Ion beams for the development of radiation resistant semiconductors

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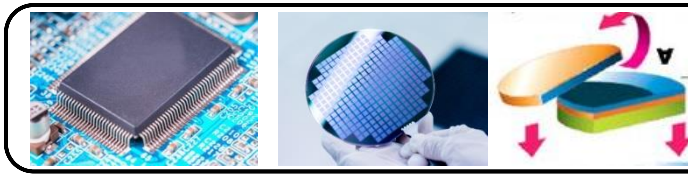
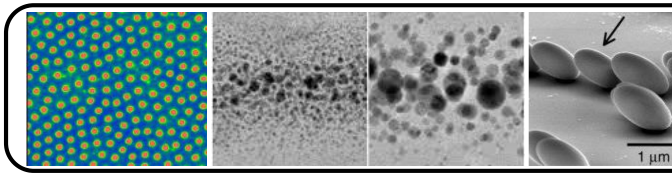
Ion-Solid Interactions: Modification

Ion Solid Interaction

Ion implantation for semiconductor processing

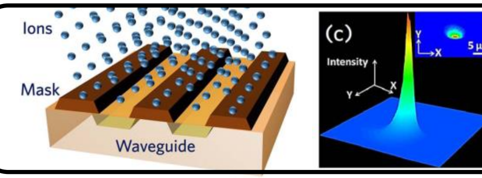


Nanostructure formation and nanopatterning

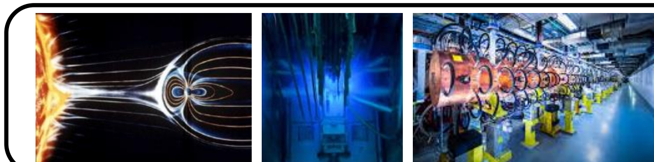


Corrosion and wear resistance in metals

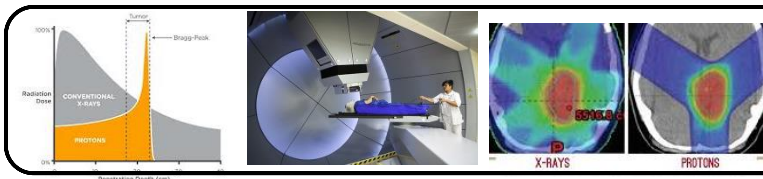
Optical materials: Waveguide formation



Radiation Environments

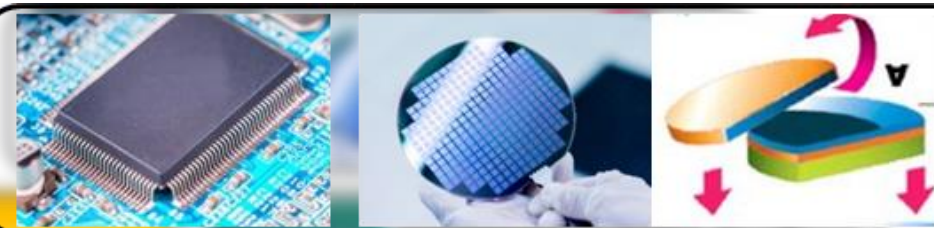


Radiation Medicine

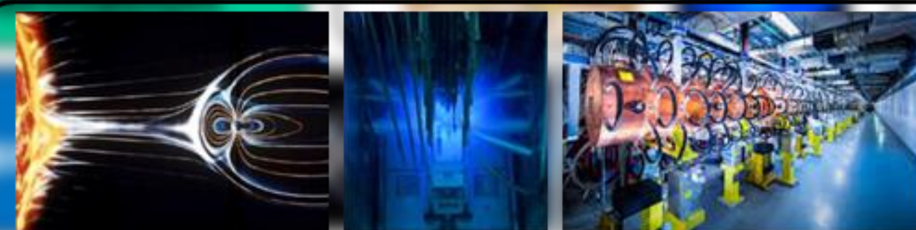


Ion Beam Modification in Semiconductors

Ion implantation for semiconductor processing



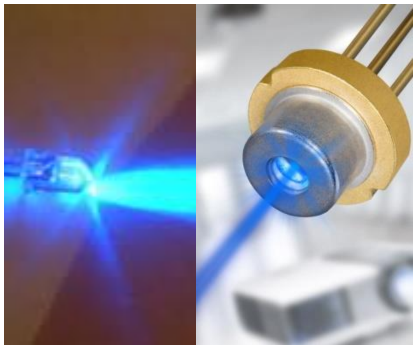
