IRRADIATION EFFECTS ON MICRO-STRUCTURAL EVOLUTION (PART 2): EFFECTS ON DEFORMATION

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Introduction

- An important objective of SOTERIA Task 4.1 and D4.1 is to gain a better understanding of irradiation effects, both proton- and neutron-irradiation, and relate that to the efforts to make predictive models of IASCC.
- Research focused on IASCC is classically corrosion-weighted → subset of IGSCC
- Some researchers have *also* reported intergranular fracture in SSRT experiments in pure argon
- This presentation focuses on **localized deformation**, in order to clarify the respective roles of deformation products such as epsilon martensite and twins, to ultimately better understand the purely mechanical component of IASCC.

Introduction

- Neutron irradiation of metallic materials produces small defect clusters in the matrix, which then serve to harden the material and to make it more prone to localized dislocation glide during plastic deformation
- Particular to irradiated austenitic stainless steels:
  - dislocation channelling
  - stacking fault formation
  - martensite formation
  - deformation twinning

ALL are manifestations of inhomogeneous deformation that can produce band-like features in the deformed microstructure when viewed in TEM.

Introduction

- Difficult to link dislocation channels and the other deformation products → the latter deformation products *also* appear in *non-irradiated* materials.
- Has led to use of terms such as "defect reduced channels", "clear bands" and "linear features" for deformation-induced bands which *may* be a consequence of channel deformation, but which *also* show contrast with the surrounding matrix that could indicate a different crystallographic orientation.
- Contributing to challenge of appropriately identifying deformation features, is fact that materials irradiated to "saturation" of defect structure, exhibit chaotic image contrasts in TEM → reduces visibility of other features in the microstructure that could be exploited in characterizing the bands.

Experimental

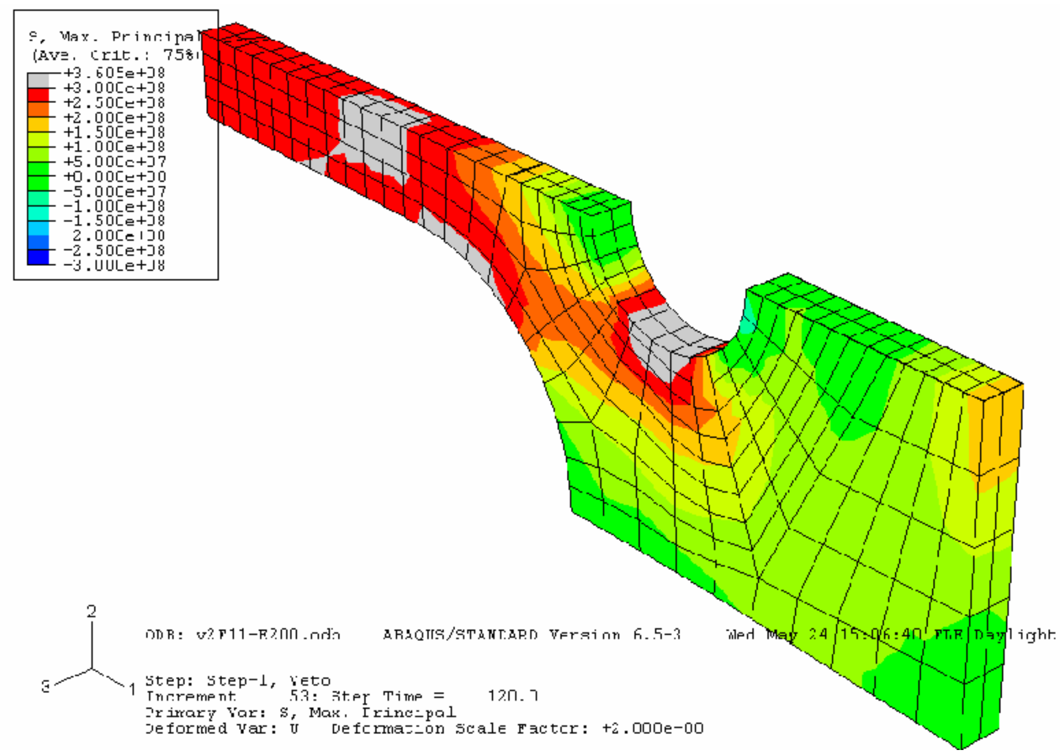
Table 1: Composition of the 304L stainless steel of this study

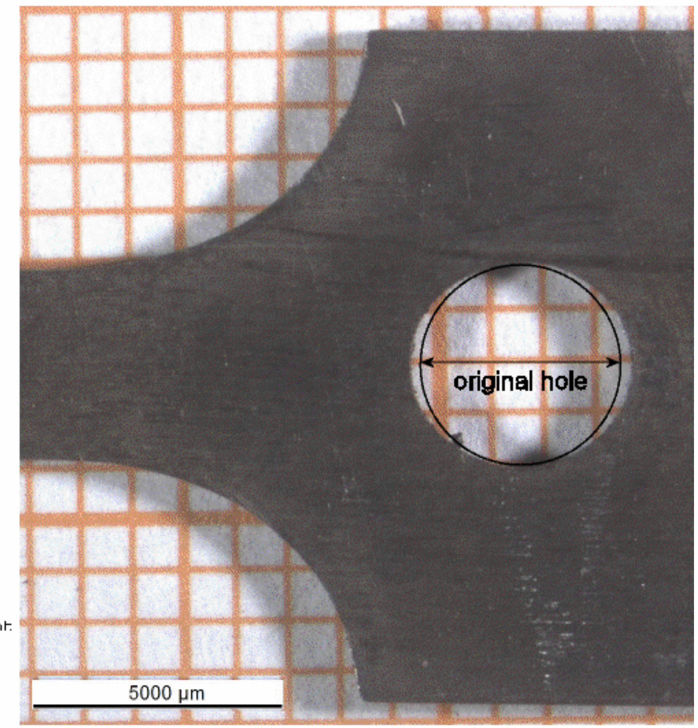
	Fe	Cr	Ni	Mn	Si	C	P	S	Co
304L	bal	18.7	9.9	1.01	0.50	0.012	0.025	0.018	<0.01

