#13: Curved Dislocations

From the previous lecture

•A dislocation can have just one slip vector

•The force of the dislocation due to an applied shear stress is given by the product of that stress and the slip vector

•The force always acts normal to the **local** line vector of the dislocation

Today's Topics

•The glide plane (or the slip plane) is defined by the plane that contains both the line vector and the slip vector

•The dislocation can have a curved shape

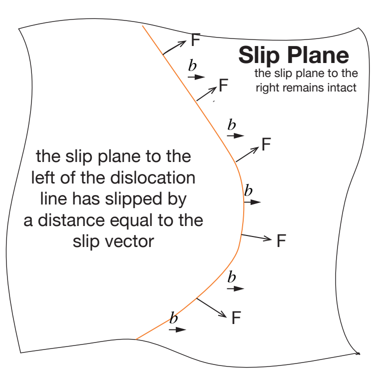
•In this configuration the slip vector can lie perpendicular or parallel to the line vector

•That section of the dislocation where the slip vector and the line vector are parallel the dislocation can "cross-slip" into a different slip plane (though in the same slip system). The segment that has cross slipped is not pinned at the points that its slip plane intersects with the original slip plane.

•How will the dislocation "segment" now move if a force is now applied to it?

The above problem leads to the Orowan equation, which is the basis for metallurgical engineering of metal that are strengthened by the dispersion of particle within the metal. These particle pin the dislocations.

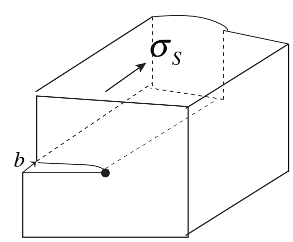
•Dislocations can meander in the slip plane!



Notes (meandering dislocation)

(i) The full dislocation has the same slip vector. This slip vector describes the slip to the left of the dislocation line by the slip vector, $\boldsymbol{b}$.

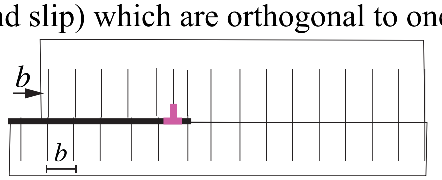
(ii) Note, however, that the force on the dislocation is always normal to the line vector. The force is exerted by the shear stress applied from the left to the right, parallel to the slip plane.



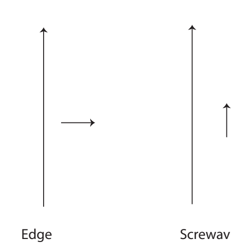
•Edge and Screw Dislocations: Glide planes for edge and screw dislocations

•Slip is confined to a plane that contains the line vector and the slip vector of the dislocation

•In case of the *edge dislocations* the plane is a two dimensional entity that contains the two vectors (line and slip) which are orthogonal to one another



•In the case of *screw dislocations* the line vector and slip vector are parallel to one another, so that glide can occur on any slip plane that contains this vector.



•Intersection of two slip (or glide) planes of the same family

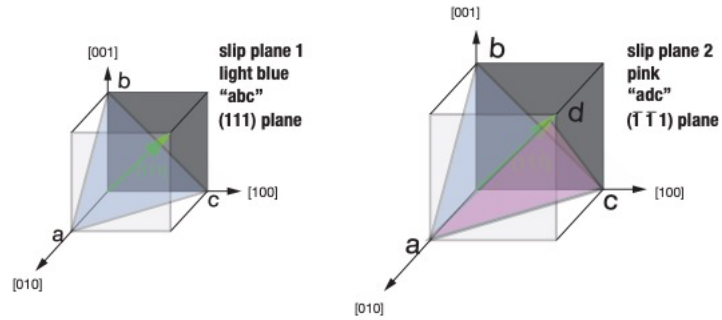
The figure on the right shows the intersection of two planes from the family {111}. More specifically plane 1 has the (111) orientation, while plane 2 is the $(\bar{1}\bar{1}1)$ orientation.

