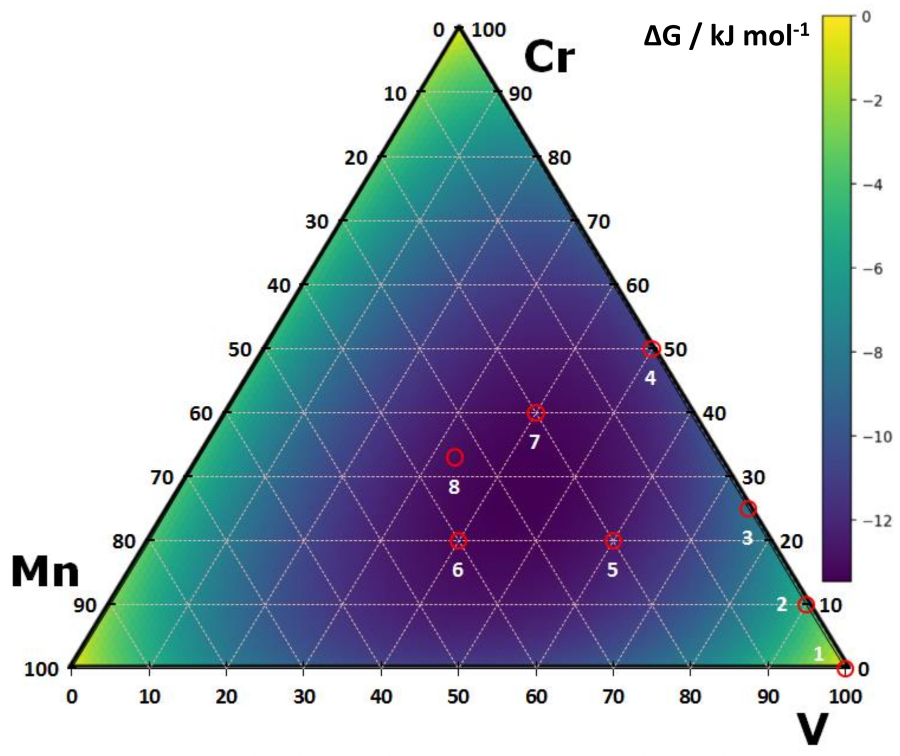

Figure 3. Calculated free energy of solid solution formation with alloy compositions labelled

Stability in fusion conditions

- Alloys were homogenised for 100 hrs at 1200 °C to ensure equilibrium microstructure
- Ternary alloys comprised of a single bcc phase with vanadium oxide impurities (Fig. 4)
- Quaternary alloys contain Ti-(C,O,N) type precipitates (Fig. 5)

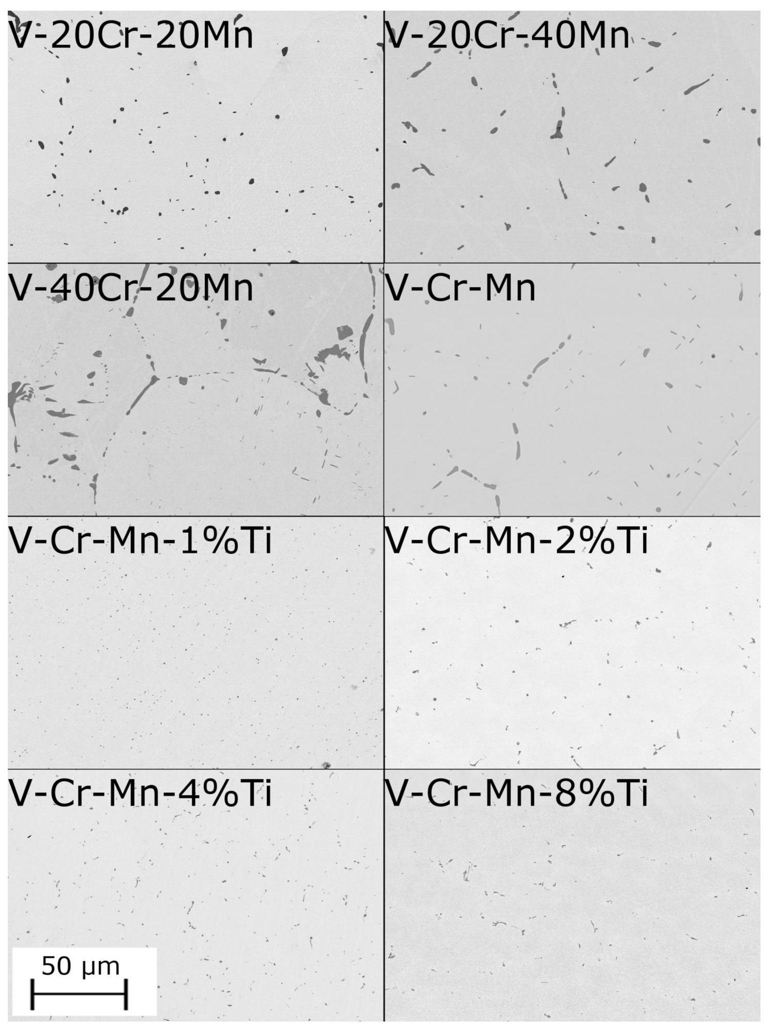

Figure 4. Backscattered electron images of the homogenised alloys.