Table 1: Irradiated materials of this study

Specimen	Irradiation si2e	Irr. temperature	Fluence, n/cm^2 (E>1MeV)	dpa*
0.11 dpa	JMTR	190°C	0.75 E 20	0.11
0.16 dpa	JMTR	185°C	1.1 E 20	0.16
0.89 dpa	Halden Reactor	290°C	6.2 E 20	0.89

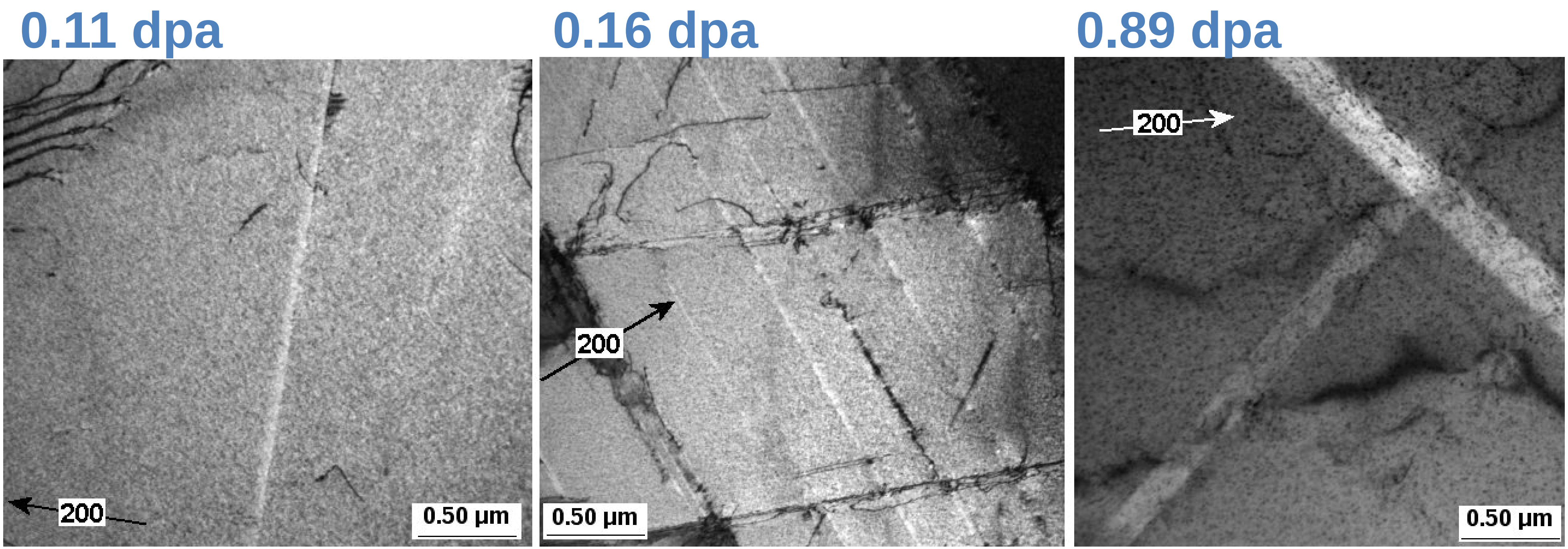
Experimental





- ❑ Peak principle stress distribution in 0.16 dpa tensile bar grip; some stress expected in grip region of SSRT bar during test.
- ❑ Confirmed by observation of some elongation of fixing pin hole following testing.
- ❑ TEM was performed on foils made from this low-strain region adjacent the hole.