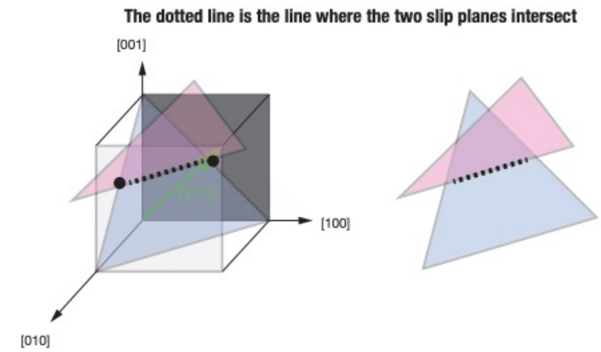
Both planes are favored for slip in the fcc structure.

The figure on lower left shows the intersection between these two planes.

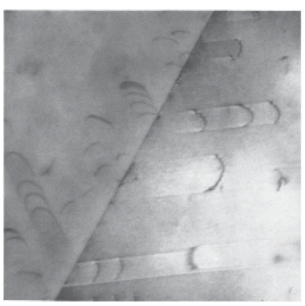
The planes intersect each other at a line drawn here as a dotted line.

A screw dislocation that touches this dotted line can move from one plane to the next, that is it can cross slip





•Cross-Slip of a Dislocation Segment



The micrograph on the left shows small segments of dislocation that are bowed out because of a force on them.

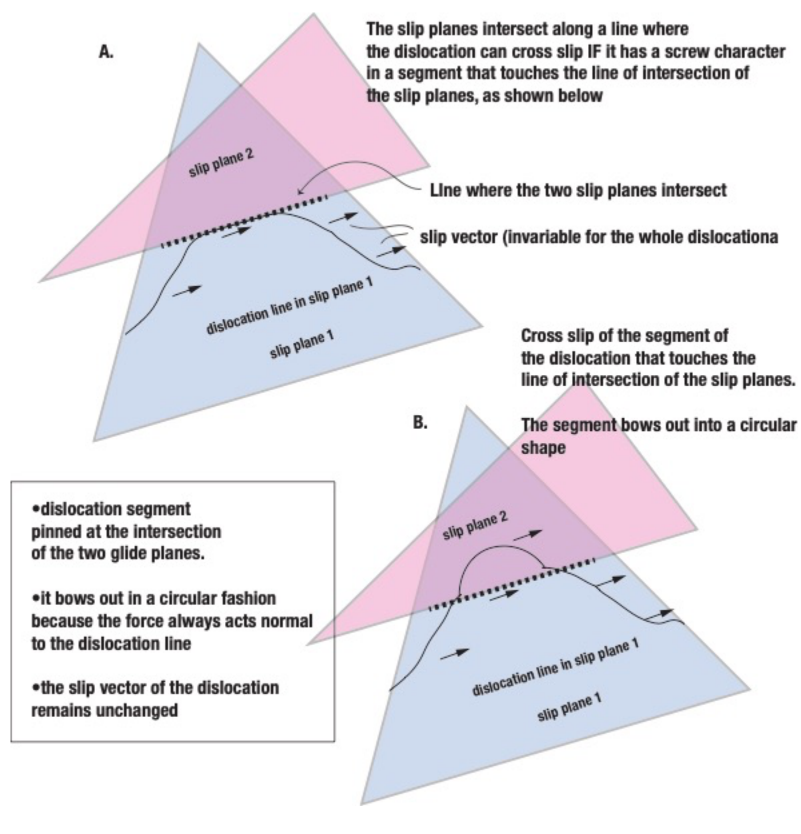
The segments are pinned where the dislocations have cross slipped from one slip plane to another that intersect one another at a line.

