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EUROfusion

Effects of Fe+ ion irradiation at 300 ^{o}C on Fe-Cr films

S. Pantousa[1,2], E. Manios[1], K. Mergia[1], S. Dellis[1], A. Ionescu[3], C. Kinane[4], S. Langridge[4], A. Caruana[4], U. Kentsch[5], P. Tsavalas[1], A. Lagoyannis[1] and S. Messoloras[1]

[1] National Centre of Scientific Research “Demokritos”, Athens, 15341, Greece
[2] Department of Physics, School of Sciences, University of Athens, Athens, 15772, Greece
[3] Cavendish Laboratory, University of Cambridge, J J Thomson Avenue 19, Cambridge CB3 0HE, United Kingdom
[4] ISIS neutron and muon source, Rutherford Appleton Laboratory, United Kingdom
[5] Ion Beam Center, Helmholtz-Zentrum Dresden-Rossendorf, Germany

FUSION TECHNOLOGY GROUP

Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών

Science & Technology Facilities Council ISIS

UNIVERSITY OF CAMBRIDGE

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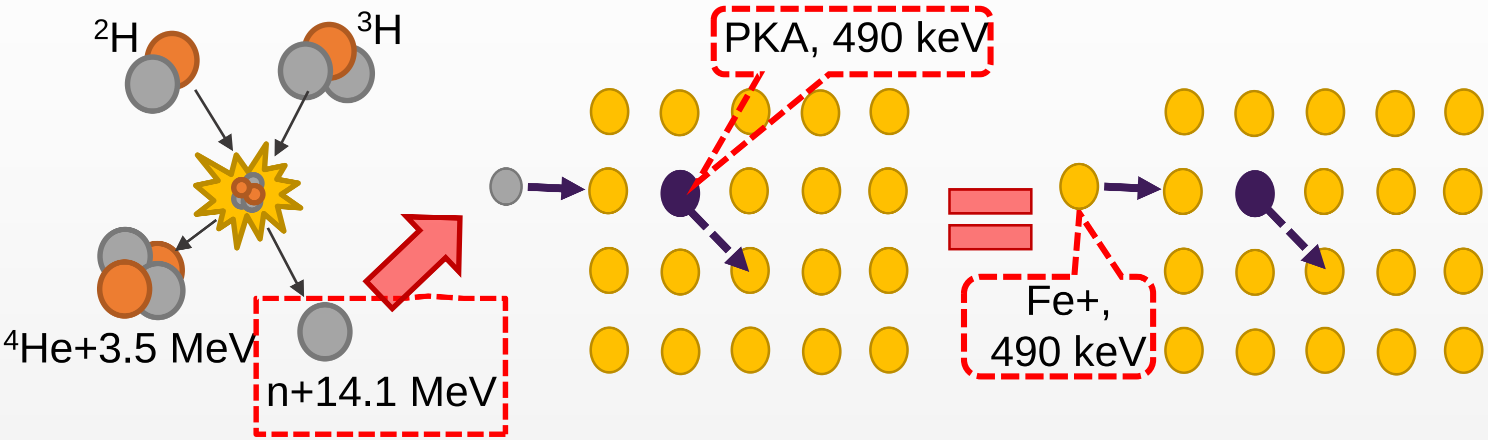
Scope/Introduction

- Ferritic – martensitic steels based on **Fe-Cr alloys:** candidate structural material for fusion power plants
- **Exposed at demanding fusion environment:** high fluxes of highly energetic neutrons and temperatures ~ 300 °C->radiation damage