Radiation Environments

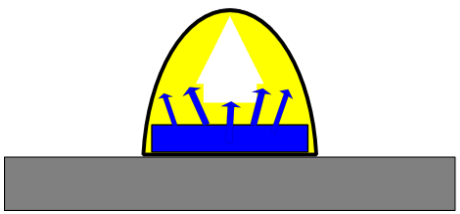


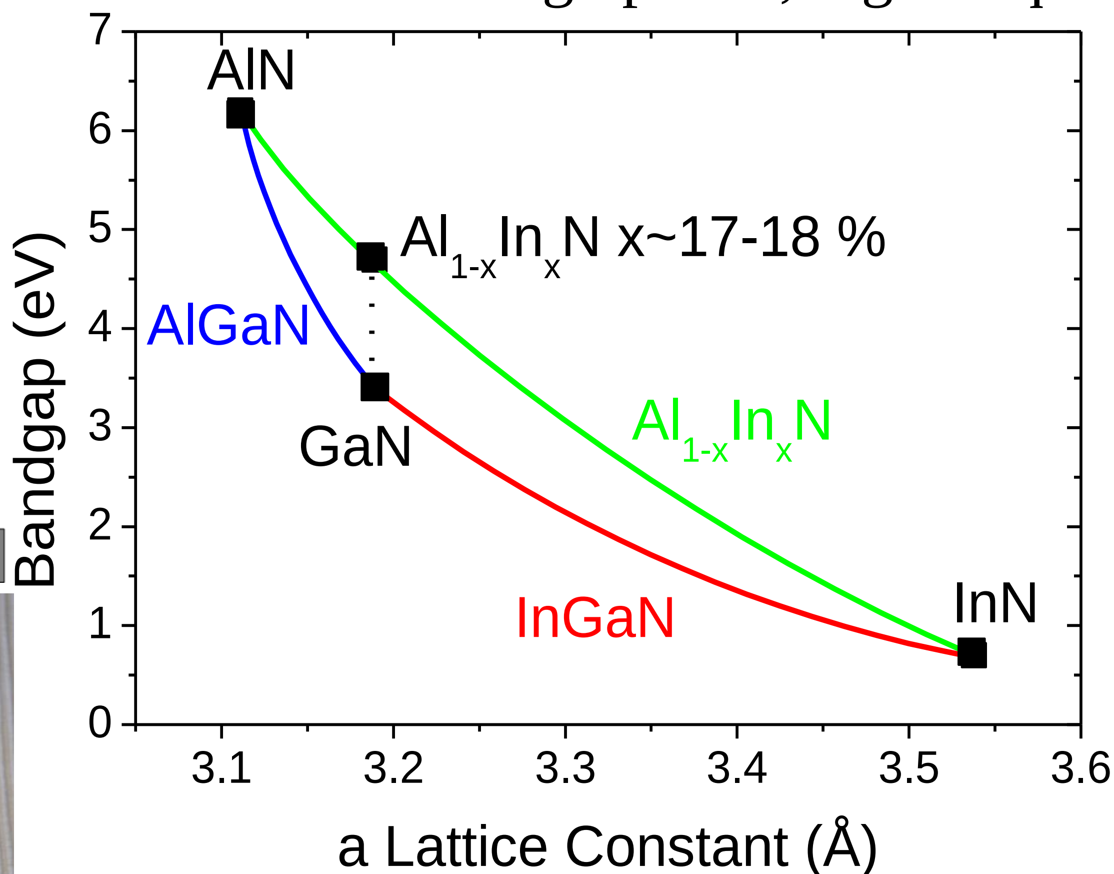
Group III Nitrides

InGaN:
LEDs, LASERS

AlGaN/AlInN: UV emitters/detectors, High power, high frequency electronics





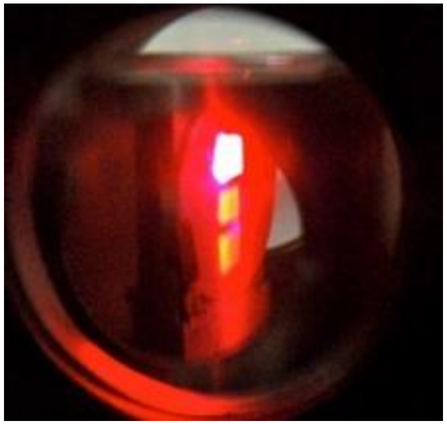


Ion implantation in GaN

- Applications of ion implantation for GaN device processing are still in their infancy.

- Promising recent advances for:

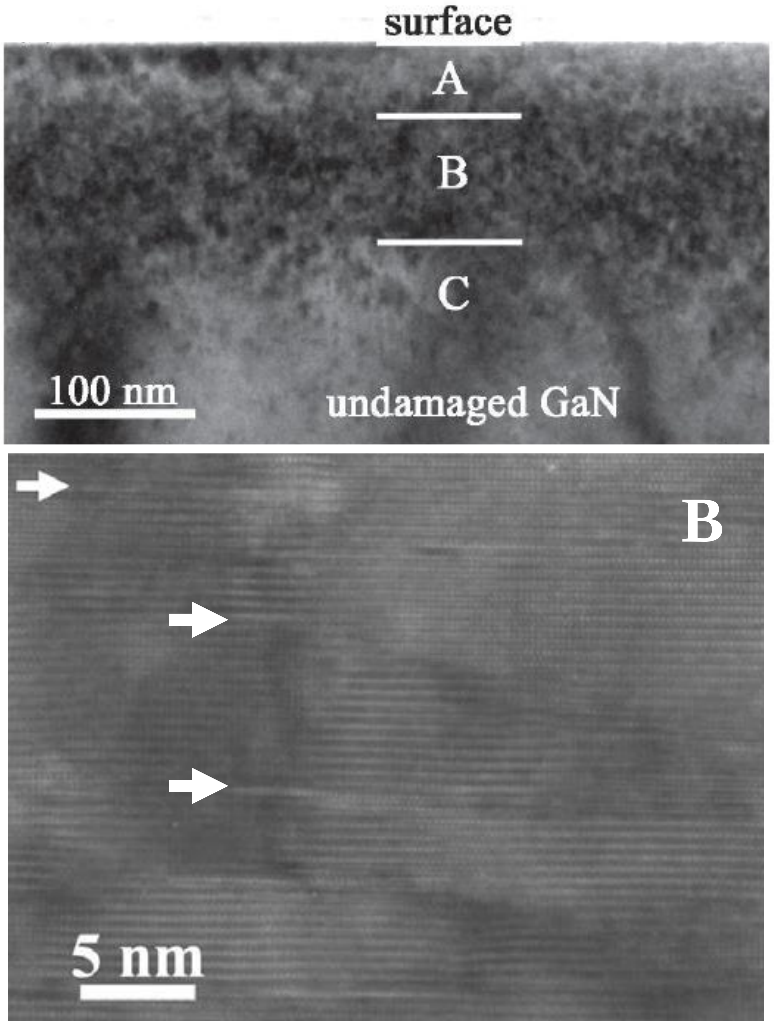
  - Current and light apertures in vertical devices
  - Implant isolation
  - Si/Mg-doping
  - **Eu-doping**



⇒ Successful optical/electrical activation relies on understanding and minimising implantation damage formation

Implantation damage in GaN

5×10^{14} Eu/cm^2 300 keV Eu



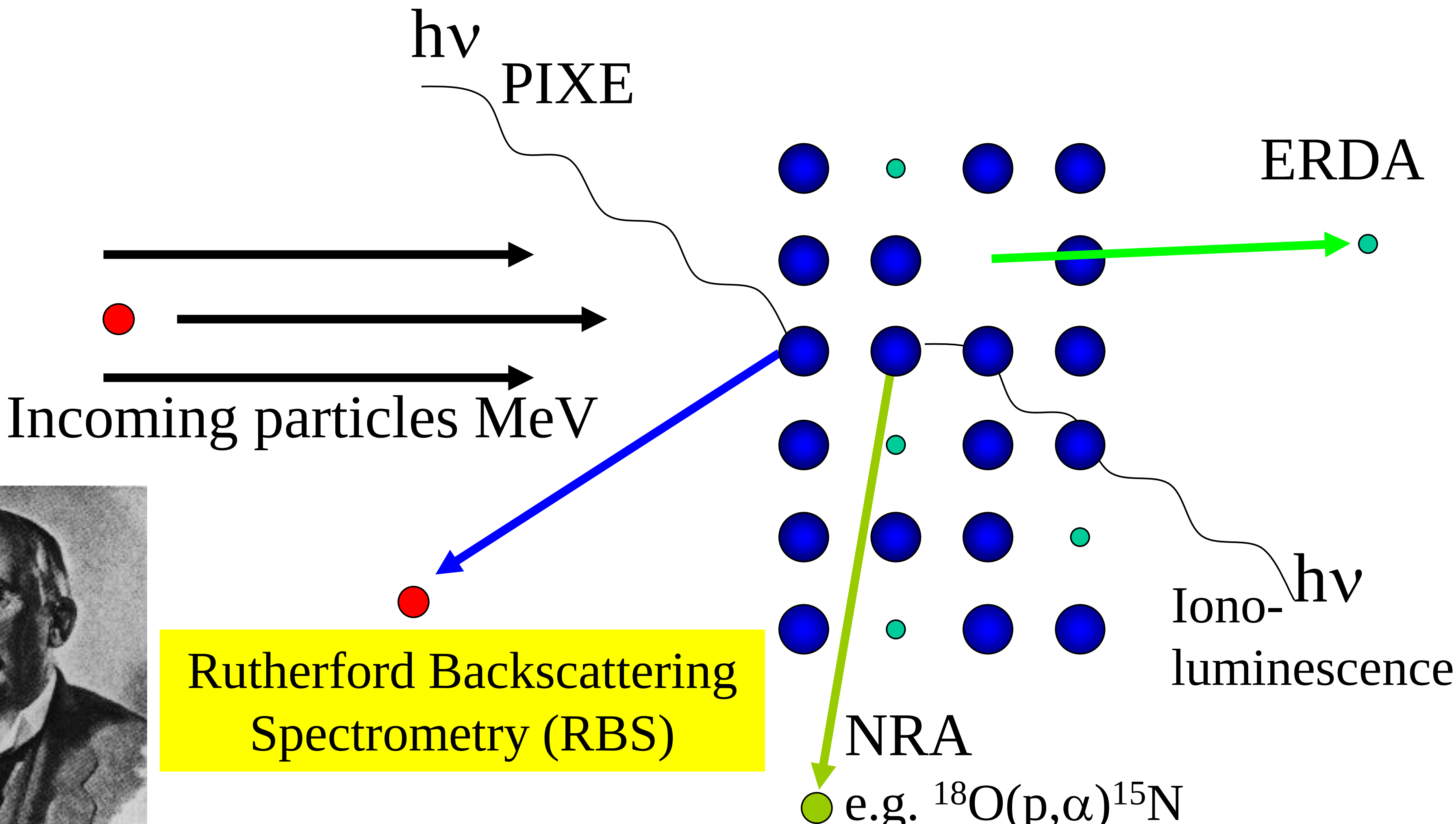
Complex damage accumulation processes:

