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The Behavior of the Bordoni Peak in Ultra High Purity Cu and its Implication for Dislocation Mechanism

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Abstract. Recent results on ultra high purity Cu have shown that the Bordoni peak grow very large after annealing at 800 °C . The size of the peak suggests that the bow-out of clean network dislocations through the kink pair formation caused the peak. Based on these results, Takeuchi proposed the model in which the Bordoni peak and yield stress at low temperatures are associated respectively with kink pair formation in undissociated and dissociated dislocations. On the contrary, here, it is proposed that the above two phenomena are controlled by kink pair formation on dissociated dislocations without jogs and with jogs, respectively.

1. INTRODUCTION

The Bordoni peak is a broad relaxation peak at low temperature first observed by Bordoni [1] in cold worked fcc metals. Seeger [2] proposed that this relaxation is associated with a kink pair formation (KPF) on dislocation lines lying along Peierls potential valley. Since all the characteristics of the Bordoni peak so far observed experimentally consist with this KPF model, this model was widely accepted as the origin of the Bordoni peak. If we assume a sinusoidal Peierls potential, the flow stress τ_P associated with the Peierls potential can be estimated roughly as

$$\tau_P / \mu \sim 3E_{KPF}^2 / (\mu b^3)^2$$

where μ is the shear modulus, E_{KPF} the activation energy of the Bordoni peak, b the Burgers vector. For example, for Cu this gives $\tau_P / \mu \sim 10^{-8}$ for $E_{KPF} \sim 0.12\text{eV}$.

On the other hand, τ_P / μ estimated from the macroscopic deformation at low temperatures gives $\tau_P / \mu \sim 10^{-5}$ which is roughly two orders of magnitude smaller than that expected from the Bordoni peak. There have been various models proposed to explain this discrepancy, but none of them seems to be convincing enough. These points were amply discussed in [3]. It is to be noted that the above discrepancy does not exist in bcc metals [3] and ionic crystals [4] where dislocations are not dissociated into partial dislocations on the glide plane.

Recently, Kosugi and Kino [5] found a new relaxation peak at 11K (for measuring frequency $\sim 50\text{KHz}$) in deformed zone-refined Al and claimed that since τ_P deduced from the activation energy of this peak consists with the flow stress in low temperature deformation, the true KPF peak is this peak but not the ordinary Bordoni peak. But then, a problem arises why the dislocation components with higher E_{KPF} do not control the flow stress at low temperatures.

Recent results on ultra high purity Cu [6] which showed that the Bordoni peak appears very large after annealing at 800 °C will be discussed in relation to the above problems in the following section.

2. CONTRIBUTION OF NETWORK DISLOCATIONS

The results on ultra high purity Cu (Z-R Cu) after heavy deformation are shown in Fig. 1 with those on 7 nine purity (7N) and 4N Cu's. Similar results after cyclic deformation are shown in Fig. 2 [7]. Main points of the results can be summarized as follows:

(1) The Bordoni peak grew during annealing up to 800 °C annealing for Z-R Cu, but remained

Figure 1: Height of the Bordoni peak (approximate) vs. annealing temperature for heavily deformed Z-R, 7N and 4N Cu [6].

Figure 2: Height of the Bordoni peak (approximate) vs. annealing temperature for cyclicly deformed Z-R, 7N and 4N Cu [7]

small for 7N and 4N Cu's. This behavior is almost the same for heavy deformation and cyclic deformation.

(2) Smallness of the Bordoni peak after 800 °C annealing for 7N and 4N Cu's can be explained entirely by dislocation pinning by impurities.

(3) The size of the Bordoni peak after 800 °C annealing in Z-R Cu can be explained by contribution of bow-out of clean network dislocations through KPF. This contribution is independent of the network size.

Here, the network dislocations should be clean from impurity atoms, other point defects and their clusters, but whether they should be clean from jogs or not will be a problem to be discussed from now on.

3. JOGS IN NETWORK DISLOCATIONS

It may be said that geometry of jogs in dislocation lines is now well understood, but present understanding of the atomic structure of jogs especially in dissociated dislocations is rather poor [8].

The glide planes of jog and its parent non-screw dislocation are different. However, how much this makes the motion of jog more difficult than the parent dislocation is a subtle problem. If one assumes that the resistance of jog to the motion of or KPF on the parent dislocation is not negligible, network dislocations should be clean from jogs in order to explain the large Bordoni peak after 800 °C annealing, as it was considered in [6].

Recently, Takeuchi [9] proposed the attracting model which might be able to remove the contradiction on τ_P 's deduced from the relaxation experiments and from the macroscopic deformation experiments. He assumed that jogs make no resistance to the motion of parent non-screw dislocations and dissociated dislocations constrict completely at jogs. He considered further that most of the network dislocation lines deviate more than 10 deg. from the glide plane and therefore are no longer dissociated into partial's due to dense constrictions at jogs. Then, he concluded that the Bordoni peak in fcc metals is associated with the motion of undissociated dislocations and the macroscopic flow stress is governed by the glide motion of dissociated dislocations.

For the sake of simplification, the following discussion will be confined to Cu. For Cu, where the width d of the extended dislocation is about $10b$, the constriction at jog in edge dislocations would be not complete and more probably extend somewhat as shown in Fig. 3 [10].

Figure 3: Jog in a dissociated dislocation as seen on {111} glide plane (only schematic).

Furthermore, the energy increase in changing from dissociated to undissociated dislocation is considered to be around 0.5 eV per one atom length of the dislocation [10]. Therefore, it seems improbable that the network dislocations are undissociated after annealing at 800 °C. Then the above model by Takeuchi would not work at least for Cu.

4. PROPOSAL OF A NEW SHORT-CIRCUIT FOR DISLOCATION MOTION

Discrepancy of τ_P 's estimated from the Bordoni peak and the macroscopic deformation at low temperatures will disappear if one can find a proper short-circuit for dislocation motion [3], i.e. a

way for dislocation to move below τ_P . Here, it will be proposed that a place of partial constriction of dissociated non-screw dislocation at jog would provide such a short-circuit.

It is difficult to estimate the Peierls energy for a dissociated dislocation because one should take account of the effect of misfit energy associated with the stacking fault [8]. However, as a rough approximation, one may consider that the two partial dislocations connected by stacking fault move through the Peierls potential as shown in Fig. 4. For Cu, since the repulsive forces

Figure 4: Partial dislocations connected by stacking fault (represented by spring) in the sinusoidal Peierls potential.

acting between two partial's are much larger than the flow stress at low temperatures, one can consider the two partial's moving with essentially a rigid separation d . In this case the effective Peierls stress will be maximum in the configuration 1-2, but much smaller in the configuration 1'-2' as shown in Fig. 4. Then, some part along partially constricted dislocation line near jog may experience much smaller stress for motion than the normally dissociated dislocation. Thus, jog in non-screw dislocation can provide a short-circuit for dislocation motion.

5. CONCLUSION

The large Bordoni peak observed after 800 °C annealing for ultra high purity Cu can be explained by the KPF model in network dislocations clean from impurities and jogs. The flow stress in macroscopic deformation would not represent the Peierls stress, but probably be controlled by the motion of partially contracted part of dissociated dislocation near a jog.

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