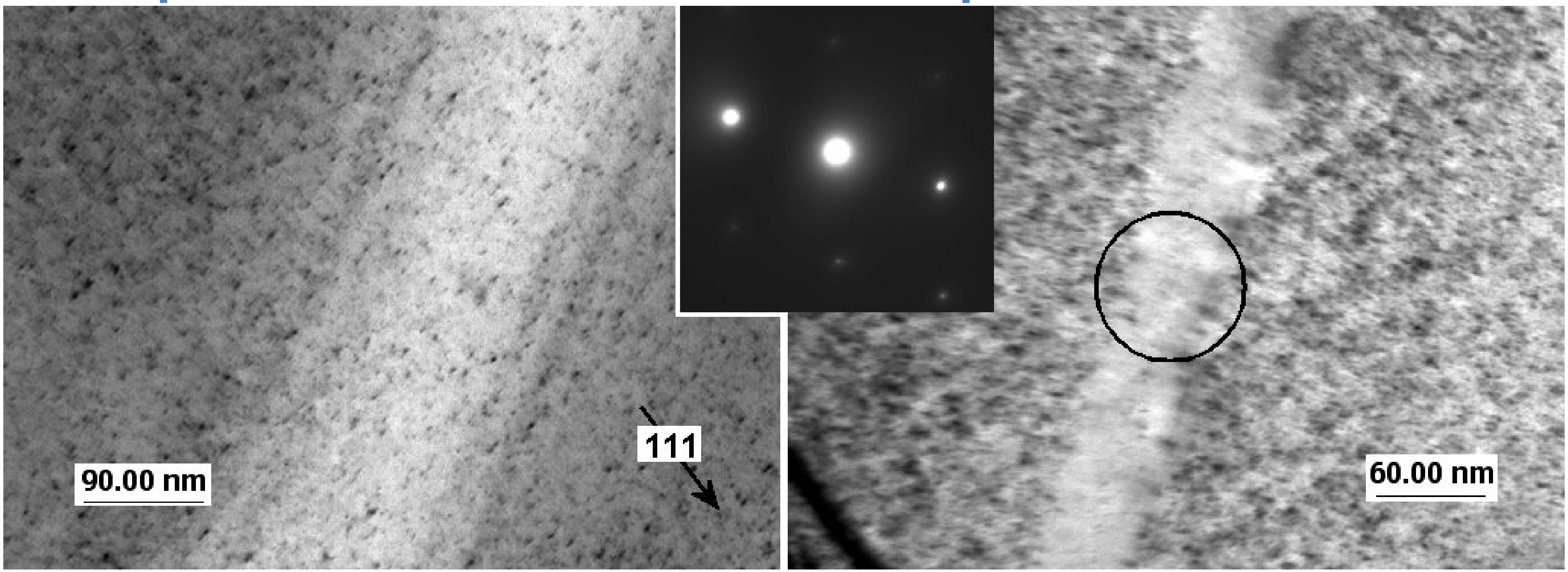
Results



Moderate magnification views of the bands show the “clear” nature of the bands among the speckled contrast of the irradiation defects in matrix.

Results

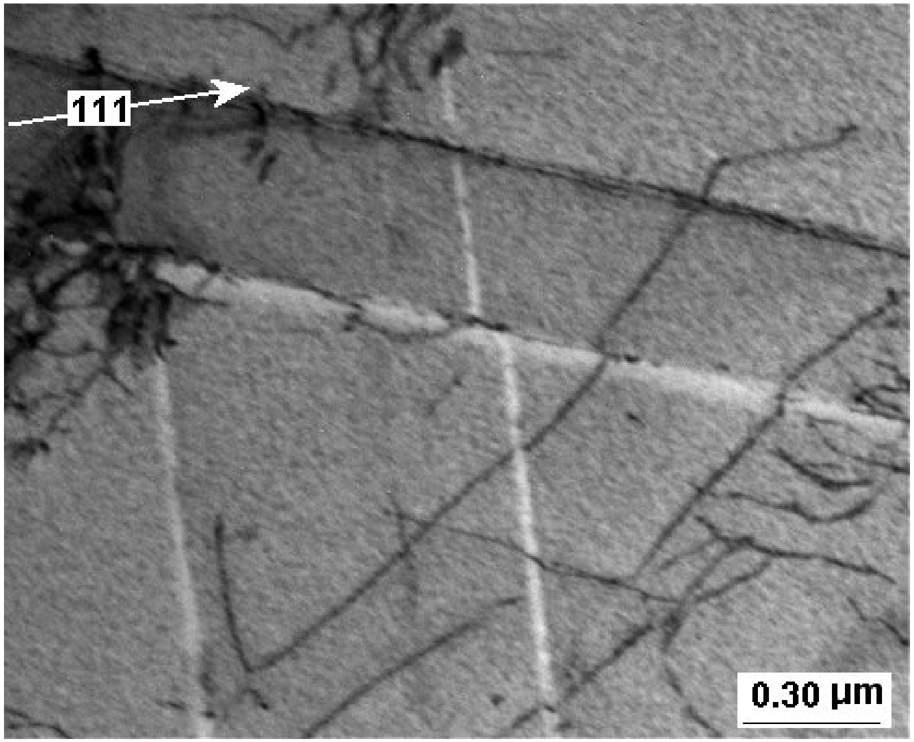
0.11 dpa **0.16 dpa**



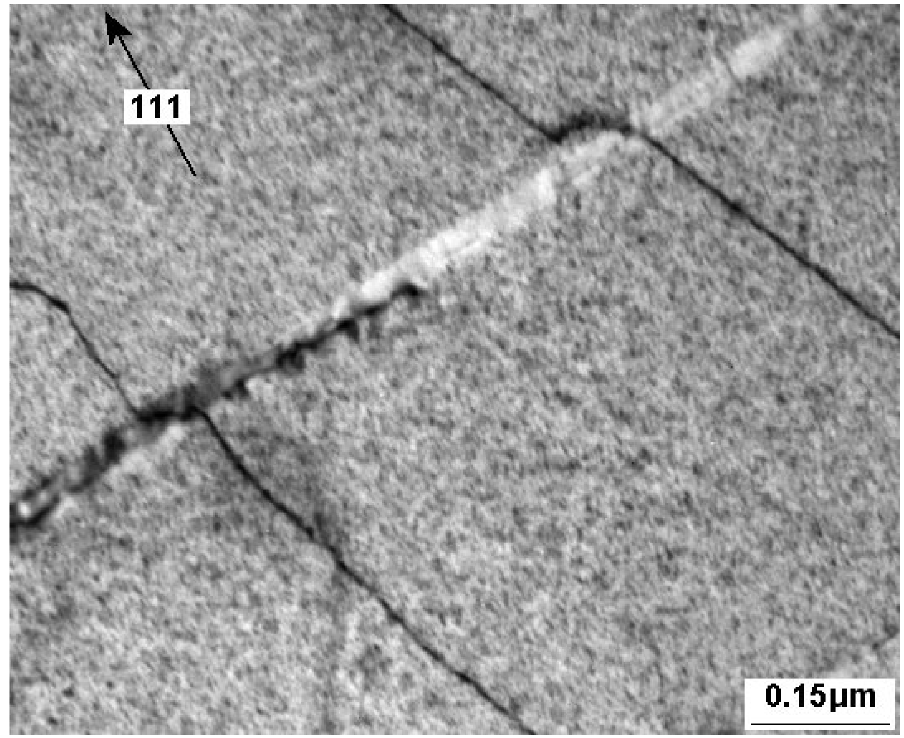
- High magnification view of bands in the materials.
- Inset SAD pattern of circled region shows that there are no extra relections in the diffraction pattern → same lattice structure in band as in matrix.