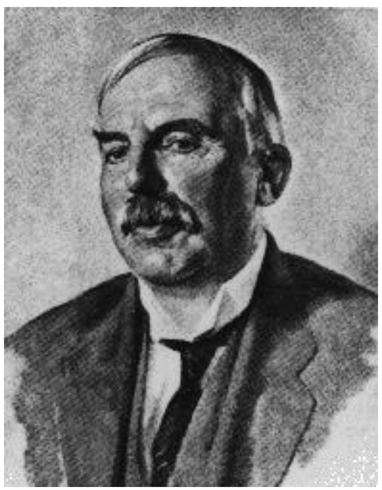
- A: nanocrystalline surface layer
- B: network of extended defects (stacking faults)
- C: large defect cluster

⇒ Important to study and quantify defect concentrations

Ruterana, Lacroix, Lorenz et al.
EPL 96 (2011) 46002; JAP 109 (2011) 013506

Ion Beam Analysis

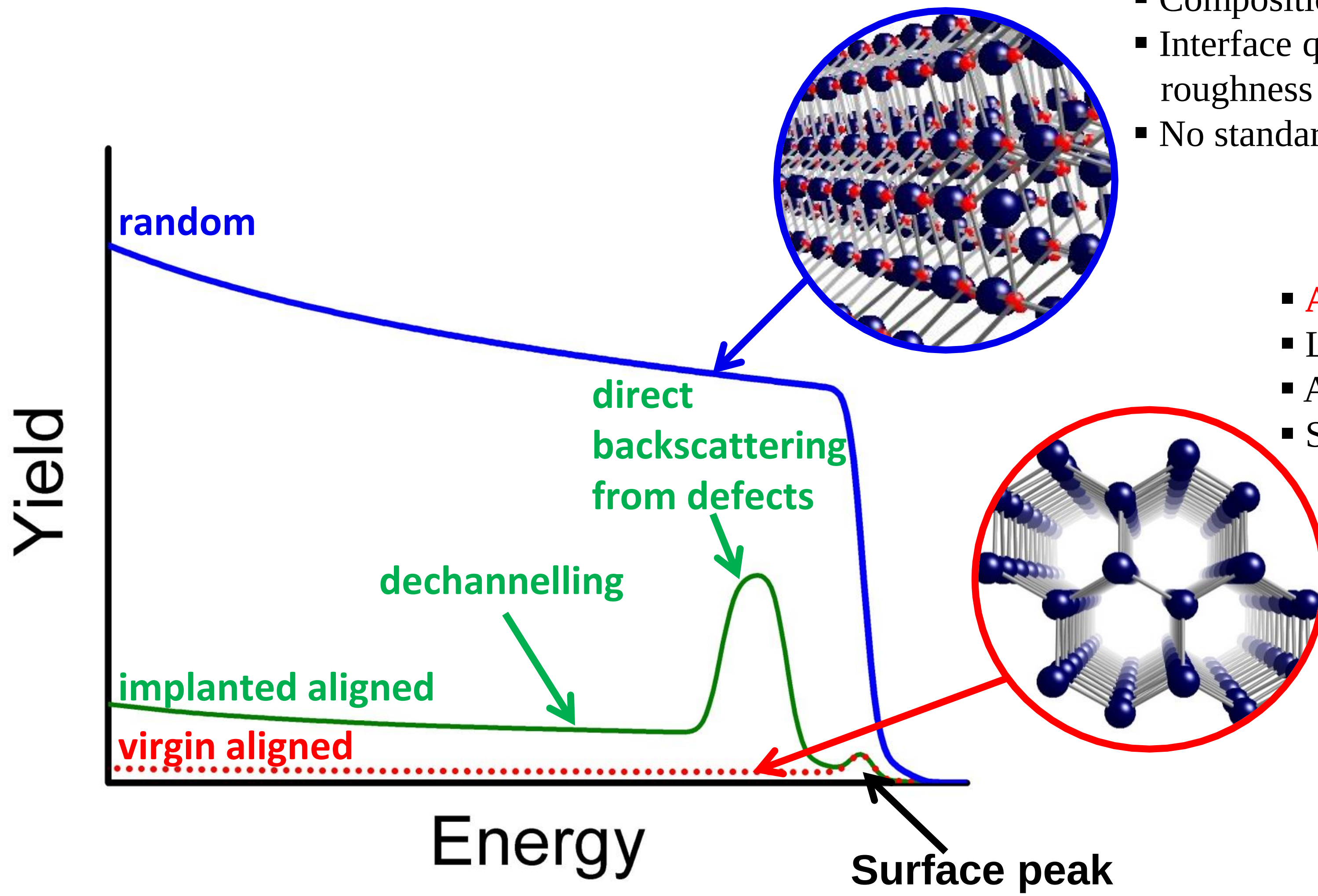




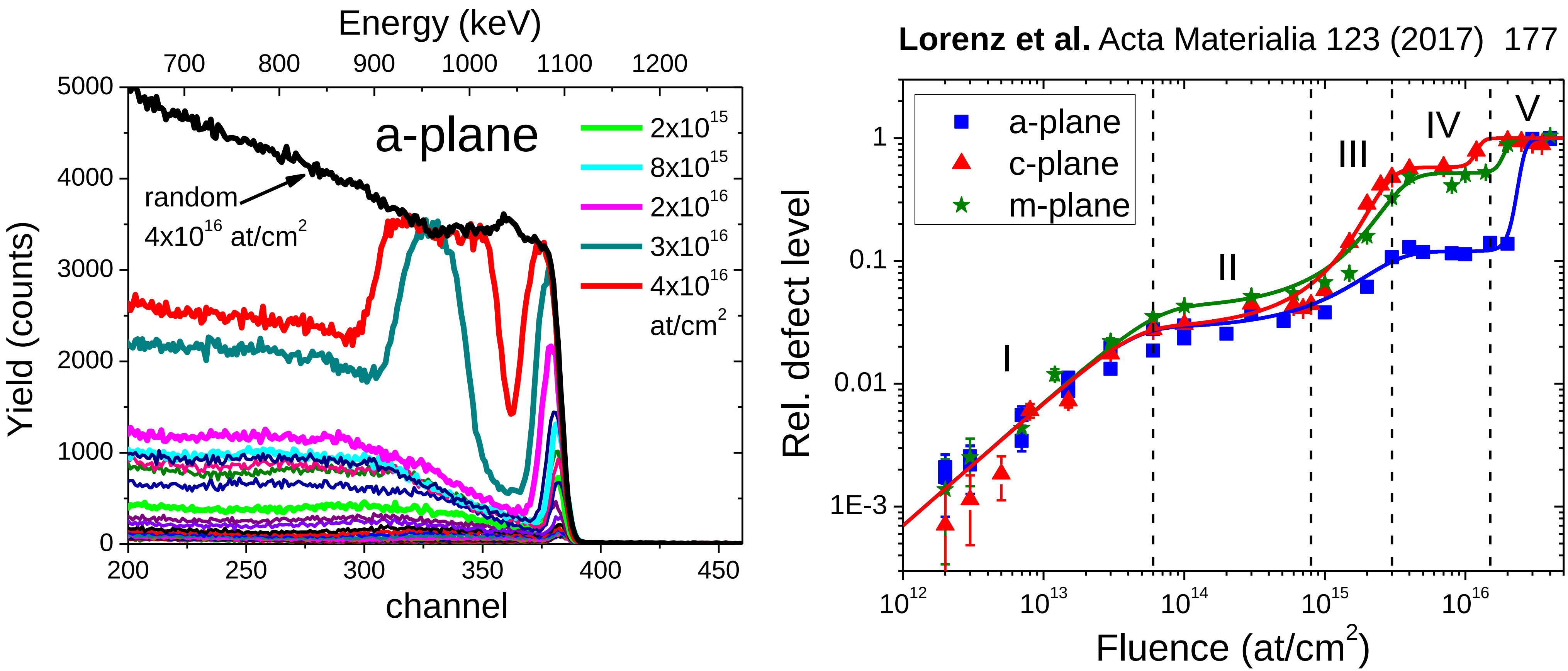
Rutherford Backscattering /Channelling

- **Random: Elemental depth profile**
- Compositional quantification