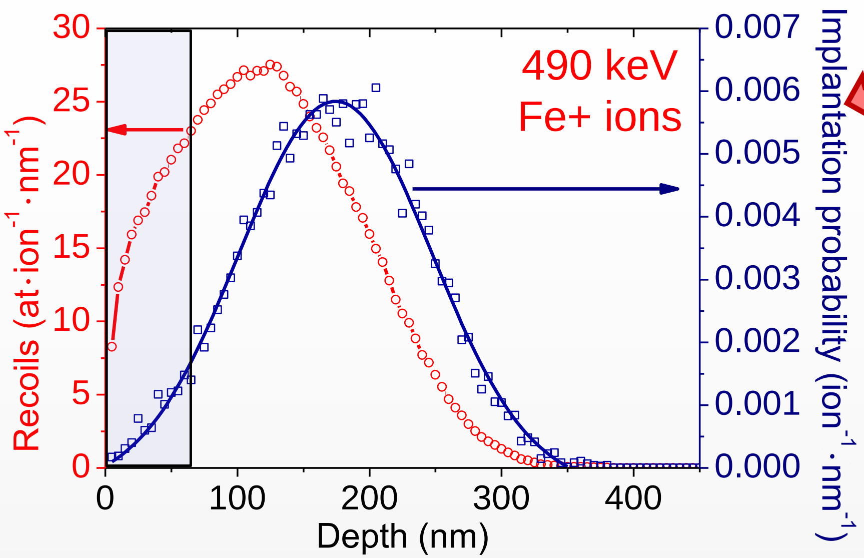
490 keV Fe+ ions: imitate the lattice damage from the Primary Knock-on Atom (PKA) produced by **14 MeV** neutrons

- Understanding **radiation induced effects** to these alloys is of paramount technological importance & a scientific challenge
- **10 at% Cr alloys** are **preferable:** present minimum Ductile to Brittle Transition Temperature (DBTT) and high swelling resistance

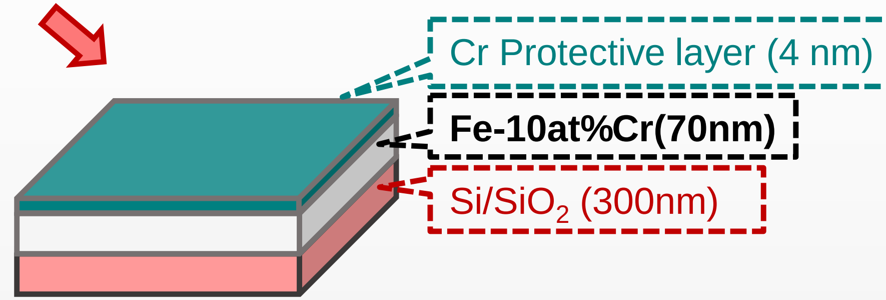
Aim of this work

Investigation of the effects caused by 490 keV Fe+ ion irradiations on Fe-10at%Cr alloy films at 300 °C and at the dose range 0.5 – 20 displacements per atom (dpa)

Methods

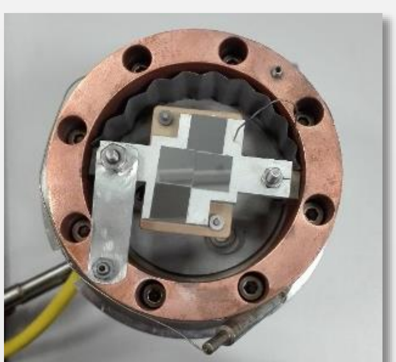


1) **Simulation** of 490 keV Fe+ ions on Fe-10at%Cr
   - **Penetration depth** ~ 400 nm
   - **70 nm:** elimination of implantation effects
2) **Fabrication:** DC magnetron sputtering high purity Fe-10.5at%Cr and Cr targets (99.95%)

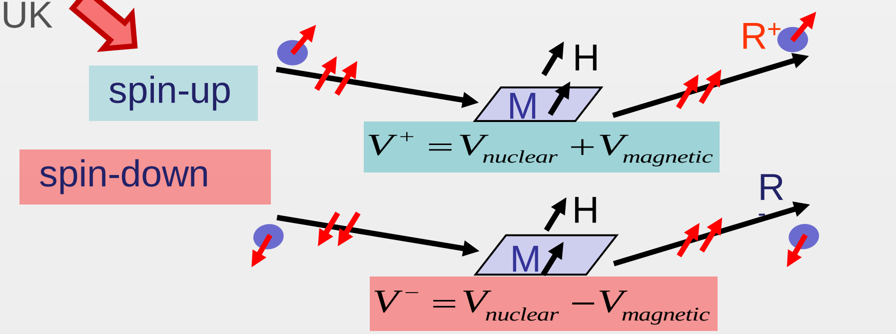


3) **Verification of Cr content:** X-Ray Fluorescence (XRF) and Rutherford Backscattering Spectrometry (RBS)-NCSRD

