Hydrogen Retention Properties of V-4Cr-4Ti Alloy

A.V. Golubeva[1], A.V. Spitsyn[1], N. Bobyr[1], M. Mayer[2], V.S. Efimov[3], Yu. M. Gasparyan[3], D.Yu. Smirnov[1]

1 – NRC 'Kurchatov Institute', Ac. Kurchatov sq., 1/1, Moscow RU-123182, Russia.
2 – Max-Planck-Institut für Plasmaphysik, EURATOM Association, Boltzmannstrasse 2,D-85748 Garching, Germany.
3 – National Research Nuclear University "MEPHI", Kashirskoe sh.31, Moscow 115409, Russia

1.1. introduction

New constractive materials – low-activated, with good thermomechanial properties are required for next-step fusion devices (DEMO reactor, fusion neutron sourses)

V-Cr-Ti alloys - promising constructive materials (vacuum chamber, lithium blanket).

In the Bochvar Institute (Russia) a base V-4Cr-4Ti was produced with good thermomechanical properties that would allow it's use in fusion devices.
The hydrogen interation with the material – a critical safaty question – was never investigated before.

In the resent work hydrogen retention in V-4Cr-4Ti alloy was investigated at gas loading and plasma irradiation.

1.2. What is known about H – V-Cr-Ti interaction?

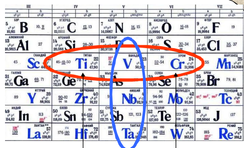
1. Ti, V, Cr – consecutive elements of IV period of the periodic table of Mendeleev
2. V-4Cr-4Ti — Improves strength & corrosion stability; Decrease swelling & hydrogen embrittlement
3. Ti, V – **hydrogen getters** (in a sertain conditions can pump out hydrogen) V-4Cr-4Ti - **?**

3.2. If Ti is a main component of getter, Cr and V reduce activation temperature

4. Some publications discuss hydrogen retention in V-4Cr-4Ti alloys of Russian and Japanese production [1-3].

4.2. Hydrogen retention properties of two V-Cr-Ti alloys of the same composition may noticeably differ

5. Hydrogen retention properties of Bochvar's V-Cr-Ti were never investigated



Heated form hydrides (Ti:H – up to 1:1)

One of the most hard materials (second after W)

Can dissolve H very good: (Nb:H – up to 1:2)

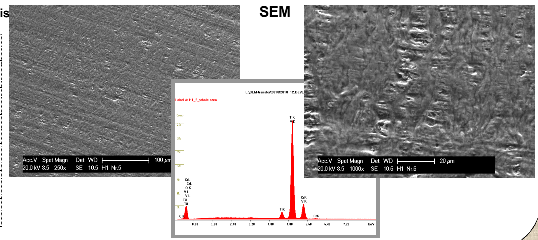
2. Material

0.2 mm thick hot-rolled V-4Cr-4Ti foil

Chemical analysis

V	92.0
Cr	3.0
Ti	4.3
Fe	0.002
Mn	<0.0005
Ca	0.043
Mg	<0.004

SEM

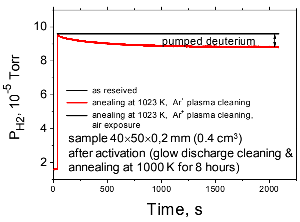


3. Interaction with gas (getter properties)

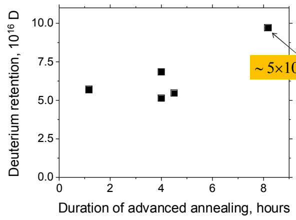
Experiment

1. $P_0 = 1 \times 10^{-7}$ Torr
2. Sample is cleaned in Ar glow discharge (several hours, 400 V, 0,1 mA/cm²)
3. Sample is annealed up to 750⁰ C (0,5-8 hours) and cooled down to RT
4. Pumping is stopped. Hydrogen fills chamber up to ~ 1×10^{-4} torr
5. Pressure decreases due to sorption by sample

Typical sorption curve



Deuterium capture as function of advance annealing



Oxide layer strongly decreases hydrogen sorption

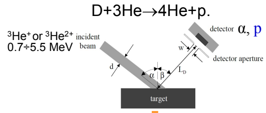
Under certain conditions (clean surface, advance annealing) V-4Cr-4Ti surface may act as a getter pump (sorbing hydrogen)

4. Deuterium plasma irradiation

4.1. Experimental

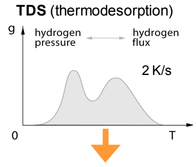
Plasma irradiation (PIM installation):
Plasma composition: 70% - D3+; 20% - D2+; 10% - D+ ,
Accelerating potential: -300 V.
Plasma density: $6\cdot10^{10}$ cm^{-3}
Fluence: 10^{19}-10^{21} D/cm²
Pressure: $5\cdot10^{-4}$ Torr
Temperature: 290 – 600 K

Investigation of retention:
NRA (Nuclear Reaction Analysis)
D+3He→4He+p.



