EUROfusion

Time and temperature resolved resistivity recovery of irradiated metals

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FUSION TECHNOLOGY GROUP

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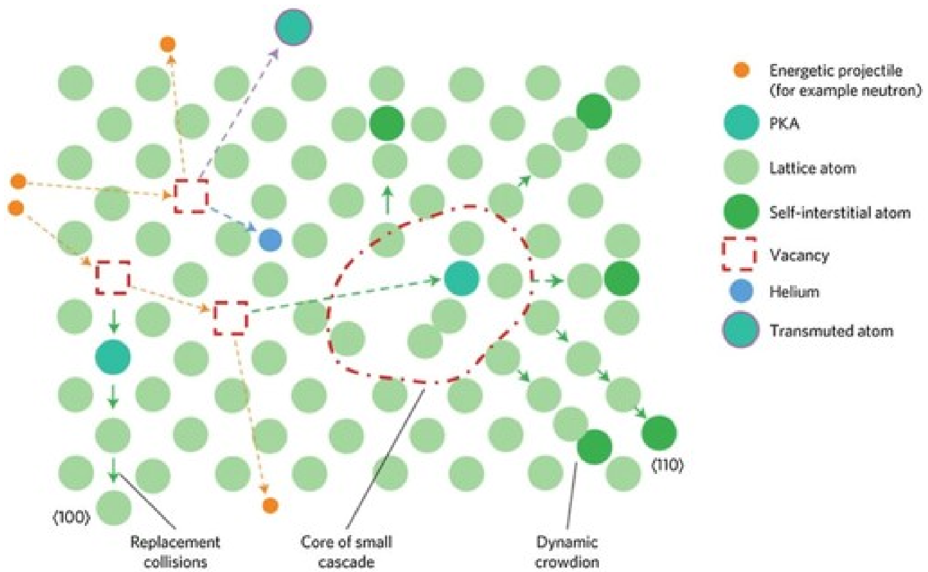
Defects form in crystals under **high energy irradiation**

- Most important: vacancies and self interstitial atoms-SIAs
- Cause degradation of physical & mechanical properties
- Fundamental defect studies are important for developing materials for next-generation energy systems.



Schematic illustration of irradiation defects
[Knaster et al. Nat. Phys. 2016]

Creep & fracture due to irradiation

Introduction / Motivation

- **Electrical resistivity** is a key method for defect studies
  - Highly sensitive to changes in defect population
  - Can be measured *in-situ* during and after irradiation
  - Resistivity recovery is observed during post-irradiation, isothermal or isochronal annealing
  - Can provide rich information: defect interaction, migration annihilation etc.

- Drawbacks:
  - **Difficult to analyze / interpret**
  - **Assumptions** needed in order to obtain defect data from measurements

Aim / Methodology

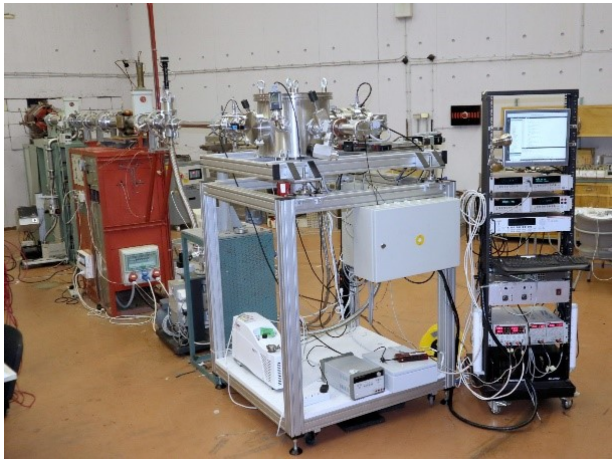
- **Our aim** is to employ modern digital measurement techniques in order to:
  - **Improve the information content & resolution** of resistivity recovery measurements
  - **Reduce the assumptions** needed for analyzing the results

Methodology:

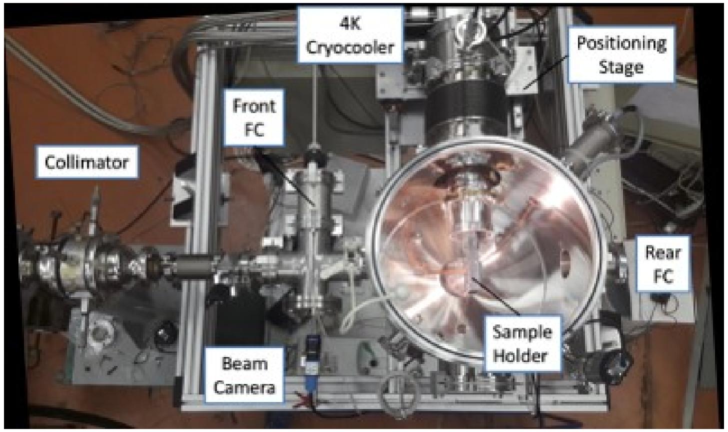
- Realize a complex post-irradiation annealing program that combines isochronal and isothermal aspects
- Thus obtaining time & temperature resolved resistivity recovery measurements

Experimental Setup and Details

- **Samples**: W single crystal (111) oriented
- **Irradiation Conditions**:
  - Irradiation conducted at 5 MV TANDEM accelerator of NCSR ‘Demokritos’
  - Facility utilized was IR^2
  - 7 MeV proton beam
  - Temperature during irradiation was kept at T= 7 K