- Interface quality and surface roughness
- No standards, non-destructive

- **Aligned: Crystal quality**
- Lattice defect profiles
- Amorphous layers
- Strain in epitaxial films



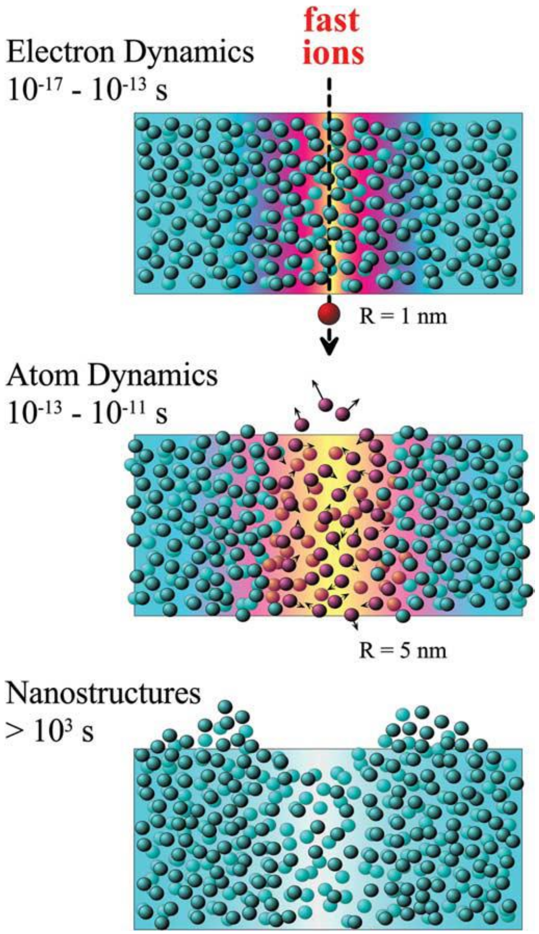
Implantation damage accumulation

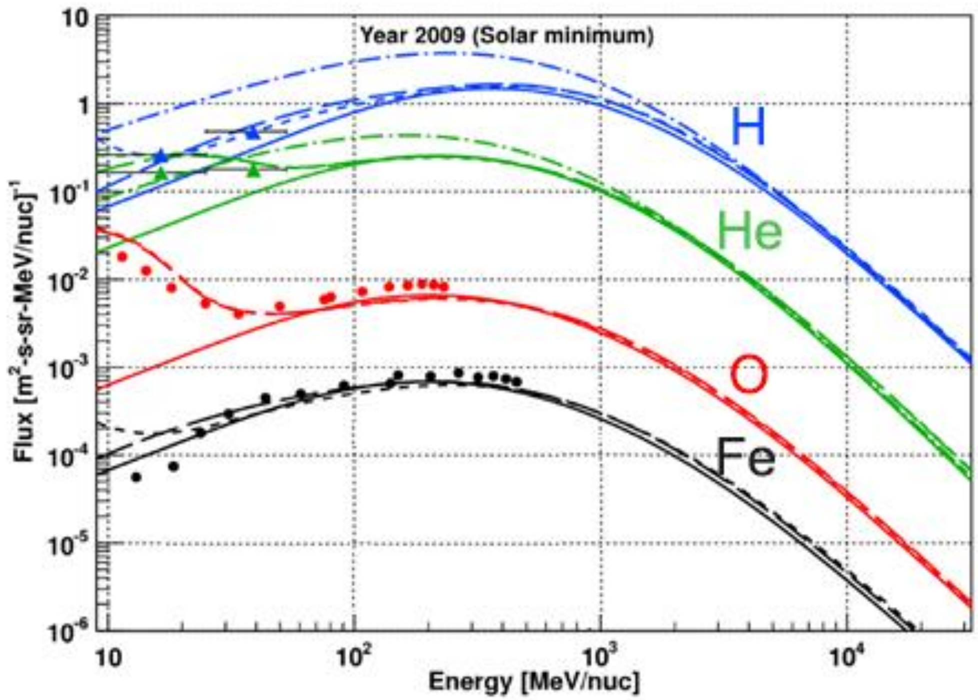


- Sigmoidal damage build-up: strong dynamic annealing
- High amorphisation thresholds
- But complex defect morphologies and accumulation

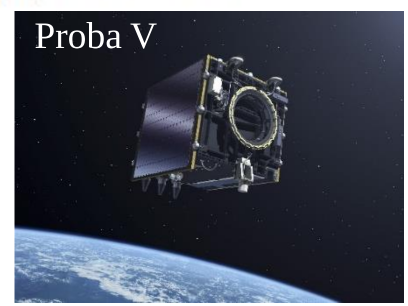
GaN for Space Applications?