4) **Irradiations:**
   - 3 MV Tandetron accelerator - IBM-HZDR
   - 490 keV Fe+ ions
   - T_{irr}=300 °C
   - Dose:0.5 – 20 dpa



5) **Sample Characterization before and after irradiation**
   - **Structural:** X-Ray Reflectivity (XRR) & X-Ray Diffraction (XRD)-NCSRD
   - **Magnetization versus depth:** Polarised Neutron Reflectivity (PNR) measurements -RT - POLREF, ISIS, UK

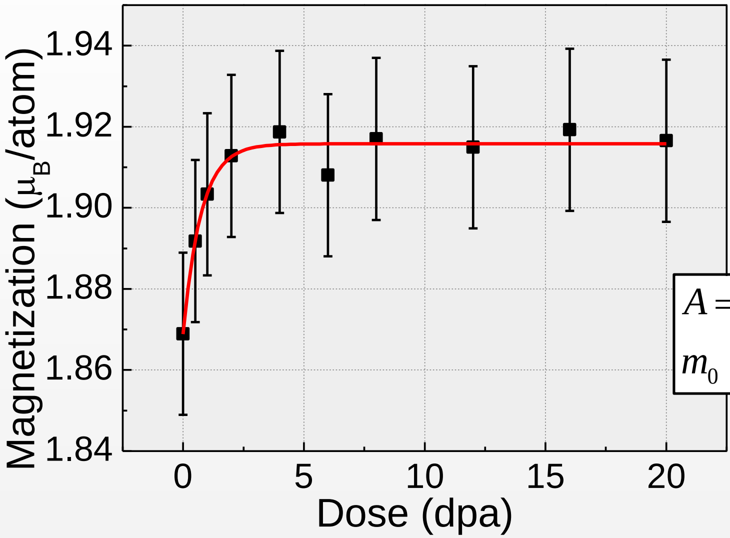


Results

After Irradiation

- **XRD:** Unaltered crystal structure
- **XRR:** Structural stability (density & thickness unaltered)

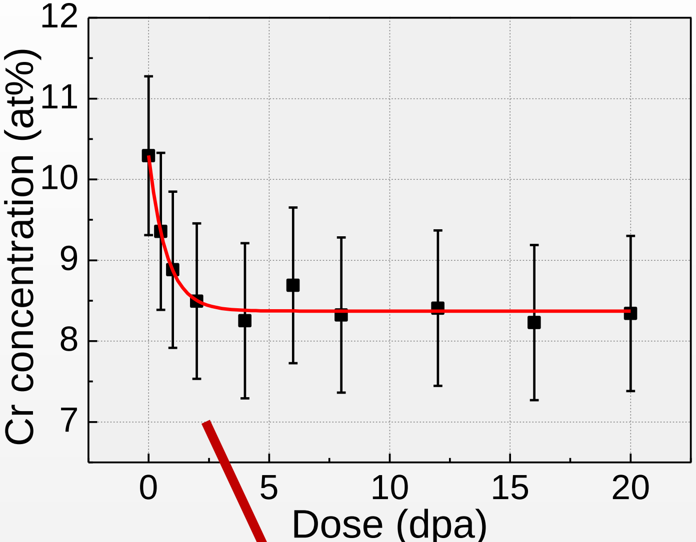
- **PNR:** Magnetization versus depth characterization



$$x_{cr} = A(m_0 - m)$$

$$A = (41.0 \pm 1.4)\,\text{at\%}/\mu_B/\text{at}$$
$$m_0 = (2.12 \pm 0.01)\,\mu_B/\text{at}$$