The segment that has cross slipped is a screw dislocation a segment of which lies along the intersection of the two slip planes

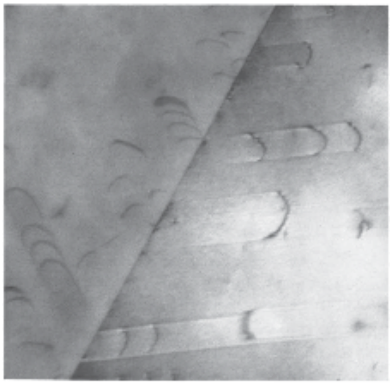
Explanation for the circular shape of the dislocation segment that has cross slipped

The figure A on the right shows the screw section of the dislocation line touching the line of intersection of the two slip planes

Figure B shows that the above section of the dislocation has migrated into slip plane 2



•Analysis of the force on a dislocation segment trapped in a slip plane (as shown in B above)

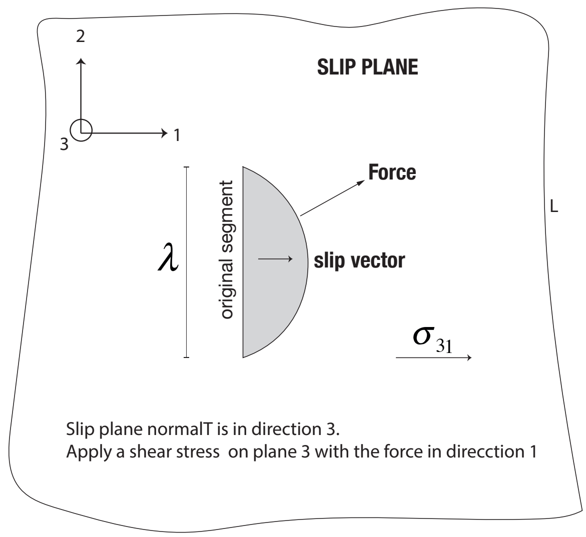


The micrograph on the left (from a transmission electron microscope) represents the plan view of a slip plane with segments of cross-slipped dislocations bowing out from a force being applied to them.

We begin by considering one such segment lying in a slip plane and consider an applied shear stress that forces it to bow out in a circular fashion.

The circle of the segment has a radius of curvature. The dislocation has a slip vector, and the segment has two pinning points. The spacing between these two pinning points is the third geometrical property of this problem.

Analysis of the above problem therefore involves the following parameters:



Geometry

1. The radius of curvature of the segment, R
2. The slip vector of the dislocation, b
3. The spacing between the pinning points (to be considered later), λ

Line Tension

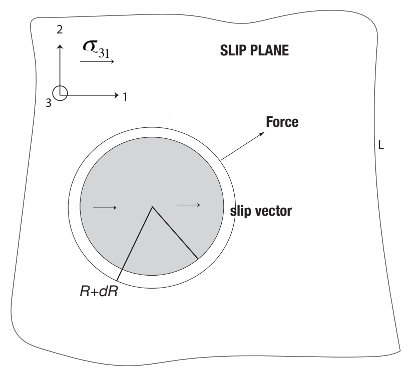
When the dislocation bows it increases its length, and thus, experiences a line tension. We describe this line tension in terms of the energy of the dislocation. The line tension is then related to the increase in the energy of the dislocation per unit length.

The energy per unit length of the dislocation is described by the following equation

$$U = \frac{Gb^2}{2}$$

where G is the shear modulus and b is the slip vector. Note the units: the right has side has units of energy per unit length since the modulus has units of energy per unit volume.

Posing the Problem



The problem must be posed in a simple way by simplifying the geometry of the curved dislocation. Since the dislocation has a specific radius of curvature, we consider a full circle of the dislocation so that the work done and the line tension can be related to one another, as shown on the right. The force on the segment will be the same on the full circle since both have the same radius of curvature, R.

It is a bit non-intuitive, but when a force is applied the circle expands equally in all directions since the force is always in the direction of the outward normal. Note that the direction of slip vector relative to line of the circle has a negative sign on the left and positive on the right.

Now let us apply virtual work. Consider that the circle expands incrementally by dR, then the work done by the force = $dR * 2\pi RF$ that is the total force on the circle multiplied by the distance moved (note that F has units of per force per unit length). This work is related to the increase in the energy of the dislocation = $U * 2\pi(dR) = (Gb^2/2) * 2\pi(dR)$.

Equating these two equations gives the result: $F = \dfrac{Gb^2}{2R}$. It relates the force to the radius of curvature of the loop.

Recall that $F = \sigma_{31} b = \sigma b$. Thus we now relate the applied stress to R, that is $\sigma = (Gb)/2R$, this is the final result.