Aumayr et al. J. Phys.: Cond. Mat. 23 (2011) 393001





Mrigakshi et al., 2012, Journal of Geophysical Research

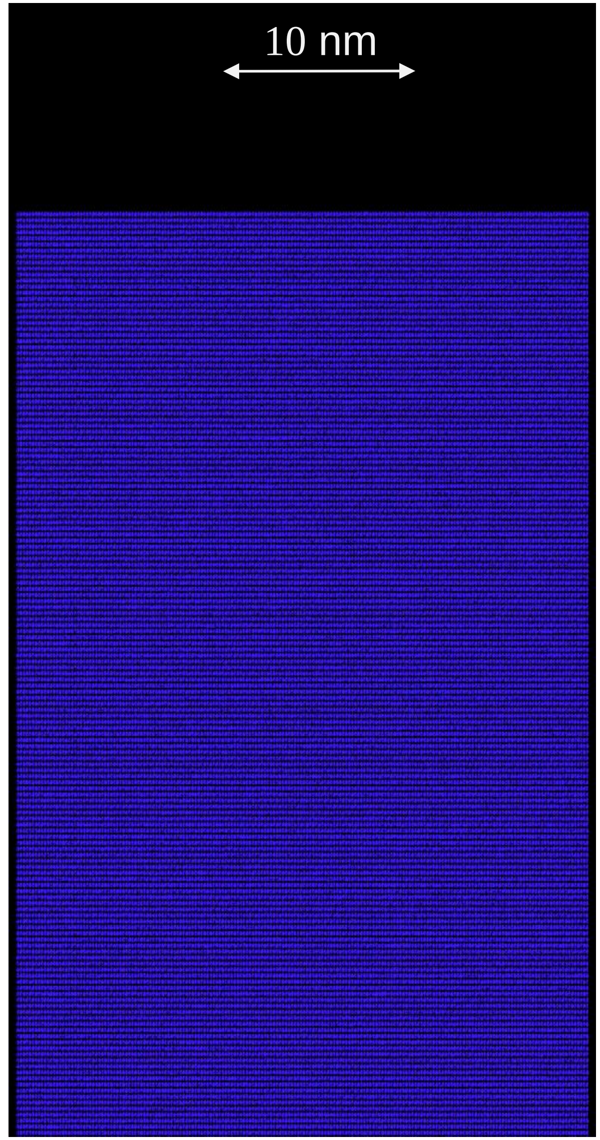


- **HZE or swift heavy ions cause mainly electronic interaction.**
- **The material melts along the track.**
- **Permanent damage can be induced.**