• Retention in near-surface layer (up to 15 μm)

TDS (thermodesorption)

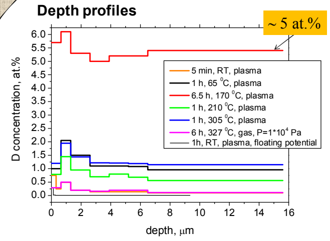


• Total retention
• States of H in material

4.2. Deuterium retention

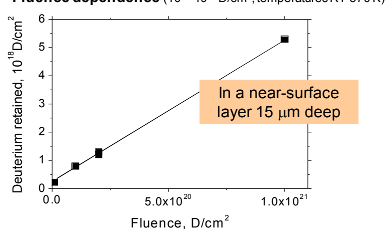
NRA

Depth profiles



• Deuterium penetrates deep in the material
• Depth distribution is almost uniform

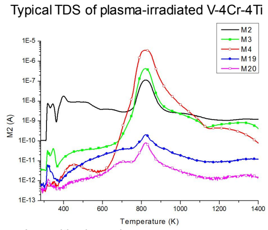
Fluence dependence (10^{19}-10^{21} D/cm², temperatures RT-570 K)



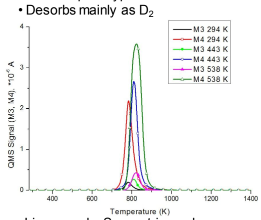
• In a range RT-570 K temperature does not influence retention significantly
• At a fluence 10^{21} D/cm² saturation is not achieved

TDS

Typical TDS of plasma-irradiated V-4Cr-4Ti

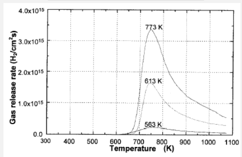


Logarithmic scale:
• TDS shape is typical for V-4Cr-4Ti
• Desorbs mainly as D_2

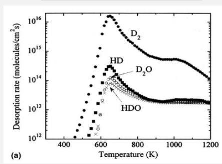


Linear scale: Symmetric peaks (second order desorption)

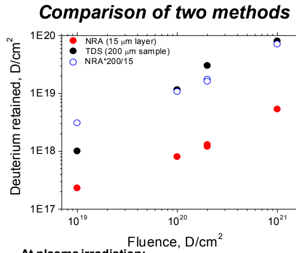
[1] TDS after exposure in H_2 gas, 80 Pa, 3 hours Russian V-4Cr-4Ti of previous generation



[2] TDS after irradiation by 1.7 keV D ions NIFS-HEAT-1 (Japanese V-4Cr-4Ti)

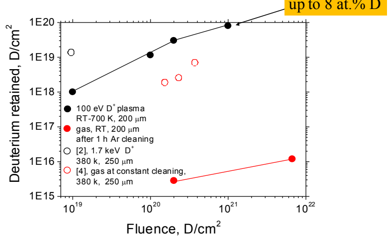


Comparison of two methods up to 8 at.% D



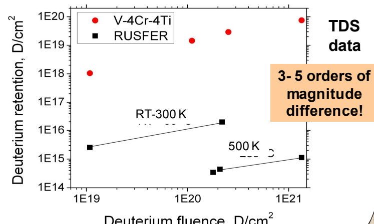
At plasma irradiation:
• Results of two methods at elevated temperatures (fluence ≥ 10^{20}) are very close
• Deuterium is distributed uniformly through the sample

Retention from plasma & gas



• At plasma irradiation retention much higher than at gas exposure can be achieved

Retention in V-4Cr-4Ti and RUSFER (ferritic steel)



Use of V-4Cr-4Ti as a fusion constructive material of the first wall without barrier coating is impossible

5. Conclusion

Hydrogen retention in V-4Cr-4Ti (Bochvar institute production) **at gas loading and plasma irradiation has been investigated for the first time**

• **V-4Cr-4Ti under certain conditions** (clean surface, advance annealing) **may act as a hydrogen getter pump** (sorbing hydrogen)

• **H retention in Bochvar's alloy is comparable with retention in Japanese analogs**

• **At plasma irradiation hydrogen accumulation may be orders of magnitude higher than at gas loading**

• **V-4Cr-4Ti accumulates huge amount of deuterium** (5 orders higher than ferritic steel RUSFER at the same condition)

• **In case of use of V alloys as a constructive material for fusion, barrier coating for decreasing of hydrogen migration through and retention in V-4Cr-4Ti are absolutely necessary**

6. Acknowledgment

This work was supported by the
Impuls- und Vernetzungsfond der Hemholtz Gemeinschaft e.V.,
Russian Foundation for Basic Research grants Nr 11-02-91322 and Nr 11-08-01069,
Russian President grant for young scientists MK-2839.2011.2

7. References

1 – A. Kh. Klepkov et. Al, Hydrogen release from irradiated vanadium alloy V–4Cr–4Ti // Fusion Engineering & Design 51-52 (200) 127-133
2 – J. Masuda et al. Diffusion and trapping of tritium in vanadium alloys, JNM 363-365 (2007) 1256-1260
3 – Y. Yamauchi et. al, Deuterium retention in V–4Cr–4Ti alloy after deuterium ion irradiation, JNM 329-333 (2004) 397-400
4 – Y. Hirohata et al, Deuterium and helium retentions of V–4Cr–4Ti alloy used as first wall of breeding blanket in a fusion reactor, JNM 348 (2006) 33–39

anna-golubeva@yandex.ru