Results

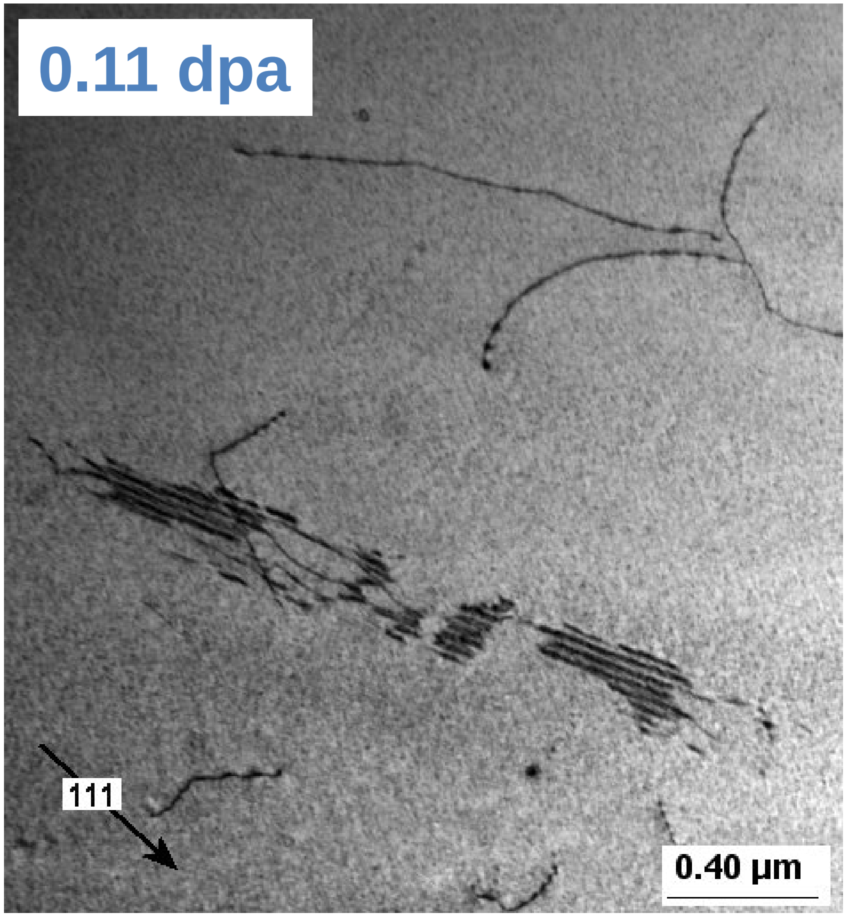
0.16 dpa

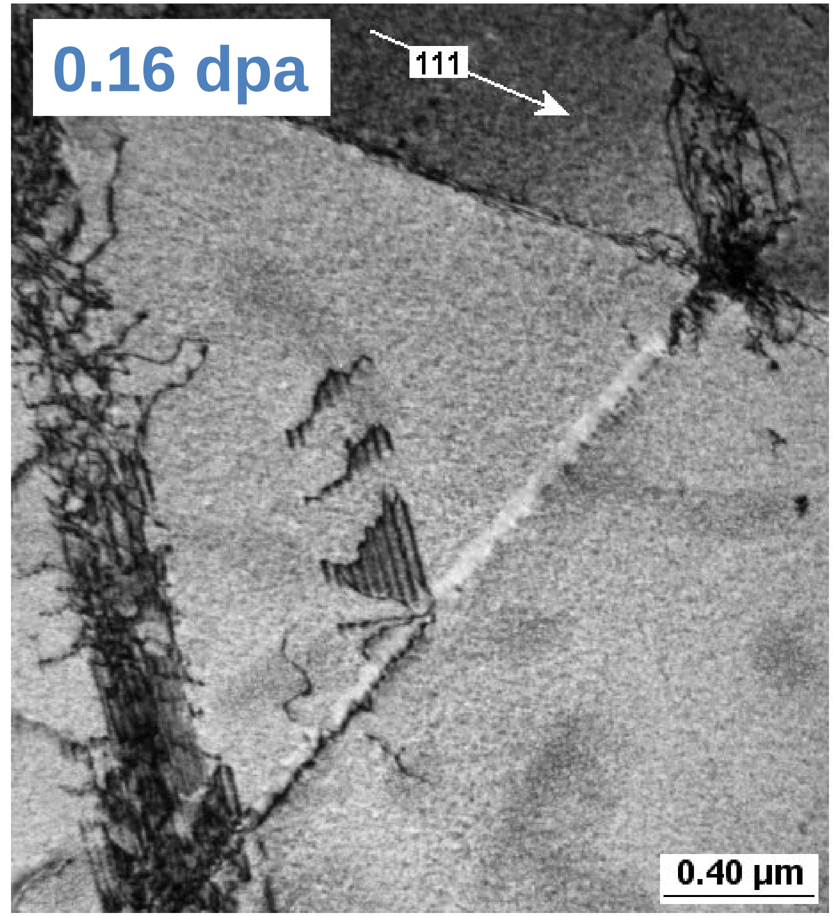


0.16 dpa

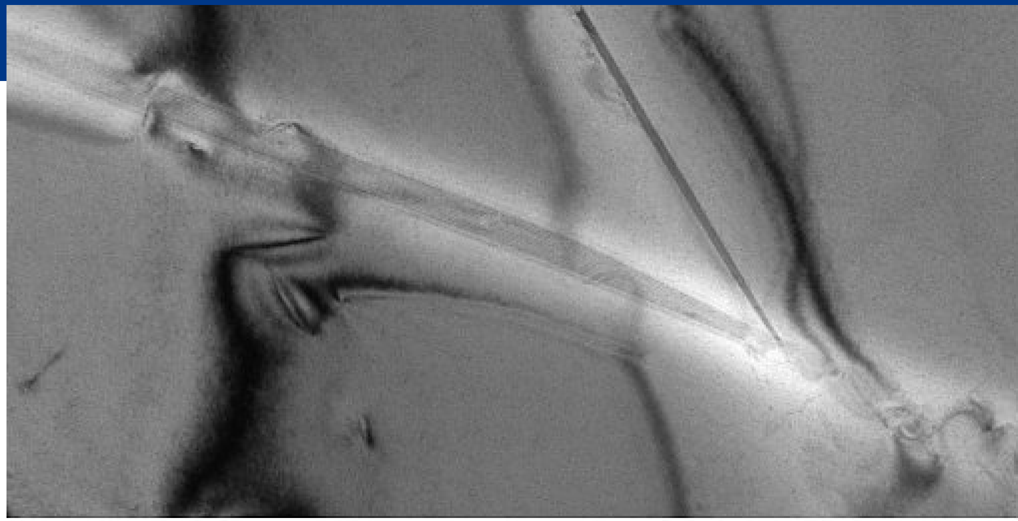


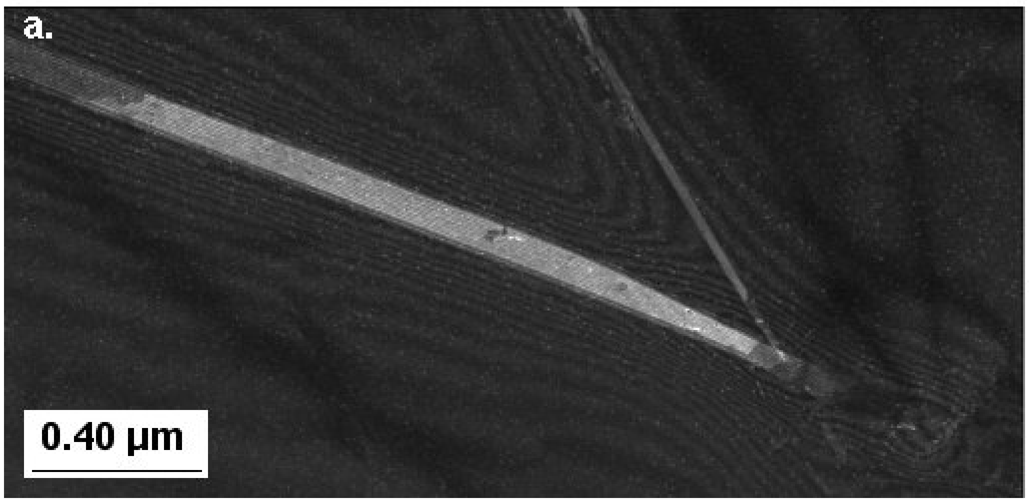
- Pre-existing dislocations crossed by bands were shifted.
- Intersections between bands also showed such evidence of local strain.



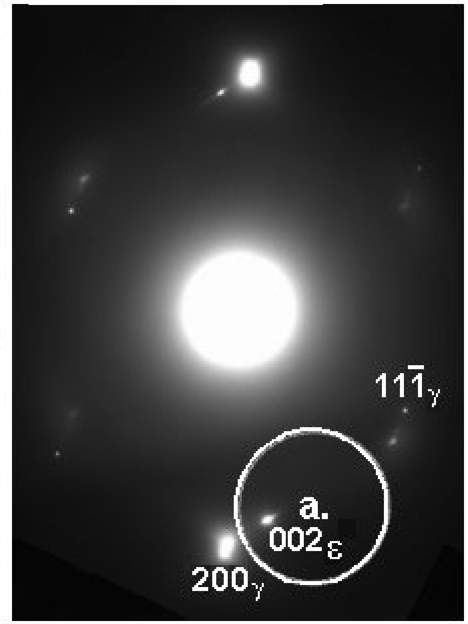


All of the specimens showed stacking faults to some degree as well, generally restricted to the channels.