Irradiation with swift heavy ions

Surface: 185 MeV Au

- Solid-Liquid phase transition
- Temperature - Pressure

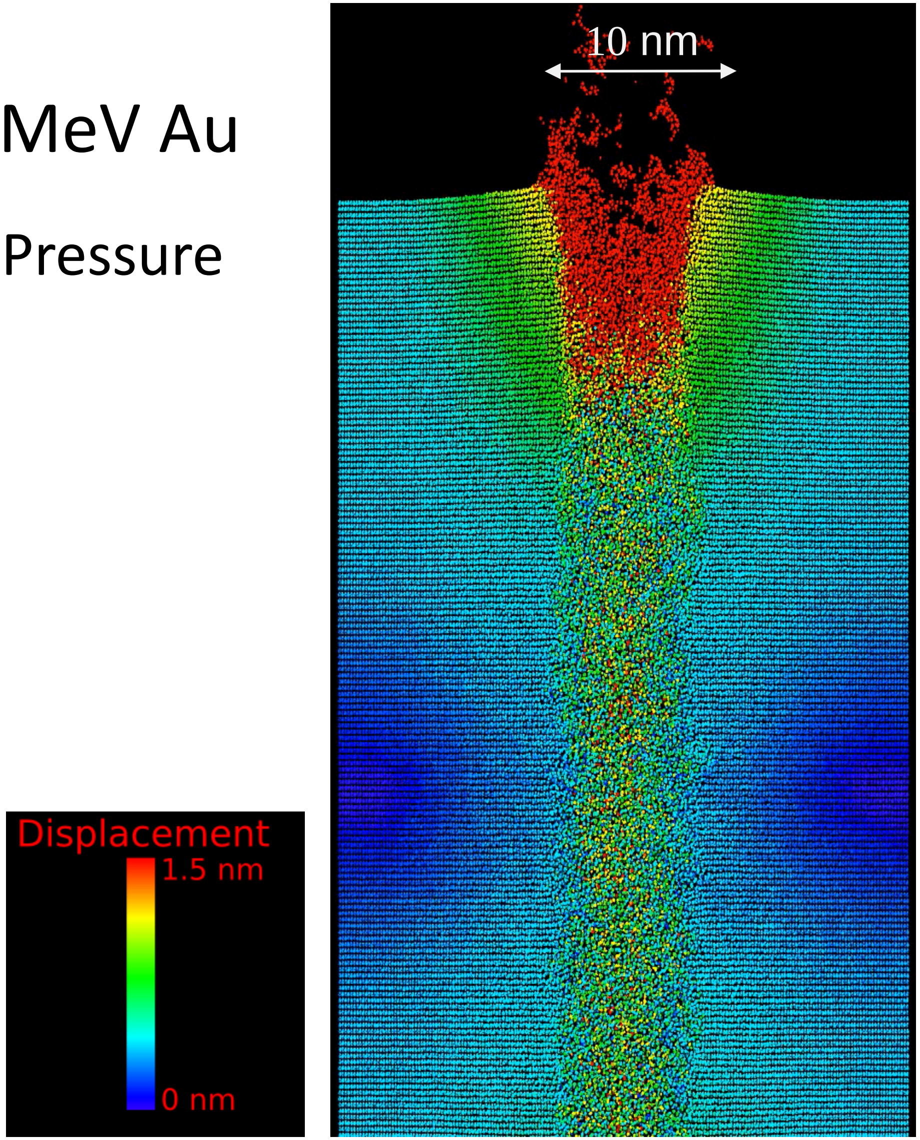


Sequeira, Lorenz et al.
Communications Physics
4 (2021) 51

Irradiation with swift heavy ions

Surface: 185 MeV Au

- Temperature - Pressure
- Sputtering

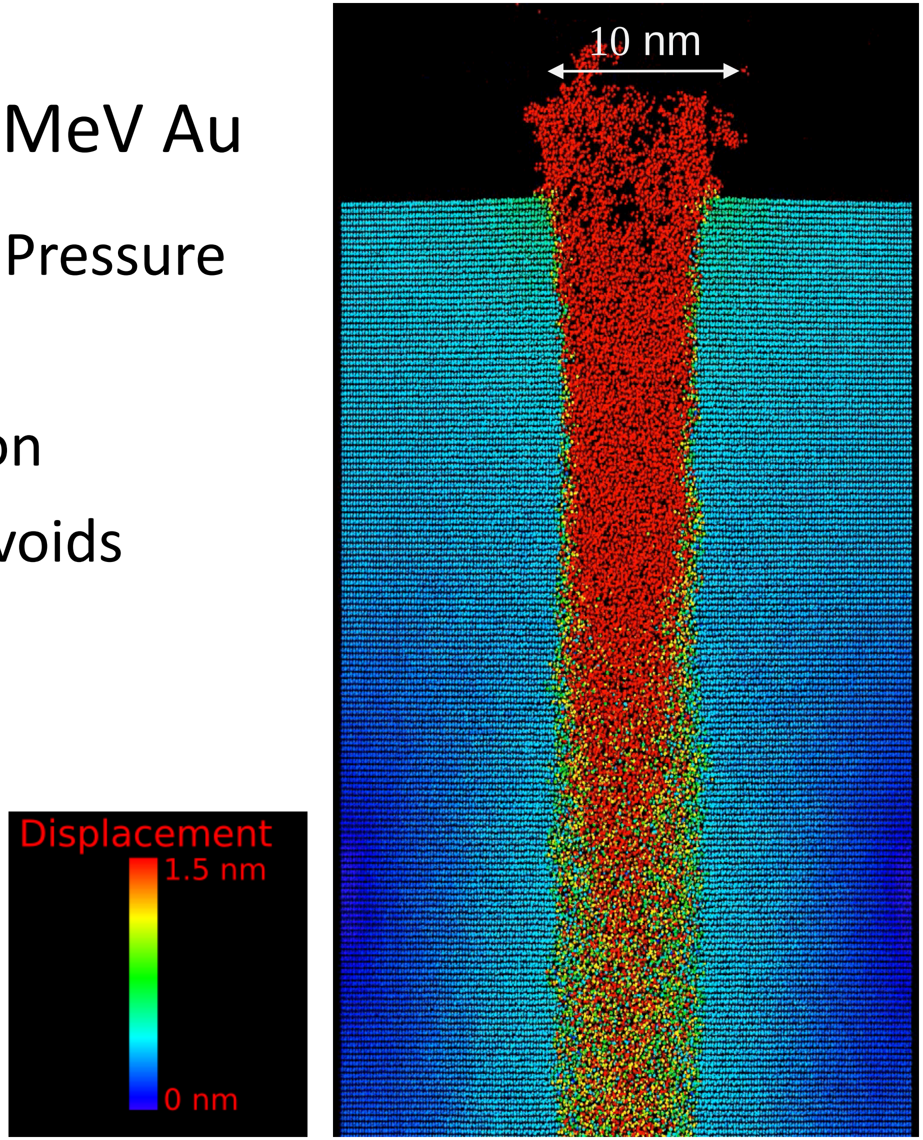


Sequeira, Lorenz et al.
Communications Physics
4 (2021) 51

Irradiation with swift heavy ions

Surface: 185 MeV Au

- Temperature - Pressure
- Sputtering
- Recrystallisation
- Nanohills and voids



Sequeira, Lorenz et al.
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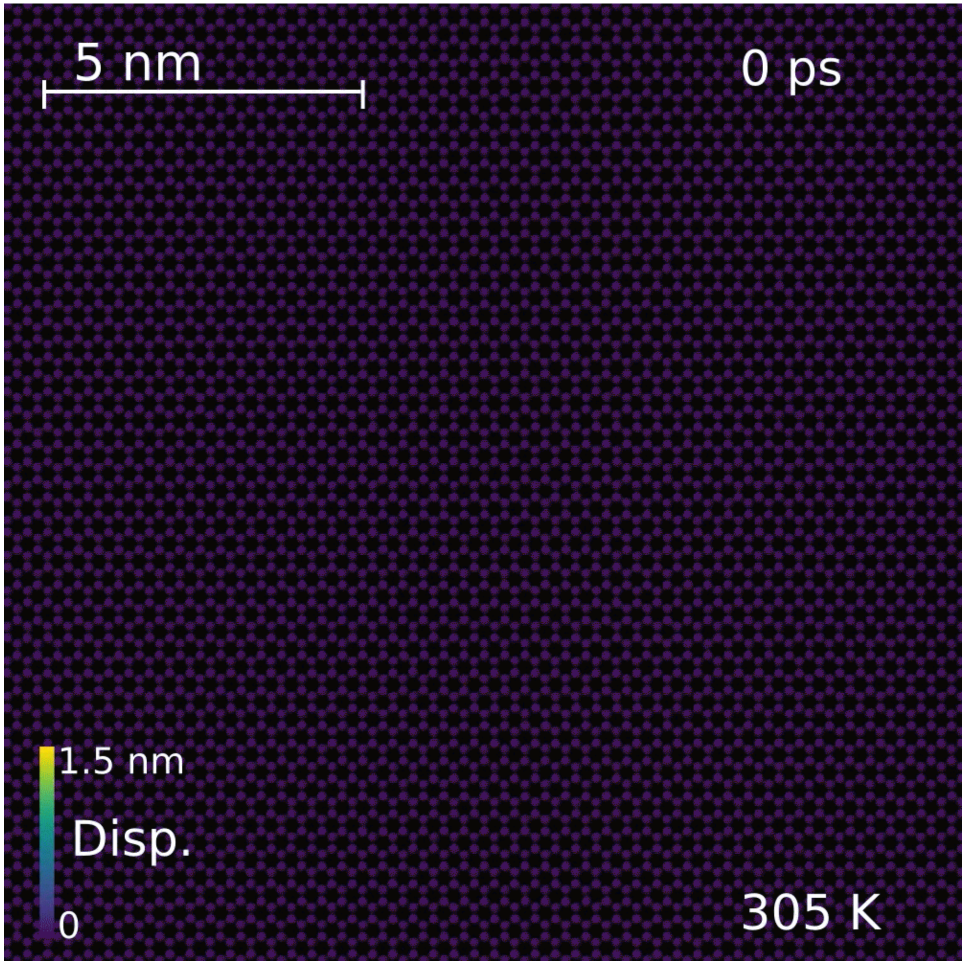
Irradiation with swift heavy ions

