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Strain rate sensitivity of flow stress under superimposition of ultrasonic oscillatory stress during plastic deformation of RbCl doped with Br^- or I^-

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Abstract

Strain rate cycling tests were carried out under superimposition of ultrasonic oscillation during plastic deformation of RbCl single crystals doped with Br^- or I^-. The relation between the strain rate sensitivity λ $(= d\tau/d\ \ln\dot{\varepsilon})$ of flow stress and stress decrement $\Delta\tau$ due to application of oscillation has a stair-like shape and is divided into three regions, two plateaus at low and high $\Delta\tau$ and the decreasing λ region between them. The stress decrement τ_p at the first bending point is considered to be the effective stress due to an impurity and the value of λ_p, the difference in λ between the first and second plateau regions is also a part of λ due to an impurity. Values of τ_p and λ_p were measured from 77 K to room temperature. Assuming the Cottrell–Bilby relation for RbCl crystals doped with Br^- or I^-. The interaction energies between dislocation and Br^- or I^- were determined to be 0.50 or 0.58 eV in RbCl, respectively.

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1. Introduction

Recently, it has been reported that the interaction energy between dislocation and impurity in alkali halide crystals can be obtained from the relation between stress and activation volume [1,2]. The relation is given by the measurement of the stress decrement due to application of ultrasonic oscillatory stress and strain rate sensitivity λ $(= d\tau/d\ \ln\dot{\varepsilon})$ of flow stress under superimposition of ultrasonic oscillation.

In this study, we carry out strain rate cycling tests under superimposition of ultrasonic oscillatory stress for RbCl single crystals doped with Br^- or I^- and investigate the interaction between dislocation and either Br^- or I^- ion.

2. Experimental procedure

Single crystals of RbCl:Br^- and RbCl:I^- were grown from the melt of reagent grade powder in air by the Kyropoulos Method. The concentrations of doped Br^- and I^- were 1 mol.%, respectively, in the melt. Samples were cleaved out of the grown ingot in size of 5 mm × 5 mm × 15 mm and were annealed at 913 K for 20 h, followed by cooling at 30 K/h to room temperature in order to control the dislocation density.

The specimens were plastically compressed in the $\langle 1\,0\,0\rangle$ direction along the longest axis of a crystal at the crosshead speed of 10 $\mu m\,min^{-1}$ by a Shimadzu DSS-500 testing machine. Strain rate cycling tests were carried out between the crosshead speeds of 10 and 50 $\mu m\,min^{-1}$ while ultrasonic oscillatory stress was superimposed at 20 kHz and its stress amplitude was kept constant, as shown in Fig. 1. Superimposition of oscillation was performed intermittently at various stress amplitudes, which was monitored by the piezoelectric transducer set between a specimen and the support rod. The oscillatory stress of the specimen was homogeneous because the specimen size was much smaller than the wavelength. The temperature range was from 77 to 253 K and its fluctuation was within ±0.3 K.

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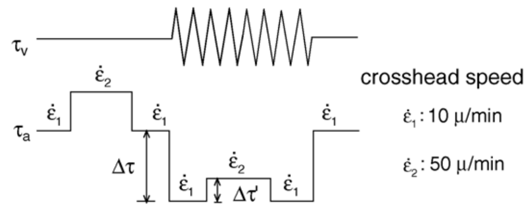

Fig. 1. Schematic illustration of stress variation. τ_v is the oscillatory stress and τ_a is the applied one. $\Delta\tau$ is the stress decrement due to superimposition of oscillatory stress. $\Delta\tau'$ is the stress change due to strain rate cycling.

3. Results

The flow stress decreases when the oscillatory stress is superimposed during plastic deformation of crystal. Fig. 2a shows that the stress decrement $\Delta\tau$ due to superimposition of oscillation increases with stress amplitude, but it varies little with strain. Fig. 2b shows that λ increases with strain and decreases with stress amplitude. The variation of λ with stress amplitude seems to be small at low and high amplitudes. In order to obtain the relation between $\Delta\tau$ and λ, their values at the same strain are read from Fig. 2 and the values are plotted at the strain of 5, 10 and 15 % in Fig. 3. The variation of λ with $\Delta\tau$ is stair-like. There are three regions. In the first plateau region at low $\Delta\tau$, λ is constant. As $\Delta\tau$ increases further, the curve bends and λ decreases in the second region as $\Delta\tau$ increases. And the curve bends again and the second plateau region appears at large $\Delta\tau$. The absolute values of λ tend to be larger as the value of strain increases. Fig. 4 shows the relation between λ and $\Delta\tau$ at 77, 163, 200, 243 and 293 K. The width of the first plateau region expands with decreasing temperature. The first plateau region disappears above 293 K. The value of $\Delta\tau$ at the first bending point is referred to as τ_p and the difference between λ in the first plateau region and that in the second one to as λ_p, as shown in Fig. 4. In Fig. 3, τ_p and λ_p appear to change little although the curve shifts upward as the value of strain increases.