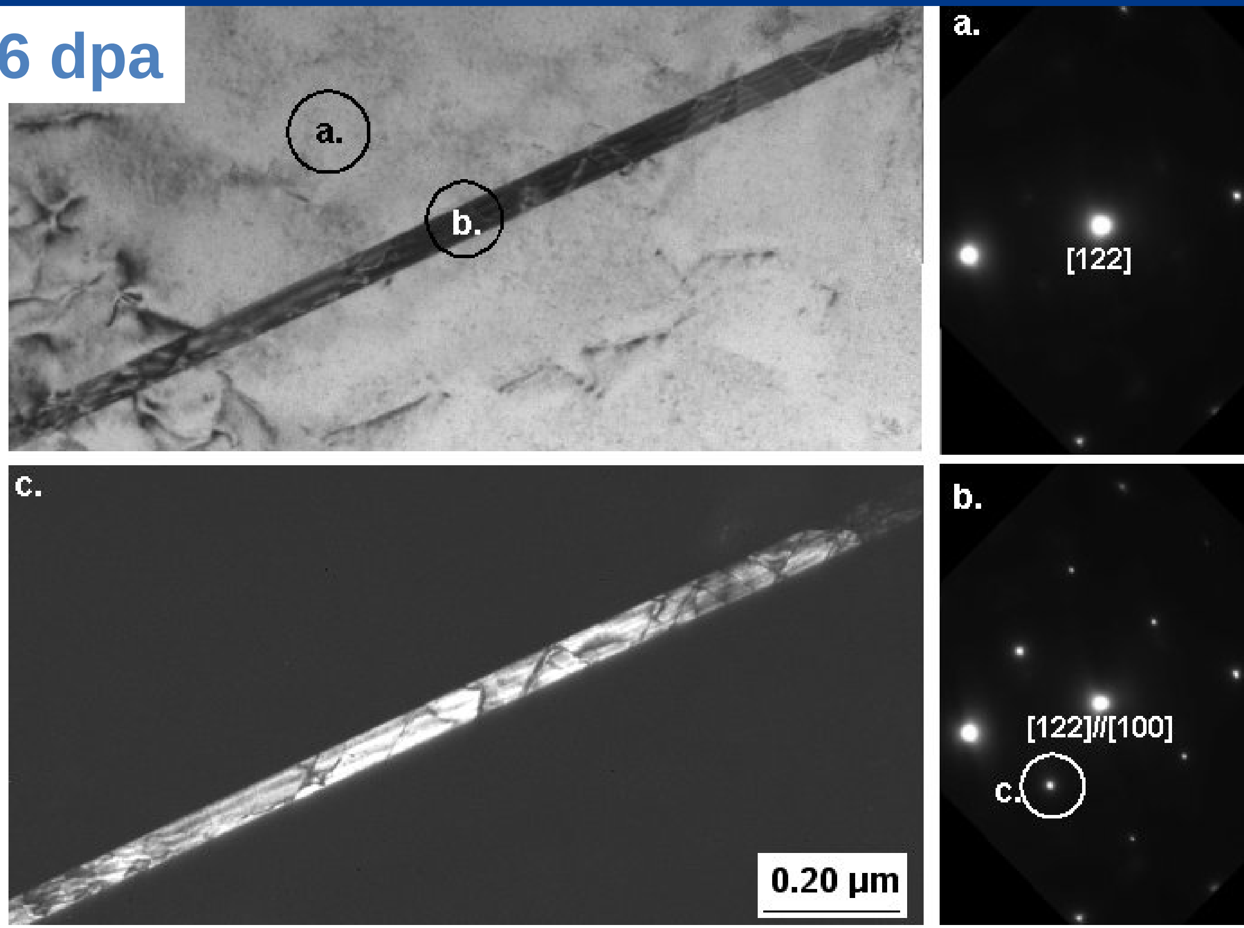


0.11 dpa

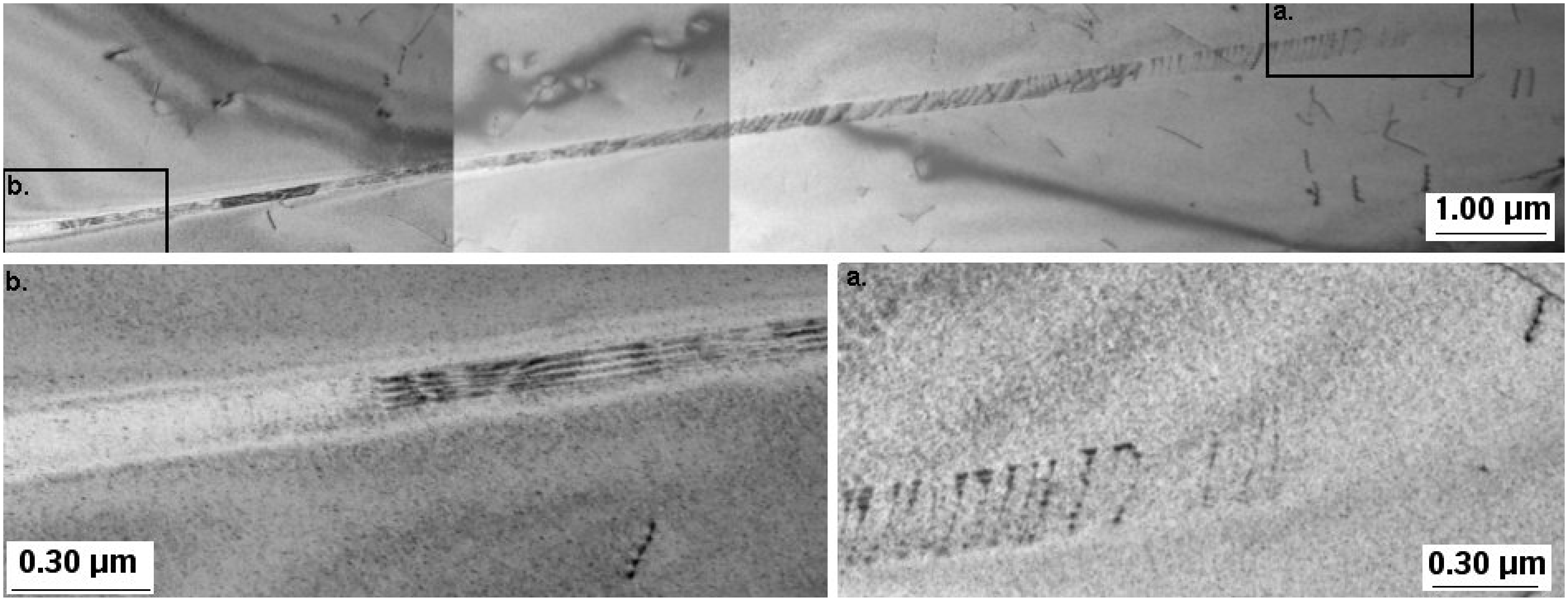


Upon accumulation of several stacking faults, satellite spots have distinct d-spacing which correspond most closely to that of HCP-epsilon martensite.