Bulk: 185 MeV Au

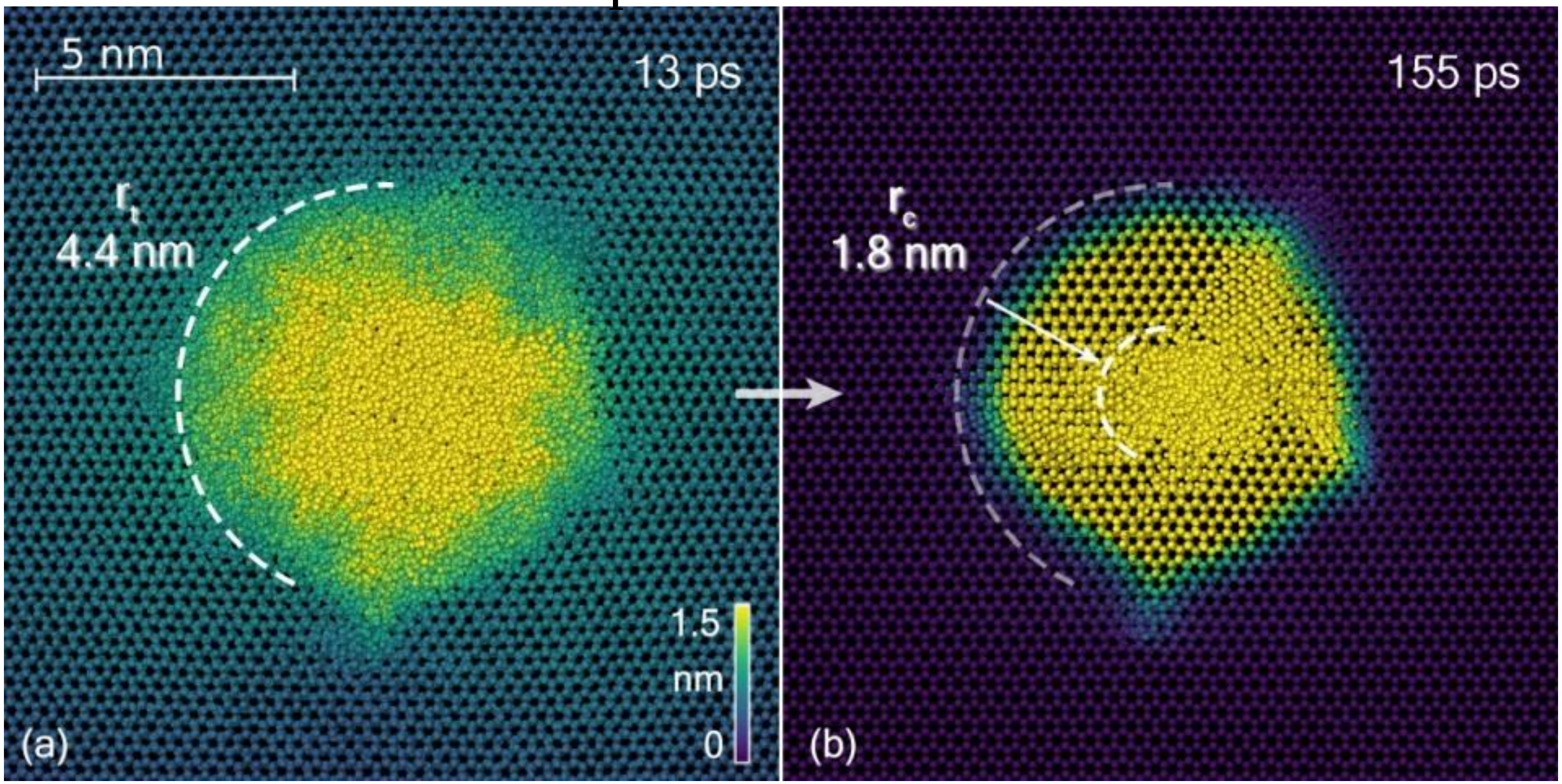


- Efficient recrystallisation due to high pressure high temperature conditions

Sequeira, Lorenz et al.
Communications Physics 4 (2021) 51

Irradiation with swift heavy ions

185 MeV Au ion impact

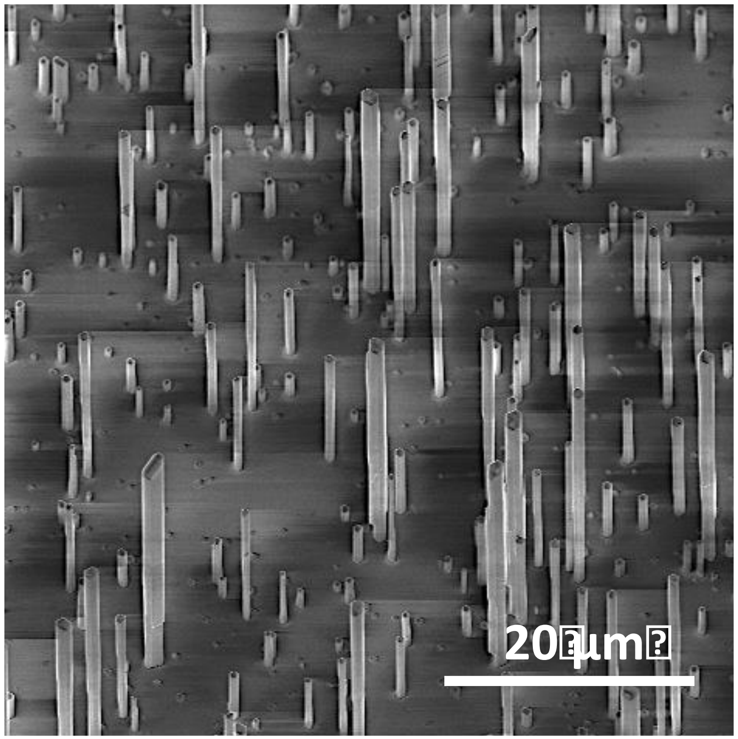


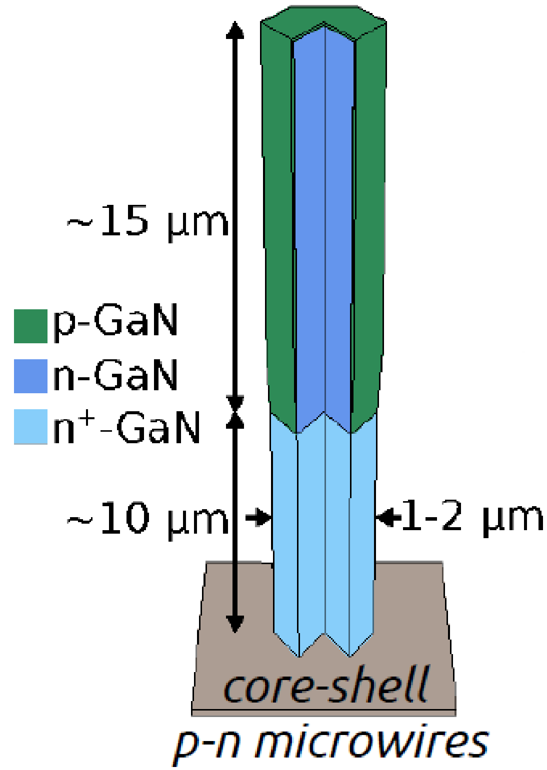
- The material melts along the track but very efficient recrystallisation occurs.
- High radiation resistance