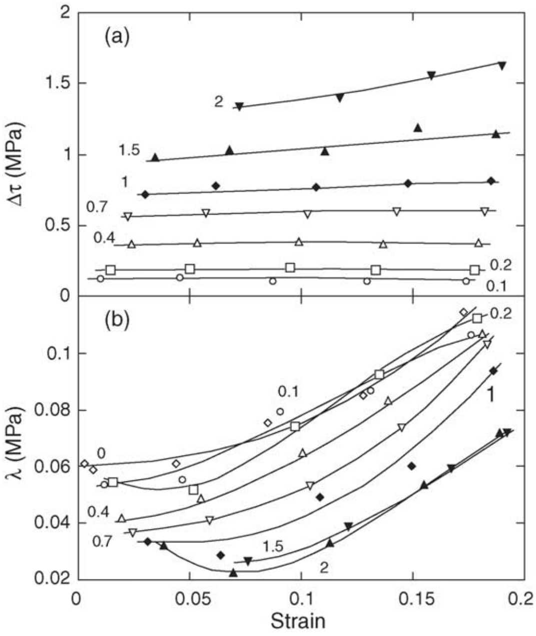

Fig. 2. Dependence of (a) the stress decrement $\Delta\tau$ and (b) the strain rate sensitivity λ of flow stress on strain at 203 K and various stress amplitudes for RbCl:Br$^-$. The numbers beside each symbol are the output voltage from the piezoelectric transducer, which is approximately proportional to the stress amplitude.

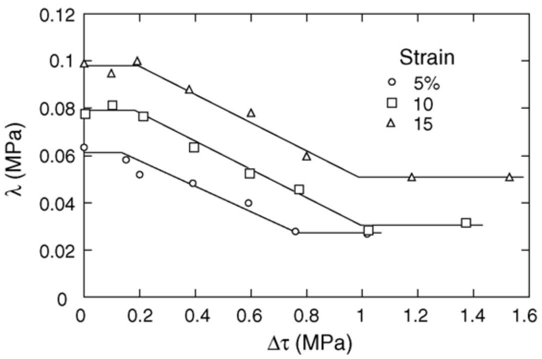

Fig. 3. Relation between λ and $\Delta\tau$ at the strains of 5, 10 and 15%. The plotted points are obtained from Fig. 2.

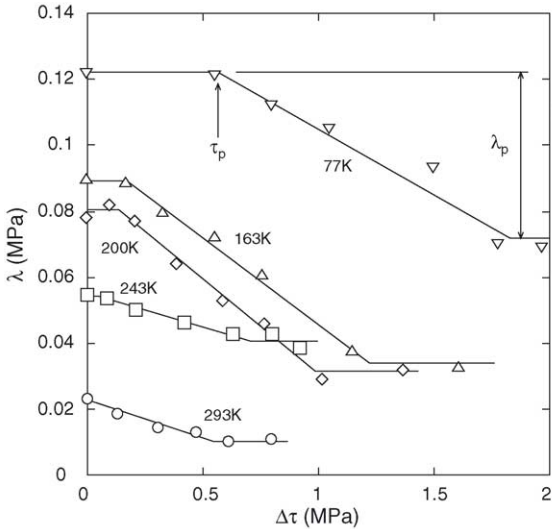

Fig. 4. Relation between λ and $\Delta\tau$ at 77, 163, 200, 243 and 293 K.

4. Discussion

The strain rate sensitivity of flow stress is inversely proportional to the activation volume or the average length of dislocation segment. The average length of dislocation segment depends on the distribution of obstacles to dislocation motion. Then, the strain rate sensitivity under superimposition of ultrasonic oscillatory stress reflects the effect of the oscillation on the distribution of obstacles. Since the obstacles to dislocation motion are considered to be impurities and forest dislocations, the measurement of strain rate sensitivity under superimposition of oscillation is expected to give us