0.16 dpa

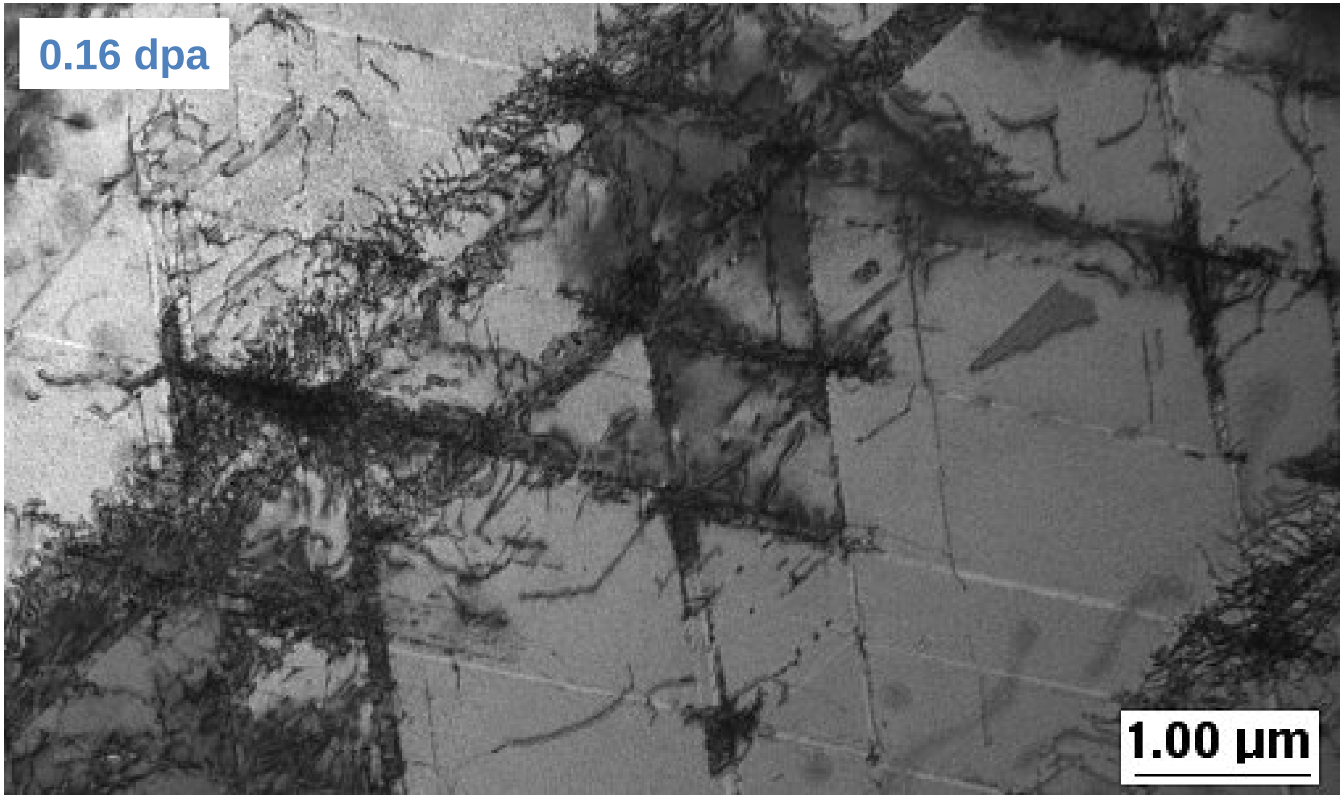


Further accumulation of overlapping stacking faults in a band introduced strong reflections corresponding to austenite phase of different orientation, indicating the formation of a twin.

