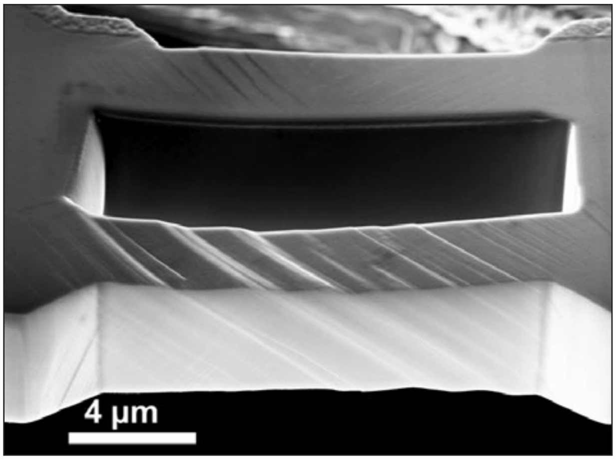
Dislocation pileups in microcantilevers may be fully reversible

As key components in microelectromechanical structures, small cantilevers are often subject to mechanical stress. This can result in the development of dislocation pileups, which can have a major impact on the behavior of the cantilevers. However, how such dislocation pileups are affected by the structure of the cantilevers, and in particular by the presence of different interfaces is not well known. An article recently published in the *Journal of Materials Research* (*JMR*) investigated how different cantilever designs affect dislocation behavior, and in particular how this can cause a reversal of dislocation pileups.

Cantilevers have been used for applications at both the macro- and microscale for centuries, says co-author Christoph Kirchlechner, a materials scientist at the Max Planck Institute in Germany. Anchored on one side, the free end of the cantilever is designed to support a structure as it comes under load. For microscale cantilevers, the mechanical properties, and especially the effects of increased flow stress, cannot totally be explained by similar properties on the macroscale. Specifically, it is not only down to the strain gradient, says Kirchlechner. Instead, research points toward a lack of dislocations and their arrangement at the micro- and smaller scales.

"In bulk materials that are ultrafine grained, we can see that dislocation pileups are important," says Kirchlechner. Dislocations moving toward an obstacle—like the neutral plane or a grain boundary in bulk materials—can jam. If they are not able to leave their slip plane, they will nicely align and form a dislocation pileup. It is known that the nature of dislocation pileups changes under stress, as expressed by the Bauschinger effect, where a change in flow stress is observed in forward and backward loading. However, what these dislocations were actually doing in response to stress is less well known. "But they've never really been looked into at the mesoscale," says Kirchlechner. "And now we have the capabilities to see them [in action] and understand the broad picture of what they are doing."

Part of why they have not been studied *in situ* is due to measurement limitations. Dislocations are easily imaged post-use in a transmission electron microscope. For this reason, mechanical properties have always been measured before or after a cantilever had undergone stress loading. However, *in situ* loading and unloading is required to see changes to the dislocation structure happening while stress is occurring, says Kirchlechner. The researchers suggest that these measurements were not telling the whole story. During the loading of stress, the dislocation arrangement looks very different.



A slotted bending beam that avoids dislocation pileup completely. © M.W. Kapp.

"As both the extrinsic (i.e., sample size) and the intrinsic (i.e., microstructural) dimensions play a non-trivial role in the mechanical performance, it is essential to develop in-depth understanding of the mutual interplay between defects, like dislocations and grain boundaries, in small-scale polycrystalline structures," says Jeff Th. M. De Hosson, Department of Applied Physics, Zernike Institute for Advanced Materials at the University of Groningen in The Netherlands, who was not affiliated with the current research.

Kirchlechner and his team created three different copper cantilever designs to study dislocation pileups and investigated how each reacted upon stress loading. In the first design, which comprised a single crystal with a slit, the dislocations could easily escape the structure, so no pileups occurred. In the absence of a slit, the neutral plane acted like a strain interface where dislocations would pile up and then be pushed further away from their starting point as more stress was added. Finally, the bi-crystalline third design acted in a similar way, except that the movement was not as fluid. Once the pileup occurred against the grain boundary, these dislocations could not be pushed out any further.

"Upon unloading, the story changes completely," says Kirchlechner. When the stress is released from the single crystalline structure, the dislocations that have been pushed far away move back in a smooth manner. For the bi-crystalline, where the dislocations are jammed right against the grain boundary with nowhere to go, the retreat of the dislocations is much more jarring. "They basically shoot back," he says.

Though strength varied by 34% within the three cantilever geometries, they exhibited the same nominal strain gradient. The study revealed that on the microscale or smaller, the Bauschinger effect can be promoted and prohibited by the insertion of different interfaces.

"[That's] the biggest surprise," says Kirchlechner. "That we can form such strong pileups during plastic deformation that they move back upon unloading in a jerky manner—as dislocation avalanches. This was really unexpected to us."

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