Resistivity Recovery of Fe-Cr alloys after low-temperature proton irradiation

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Introduction

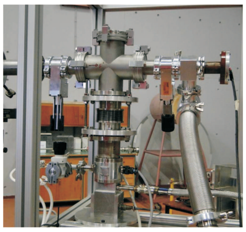
Motivation

- The behavior of Fe-Cr alloys under irradiation is of crucial technological importance since these alloys form the basis of ferritic/martensitic steels employed in fusion and fission technology.
- Currently, extensive theoretical work is carried out in order to elucidate radiation damage effects in Fe-Cr alloys and develop predicitve tools for their behaviour in a fusion environment.
- Electrical resistivity, as it is highly sensitive to defects in metals, has been widely used for the study of radiation damage
- With controlled post-irradiation annealing, valuable information can be extracted for the properties and kinetics of defects and their interactions.

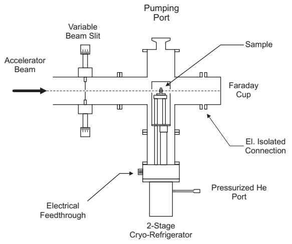
Current work

- A low-temperature ion irradiation facility employing *in-situ* resistivity measurements has been developed at the "Demokritos" TANDEM accelerator.
- This facility has been utilized in determining the nature and behavior of radiation defects produced by ion bombardment in pure Fe-Cr model alloys.
- The collected experimental results would be compared with theoretical predictions and may be utilized for the validation of theoretical models.

Ion Irradiation Facility

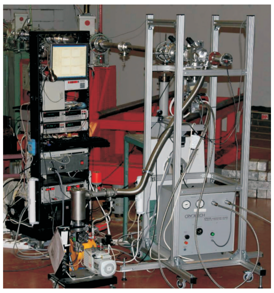


Sample stage with Cold-head



Beam-line integration

- 5MV TANDEM accelerator, producing H, D, He and light ions up to O
- Closed-cycle He refrigerator coupled into the accelerator beam line
- Base T = 10K, during irradiation 20 < T < 50 K due to beam heating
- Beam area 1 x 1 cm^2, current up to 0.5 μA
- In-situ electrical resistance measurement with 10^{-7} Ω resolution
- Fast step annealing up to T = 700 K



The Irradiation facility during operation

Experimental Results

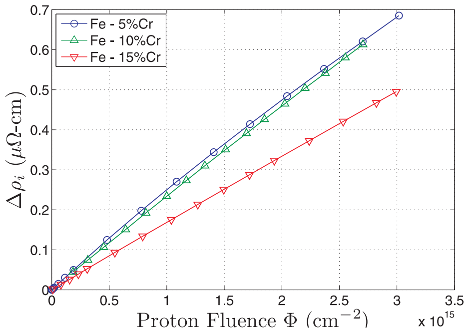
Sample preparation

- Purified Fe-Cr model alloys fabricated by induction melting
- Cr concentrations 5, 10 and 15 at. %
- C, N, O impurities below 5 ppm
- Cold-rolled to 50 μm thickness and annealed at 800°C
- Strips of 15 x 2 mm^2 were cut and instrumented with potential leads for the electrical measurements

Irradiation Conditions

- 5 MeV protons, max fluence 3x10^{15} cm^{-2}
- Penetrate through the 50 μm sample
- Sample T = 50 K during irradiation

Resistivity increase during irradiation

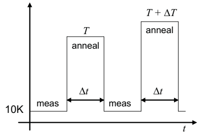


- Linear resistivity increase with dose - no saturation effects
- Damage rate is almost equal at 5 and 10 at% Cr but reduced in the 15% Cr alloy
- This cannot be attributed to differences in damage efficiency since Fe & Cr interaction with proton is very similar.
- May be due to increased recovery in the 15% Cr alloy which occurs during irradiation (due to stage I occurring at lower temperature in this alloy)

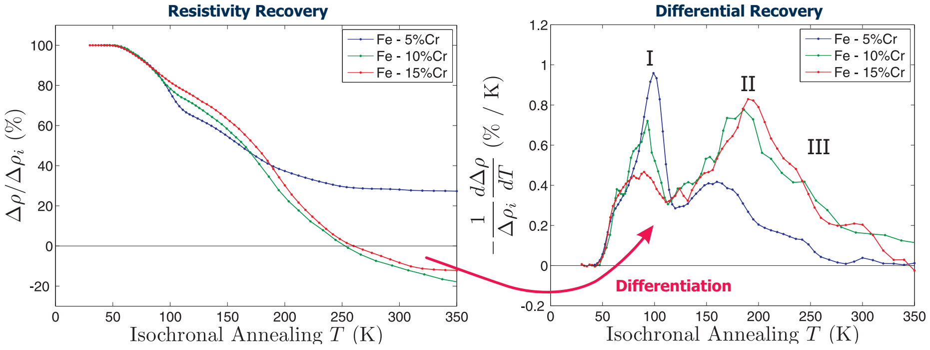
Post-irradiation annealing

- Sample is subject to isochronal annealing steps at successively higher temperature
- Between annealing steps the sample returns to 10 K for measurement of the residual resistivity
- $\Delta T/T \sim 0.05$, $\Delta T/\Delta t \sim 1$ K/min

Step anneal/measure schema



Resistivity Recovery **Differential Recovery**



Conclusions

- The rate of damage recovery peaks at specific temperature regions
- These recovery stages are best exemplified in the differential recovery spectrum, marked with I (~100 K), II (~200K), III (~250K)
- A direct analogy of these stages exists with the ones observed in pure Fe which have been previously identified as
  - I : Frenkel pair recombination, interstitial migration
  - II : migration of interstitial clusters
  - III : migration of vacancies
- The presence of Cr affects the position of the stages relative to Fe (I shifts to lower, II to higher T)
- The recovery peaks are wide, overlapping and they generally show a rich substructure. This can be attributed to the multitude of possible defect combinations (e.g. Fe-Fe, Fe-Cr, Cr-Cr interstitial dumbbell configurations) which result in a distribution of activation energies.
- Amplitude and position of the stages depends on Cr concentration.
  - Stage I becomes weaker and shifts to lower temperature with increasing Cr concentration
  - Stage II shows exactly the opposite behavior
- At T > 300K the resistivity goes above (5% Cr) or below (10 & 15% Cr) the pre-irradiation value. This is probably due to radiation-enhanced alloy ordering caused by the mobile vacancies in stage III.

Future work

A systematic dataset of resistivity recovery at different Cr concentrations and irradiation doses will be completed. The results will be compared to recent theoretical results

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