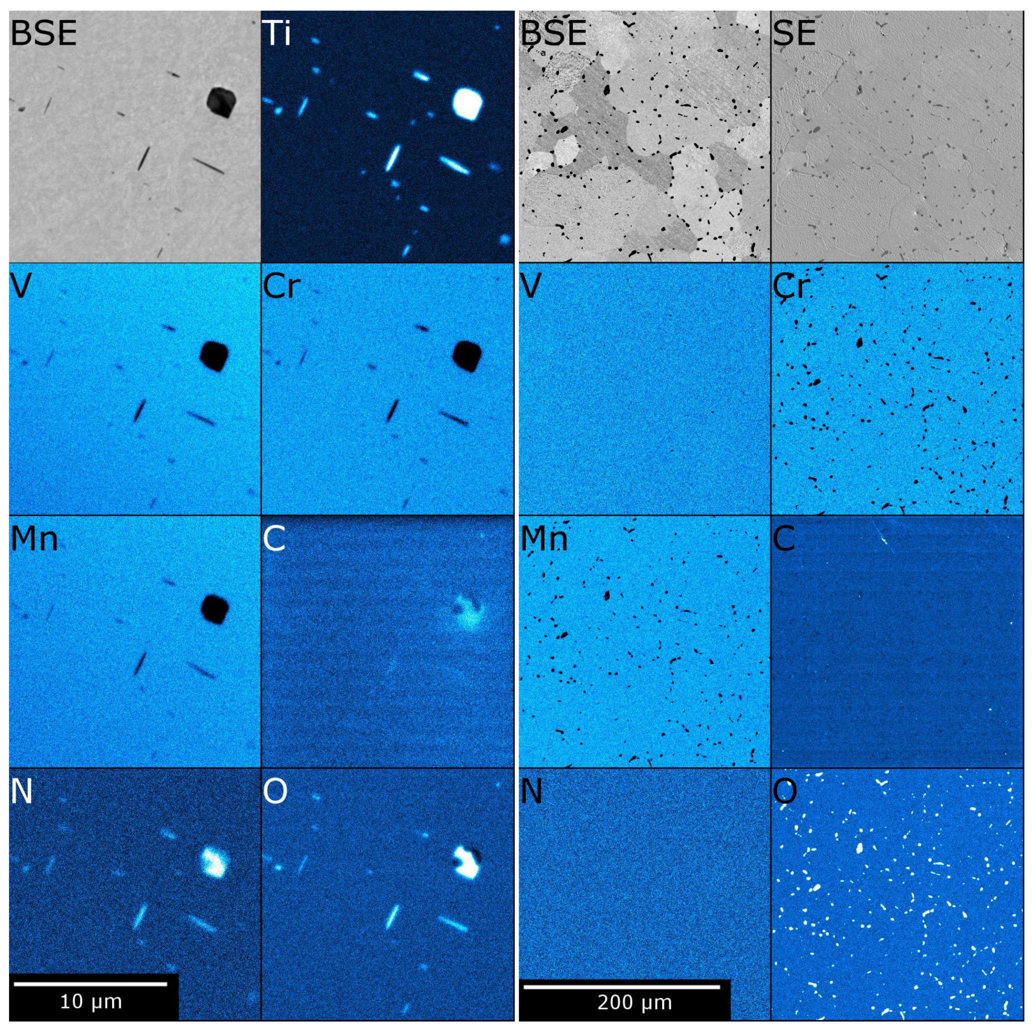

Figure 5. EPMA images of alloy V-40Cr-20Mn (left) and V-Cr-Mn-8%Ti (right)

- Alloys were heat treated at 600, 800 and 1000 °C for 100, 300 and 1000 hrs
- No significant changes in microstructure observed, still bcc phase with light precipitates
- Results imply the V-Cr-Mn system is **stable across a range of fusion relevant temperatures**[5] (even with small additions of Ti)

Future work

- Now that phase stability has been confirmed, focus is on other fusion relevant properties
- Corrosion properties and ion irradiation studies will be undertaken

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