Sequeira, Lorenz et al. Communications Physics 4 (2021) 51

GaN microwire particle sensors

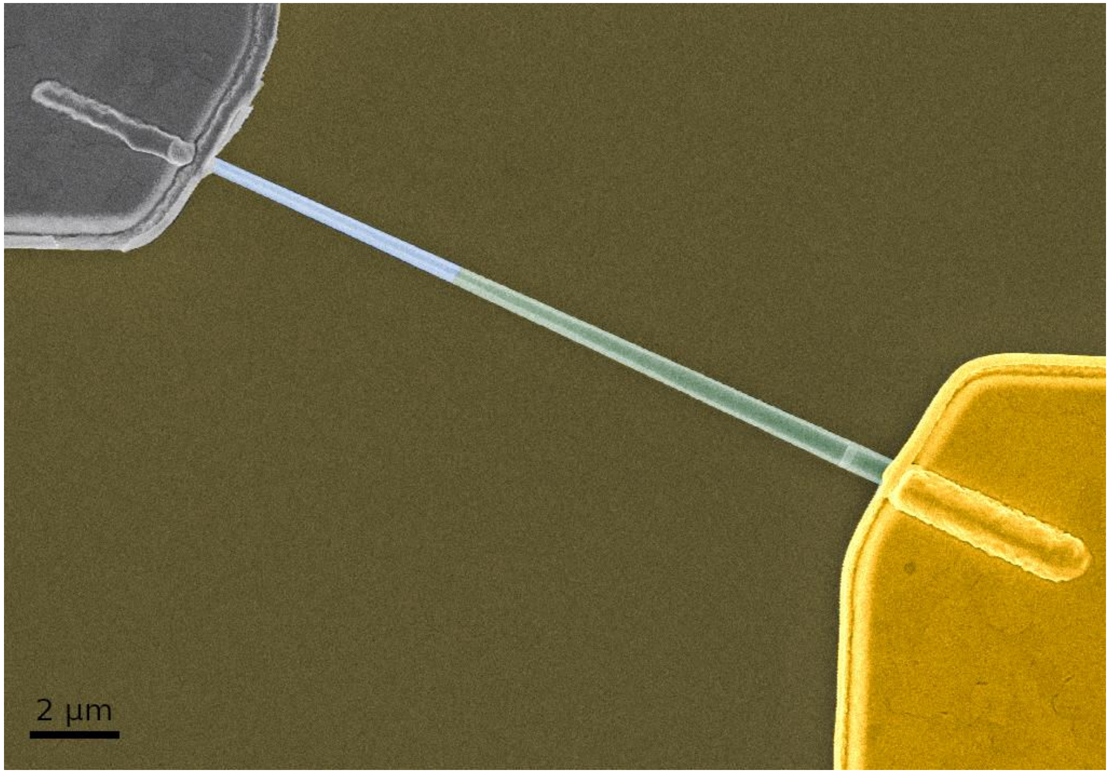
Verheij, Lorenz et al. APL 118 (2021) 193501
J. Phys. D 51 (2018) 175105





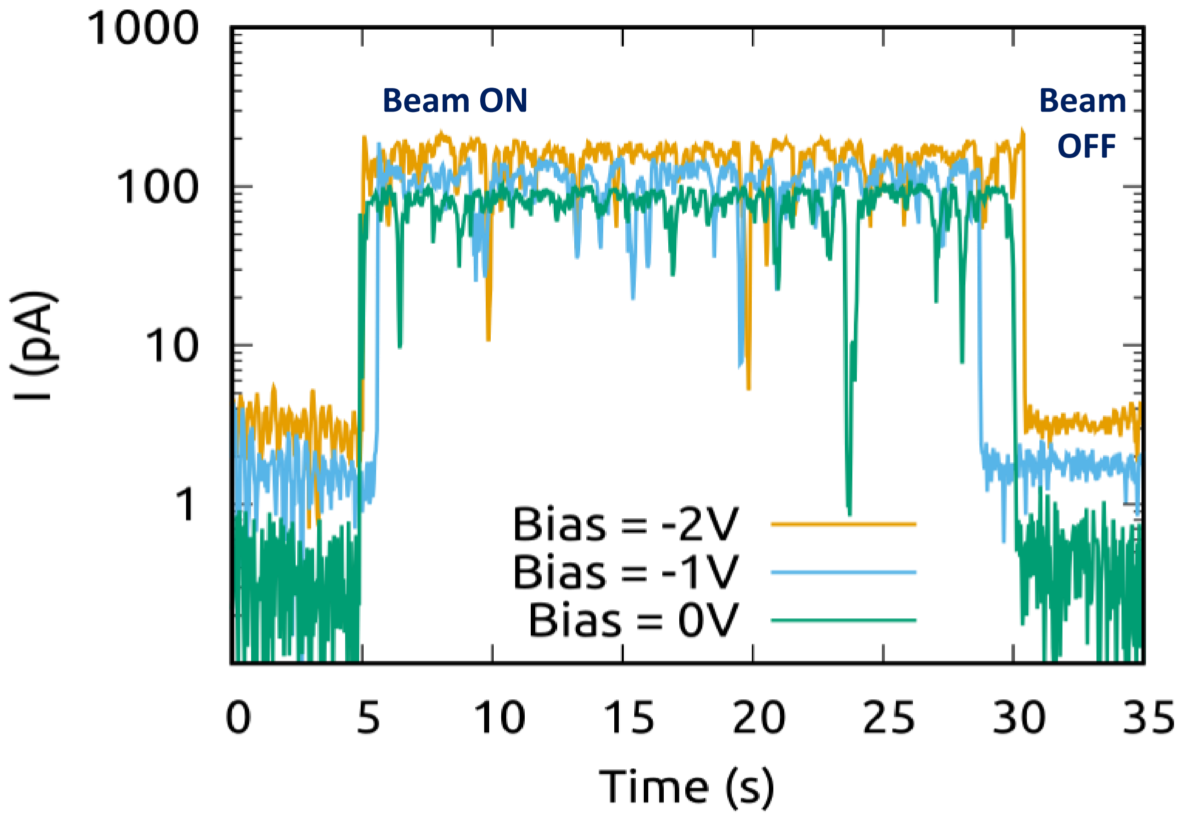
- GaN microwires show superior crystal quality than thin films, are small and light-weight and can be incorporated into flexible substrates.

GaN microwire particle sensors



- Fabrication of single wire devices with electrical contacts at their extremities using photolithography

GaN microwire particle sensors



- **pn-junction microwire sensors show fast response and good radiation hardness**
- **Potential for self-powered devices**

D. Verheij, Lorenz et al. APL 118 (2021) 193501

Summary

- **Implantation damage build-up in GaN is very complex and needs to be better understood to implement ion implantation on industrial scale device processing.**

- **GaN is a very radiation resistant material which makes it interesting for applications in space and nuclear facilities.**

- **GaN p-n junction microwires yield fast proton detection (even without applied bias – self-powering) and they show high radiation resistance during intense proton beam irradiation.**

Collaborators and Funding

IST M. C. Sequeira, D. Verheij, M. Peres, S. Magalhães, P. Jozwik, L.C. Alves, E. Alves, S. Cardoso

CEA Grenoble, France (GaN microwire growth) C. Durand, J. Eymery

University of Ulm, Germany (GaN film growth) F. Scholz

University of Jena, Germany (in-situ implantation-RBS) E. Wendler

CIMAP, France (TEM) M-P. Chauvat, P. Ruterana

University of Canberra, Australia (SHI irradiations) P. Mota-Santiago, P. Kluth

University of Helsinki, Finland (MD simulations) F. Djurabekova, K. Nordlund

Funding by FCT Portugal is acknowledged

Thank You!