[K. Mergia et al..J. Phys. Con. Mat, (2020)]



Magnetization increases with irradiation dose up to **~4 dpa**, and remains **constant afterwards**

✓Attributed to **Cr depletion** from the Fe-Cr matrix

✓Decrease of **solute Cr** content in Fe-Cr matrix as a function of dose

Initial Cr content — Saturation constant

$$C(d) = C_0 - C_\infty (1 - e^{-d/d_0})$$

Equilibrium Cr content

$$C_{eq} = C_0 - C_\infty$$

C_0 (at%)	C_∞ (at%)	d_0 (dpa)	C_{eq} (at%)
10.3 ± 0.1	1.9 ± 0.2	0.7 ± 0.1	8.4 ± 0.2

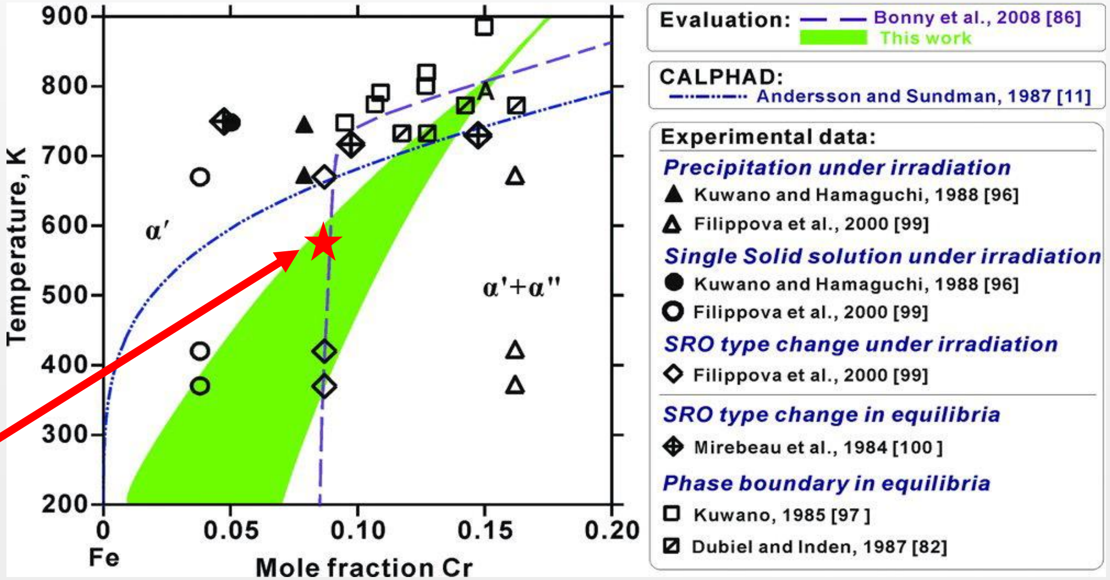
Conclusions

- The **magnetization** of the Fe-Cr layer increases as irradiation dose increases up to about **4 dpa,** and **remains constant** for further increase of the dose
- This increase is attributed to the **Cr depletion** from the Fe-Cr matrix
- Solute Cr tends to the asymptotic value **C_{eq}=(8.4±0.2)at%,** which is in good agreement with the **phase diagram** of the alloy, regarding the solubility of Cr at 300 ^{o}C
- At the temperature of 300 ^{o}C **thermal diffusion is not adequate** to drive decomposition of the alloy

- Cr depletion arises from the **radiation enhanced Cr diffusion**
  - Irradiation produces **sinks** in which **Cr agglomerates**
  - **Diffusing Cr** may **segregate** at **grain boundaries**

C_{eq}=(8.4±0.2) at%

Fe-Cr Phase Diagram



[W. Xiong et.al, Crit. Rev. S.S.Mat. Sci. (2010)]