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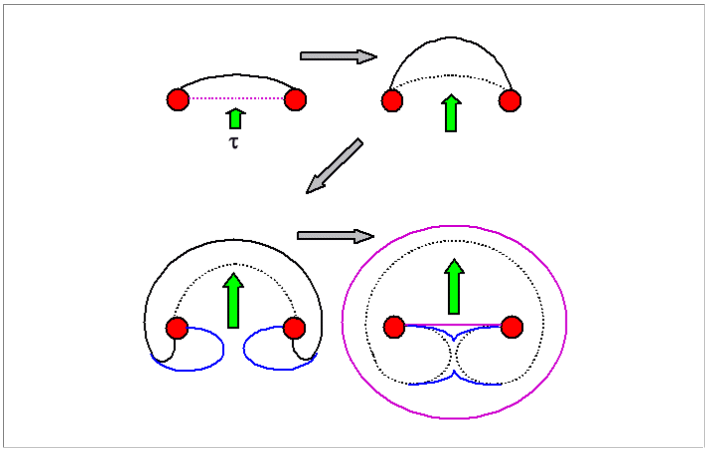
Dislocation Science

Science

3. Specialities

Generation of Dislocations

- How are dislocations made? If we take a piece of a standard silicon (Si) wafer, it does not contain a single dislocation. Cut out a piece and do a standard tensile test at high temperatures where silicon is no longer brittle, and you get plastic deformation - after you produced sufficient dislocations.
  How that happens is not a big mystery. I have illustrated it already in this link.
  - A tiny little dislocation is generated at the surface in the shape of a half loop. After that nucleation event took place, the dislocation can move, getting "bigger" or better longer. The nuclei that generates the embryonic dislocations can do so again and again, sending a whole sequence of dislocations down the same glide plane. Of course, like always, nucleation is a difficult process and takes some extra energy. This energy must be provided by some extra stress and that's why you find a peak in the stress - strain diagram in the beginning of plastic deformation.
- However, dislocation-free single crystals are exceedingly rare. Besides silicon (and the occasional germanium crystal) there is nothing else, certainly no metal, that does not contain at least some dislocations. However once more, a lot of metal (poly) crystals may not contain *enough* dislocations to provide for massive plastic deformation. I have claimed that dislocations multiply like rabbits but is that really true?
  - Does a male dislocation ***woo*** a female dislocation with the aim to stick its little... - well, you know how that is done. Or do we need to enlist the ever busy bees? Do they need some kind of sex or, maybe, just sprout a new dislocation by division?
- OK - I tell you how it's done. Look at the figure below. Here is the description of what you see in the top two panels:
  - We have a segment of a dislocation firmly anchored at two points (red circles). How the dislocations continues from these obstacle is not shown; they might, for example, move out of the screen plane. Without a shear force acting on the glide plane = screen plane here, the dislocation would be straight as shown be the dotted purple line.
    Now we turn on a small shear stress τ. The dislocations feels a force $\boldsymbol{F} = \boldsymbol{b} \cdot \tau_{res}$ that is always at right angles to the dislocation line and bows our as shown by the sold black line.
    In the next panel the shear stress is increased and the dislocation bows out more. As soon as its shape is about a semicircle, something new happens; this is shown in the panel on the left below.



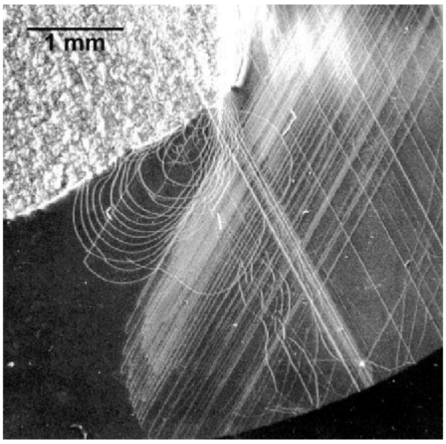
Dislocation generation by a "Frank-Read" or "Orowan" mechanism.

  - As soon as the force acting on the dislocation segment (with length ***R*/2)** is large enough to bend the dislocation into a semicircle with radius ***R***, everything that follows happens quickly and without need of more external stress. The bowing proceeds as as shown. The "ears" that are formed touch each other. Since the two segments touching have the same Burgers vector (it is one and the same dislocation, after all) but line vectors with different signs, they annihilate and leave back the original dislocation segment plus a dislocation loop.
    As long as the shear stress is still there, the loop will move and grow bigger, and the segment goes through the full cycle again. And again. And again ....
    This maximum shear stress needed is $\tau_{max} = Gb/R$ with ***G*** = shear modulus of the material, ***b*** = Burgers vector

of the dislocation. If you supply reasonable numbers, you see that it doesn't need a lot of stress to get this "**Frank-Read**" or "*Orowan mechanism*" going.
I won't pass judgement her who, exactly, discovered what is going on here. I guess it is fair to say that **Orowan** put down the basics about bowing out etc., while Frank and Read worked out the details independently but published together in 1950.

- You might think that this is a bit artificial and complicated, sort of having sex with yourself after parts of you switched a sign. Well, yes - but for dislocations it comes as naturally as making babies comes to you. You do not need to know the theory about what you are doing. You just do it. It comes naturally - but looks pretty weird to outsiders like those aliens with the tentacles. From the viewpoint of dislocations, you are the alien.

There are more mechanism, always relying of some dislocation interaction driven by the stress they feel. Since the decisive part goes rather quickly, it is difficult to watch them doing it and to catch them in the act. As in your case, however, it is sometimes possible to see their progeny still around the place of their birth.
Here is a picture illustrating this:



X-ray topography picture of a Frank-Read type dislocation source.

Source: Thanks, K. B. Kostin (a former student of mine) for letting me have that picture

- The picture resulted from an of investigation into "wafer bonding", where two Si wafers are placed on top of each other and "bonded", so that a single piece of Si results - with a grain boundary in between. The mottled area in the upper left hand corner shows such a bonded structure, whereas the dark area containing the dislocations as white lines, remained unbonded.
Dislocations were introduced into one of the wafers and one point on the edge of the bonded area acted as a Frank-Read source. The nested series of dislocation loops is splendidly visible. There are also lots of straight dislocations which have moved considerable distances from their point of origin.
Another picture showing dislocation sources (of some other kind) in action can be found here

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