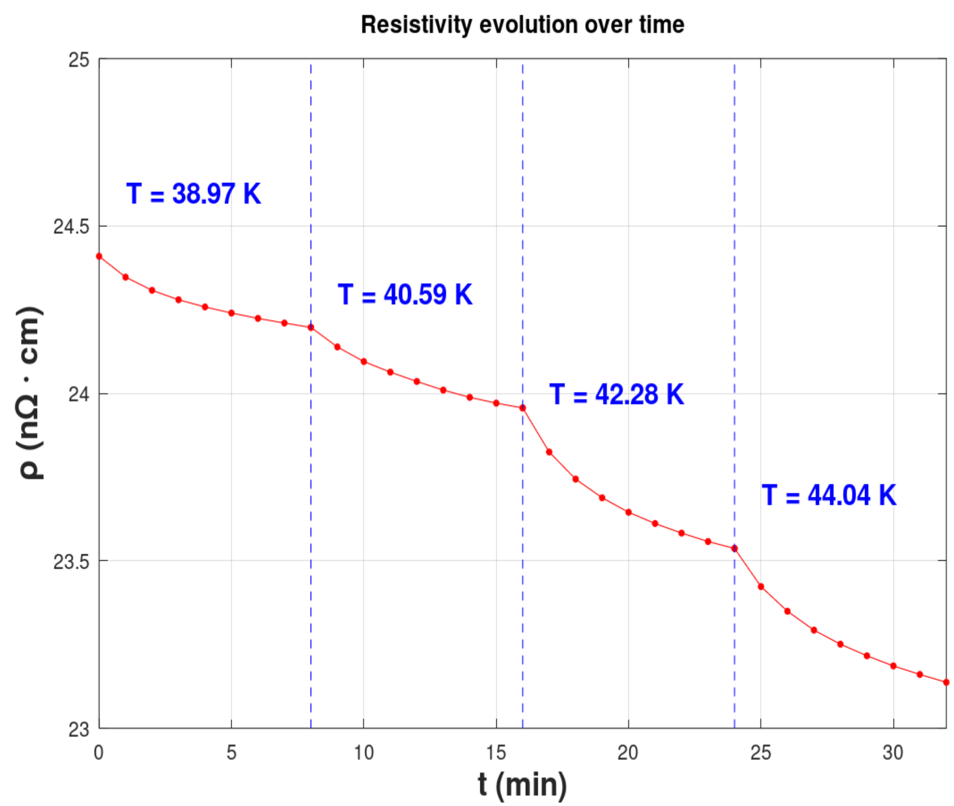
IR^2 beam line overview



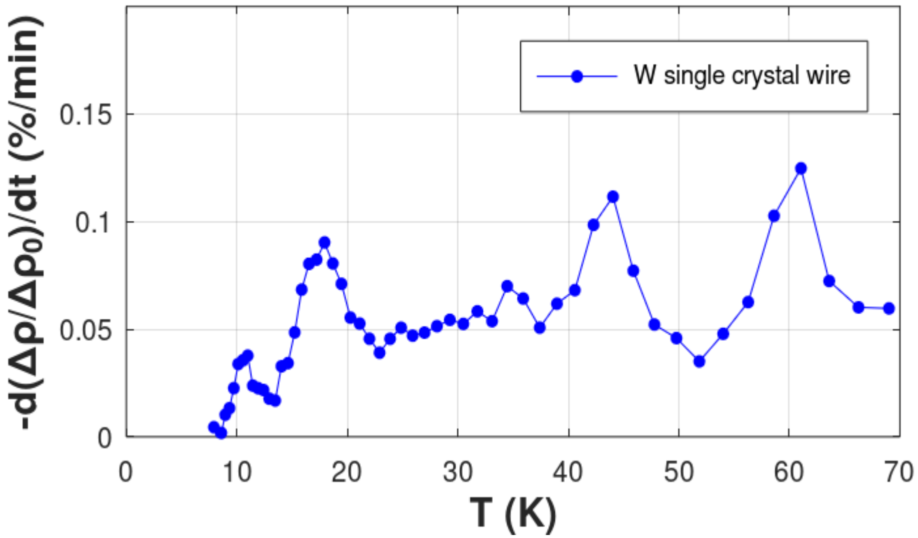
IR^2 main components

Time resolved resistivity recovery

- **Resistivity recovery:** Utilizing isothermal and isochronal annealing
- **Annealing Conditions:**
  - $8 < T < 70$ K
  - $\Delta T/T = 0.04$
  - **At each temperature, 8 resistivity measurements for Δt=1 min**