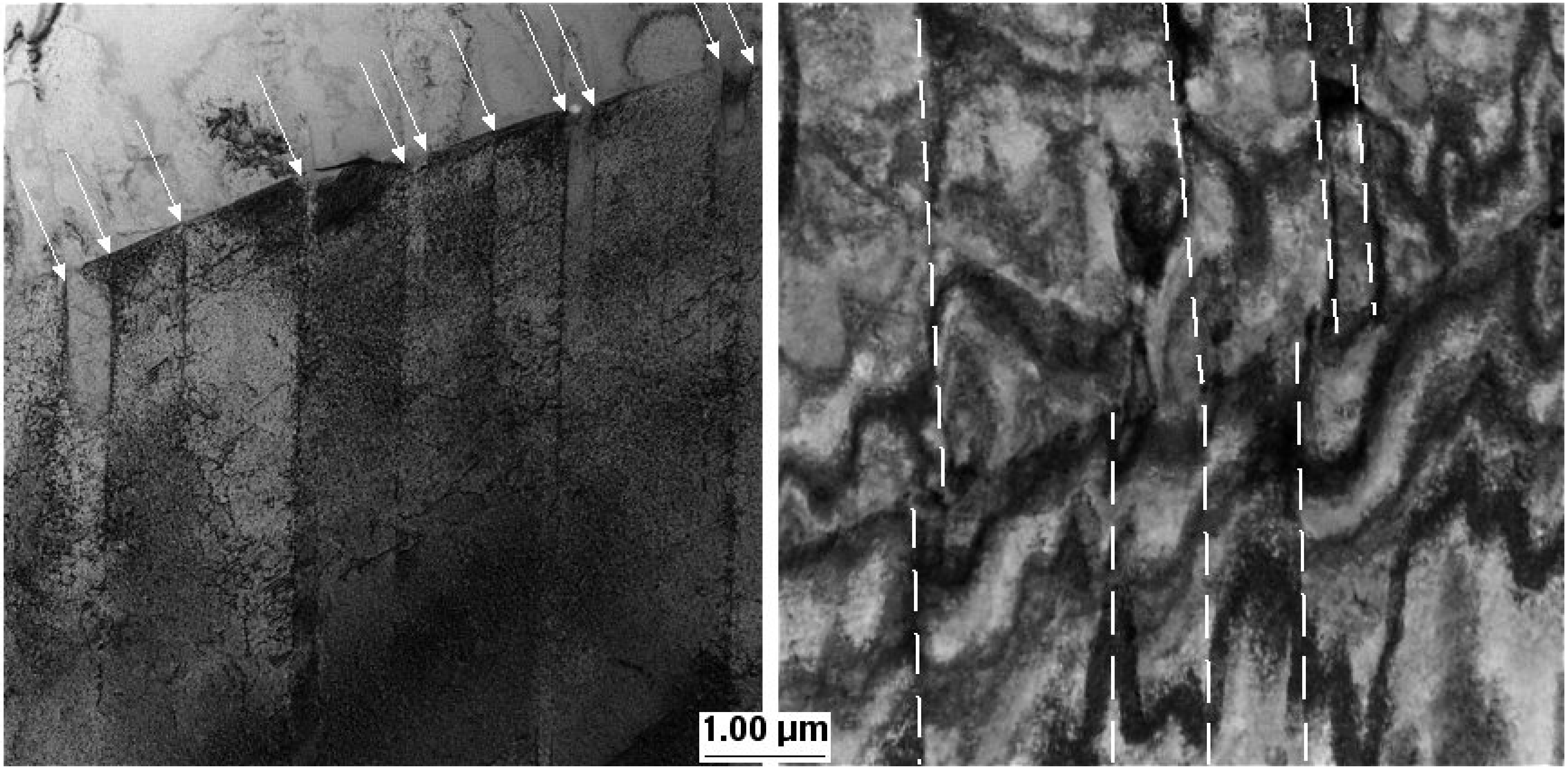


Channel in 0.11 dpa material demonstrates several stages of evolution process:

- head of channel marked by several dislocations (a.)
- followed by gradual separation of partial dislocations, overlapped in some regions → strong contrasts indicating different planar stacking
- left behind a band with reduced defect density (b.).



In regions experiencing more significant straining, the dislocations were less constrained to the bands themselves, and in fact, the more broad dislocation activity quickly obscured the channels.



Side-by-side comparison of mildly-strained (left) and heavily strained 0.89 dpa material at a grain boundary; spacing of channels in the mildly-deformed condition corresponds to frequency of the bowed lattice in the more heavily deformed material (manifested as wavy contrast between prior channels, marked by dotted lines).

Discussion

Results of examinations of mildly irradiated, mildly deformed 304L SS confirmed that:

- dislocation channel deformation can occur at very low dose
- clear bands produced are readily populated by extended stacking faults
- SFs can overlap to produce hcp epsilon martensite and twin-type planar stacking along the bands,
- *exclusive* to significant dislocation activity outside of bands.

Findings indicate that formation of clear bands by dislocation channel deformation, and formation of twins by overlapping stacking faults in those same bands, are not mutually exclusive...

rather, they can often be the same phenomenon observed at different stages of evolution.

Discussion

None of the materials of the study exhibited the yield peak and little or no further macroscopic strain hardening that is commonly attributed to channel deformation.

- Nonetheless, results of this study have shown that such localized deformation was indeed present in these materials, at least in the early stages of straining.
- Localization was clearly in the form of defect-reduced, dislocation channels.

Discussion

- THUS, although the clear channels are no longer visible as such, their manifestation is still evident in the microstructure → they most likely still promoted strain localization.
- Interaction of the channels with the grain boundaries could then be expected to produce high local stresses.

Conclusion

- Examinations of mildly irradiated and subsequently mildly deformed 304L austenitic stainless steel have confirmed that:
  - Dislocation channel deformation can occur at very low dose
  - Clear bands produced are readily populated by extended stacking faults → can overlap to produce hcp epsilon martensite and even twin planar stacking along the bands, exclusive to any significant dislocation activity outside of the bands.
- The interaction of the channels with the grain boundaries could produce high local stresses, which in turn could promote fracture along the grain boundaries.