Experimental Results

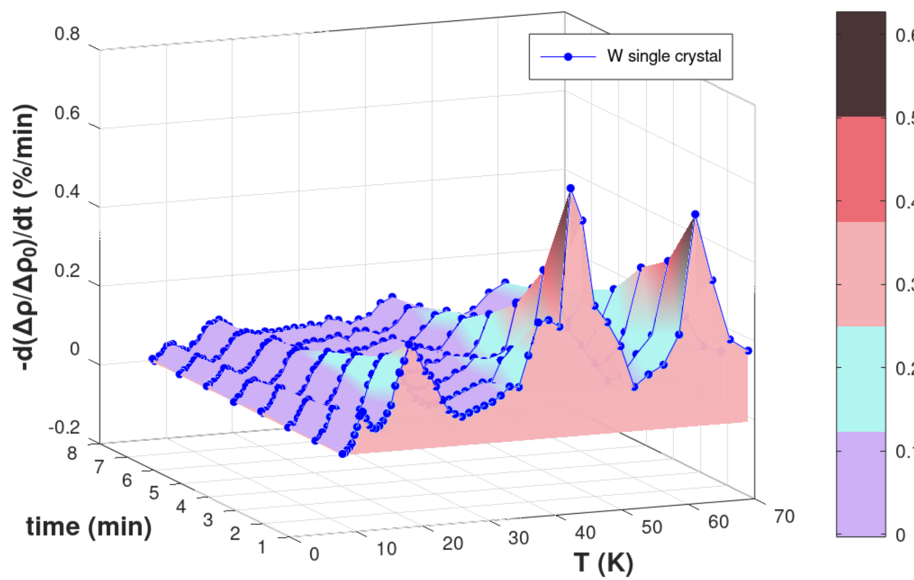


Traditional Isochronal Annealing

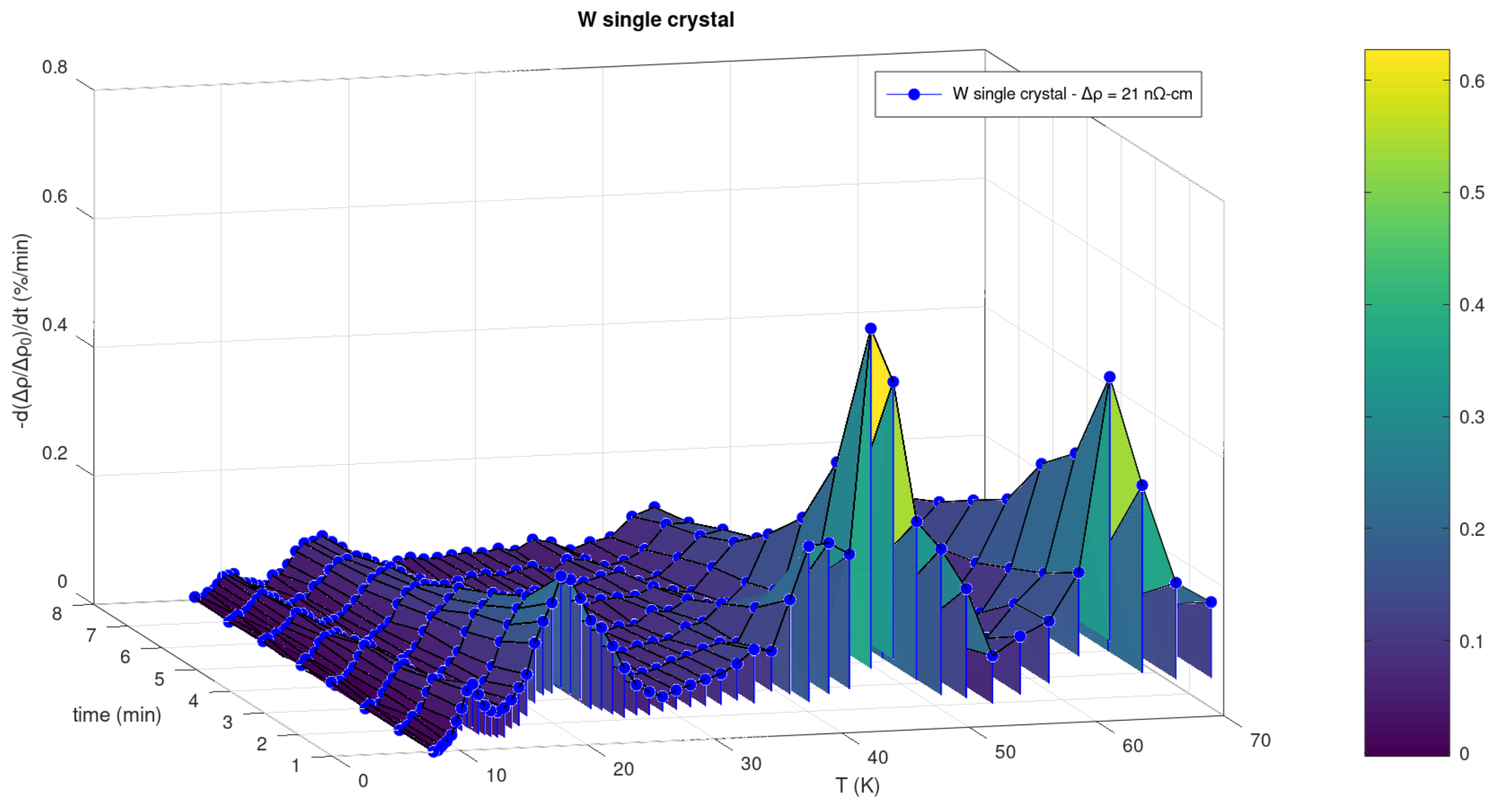
- One measurement per temperature for constant holding time
- Result: $\rho(T)$

New Method

- 8 measurements per tempe-rature at 1 min intervals
- **Result: $\rho(T, t)$**
- **Significantly increased information content**
- **May give insight into the defect kinetics mechanisms**



Experimental Results

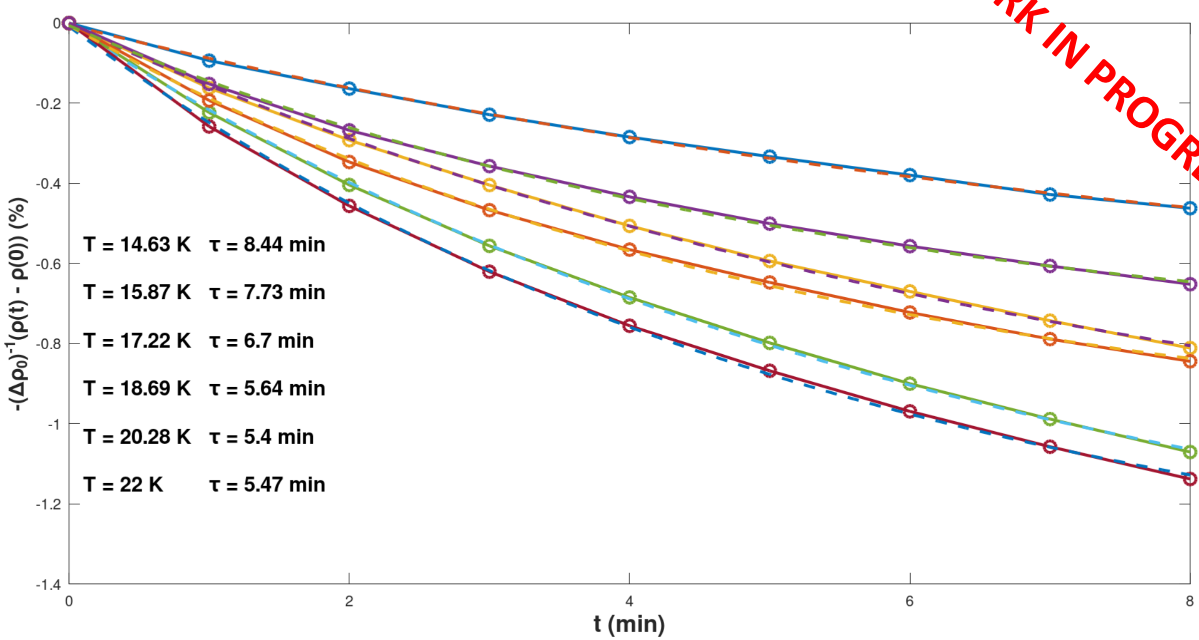


Display of resistivity recovery through time and temperature [video link]

Data Analysis

- Many possibilities for analysis
- Here we present the most simple one
- Assuming 1st **order kinetics,** $\frac{dN}{dt} = -\frac{N}{\tau} \Rightarrow N(t) = N_0 e^{-t/\tau}$
- $\rho(t,T) - \rho(0,T) = A \cdot N_0\left[e^{-t/\tau} - 1\right] = A \cdot N_0[e^{-\frac{t}{\tau(T)}} - 1]$

WORK IN PROGRESS



Different kinetic models will be tested in order to determine physical parameters, and compare different models

Conclusions

- A new method for conducting resistivity recovery experiments is presented
- Combining isochronal & isothermal aspects in the annealing process we obtain time & temperature resolved resistivity recovery
- This is realized by the highly automated digital measurement system of IR^2 facility
- A test measurement is presented on a proton irradiated W single crystal
- Examples of data analysis show the new possibilities offered by this method

Acknowledgements

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- ***Thank you for your attention …***

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