Investigation of Low-Temperature Dislocation Structure and Dynamics in the High-Entropy Alloy $Al_{0.5}CoCrCuFeNi$

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INTRODUCTION:

Low temperature dynamics and kinetics of dislocation motion in the high entropy alloy $Al_{0.5}CoCrCuFeNi$ were comprehensively studied in a wide range of elastic deformations using two different experimental methods (mechanical resonance spectroscopy and active plastic deformation). A theoretical analysis of the low-temperature processes of plastic deformation and acoustic relaxation in a high-entropy alloy $Al_{0.5}CoCrCuFeNi$ was carried out.

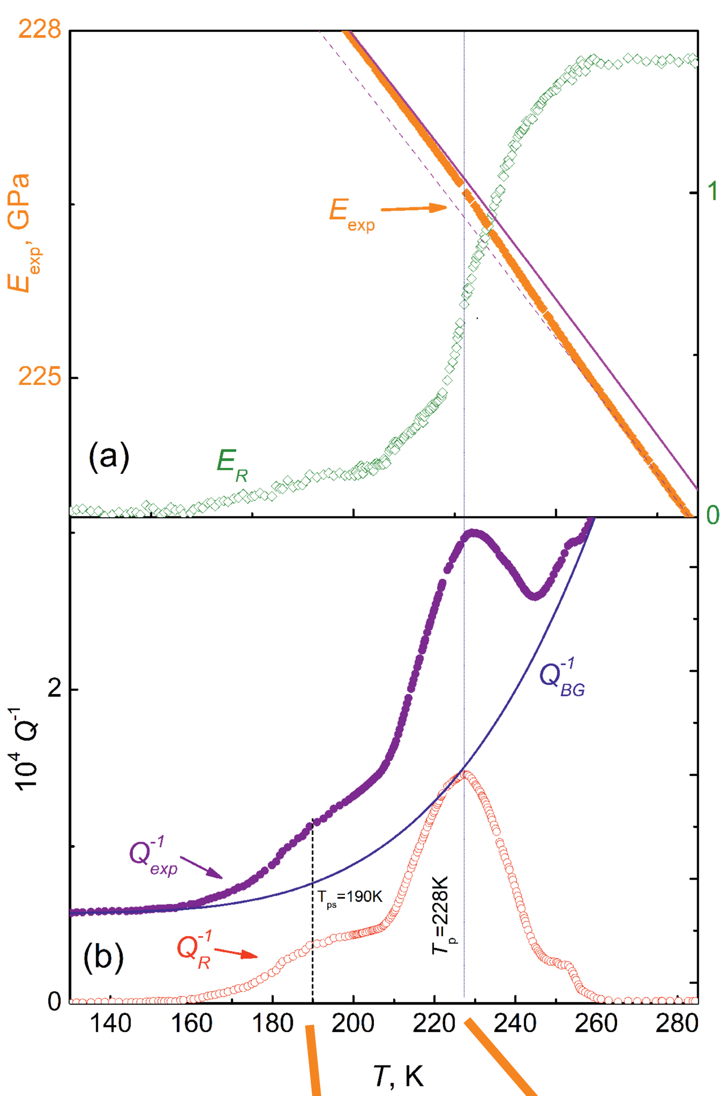
A dislocation model [1] is proposed that allows adequate description of the experimentally observed features of low-temperature plastic deformation and acoustic relaxation in the studied high-entropy alloy

A detailed study of the dislocation structure of the studied high-entropy alloy $Al_{0.5}CoCrCuFeNi$ at room temperature was performed using X-ray structural analysis methods, and a numerical estimate of the dislocation density was obtained.

EXPERIMENT

alloy $Al_{0.5}CoCrCuFeNi$ was studied in 2 structural states:
(I) - initial cast;
(II) - after high-temperature annealing in vacuum at 975 °C for 6 hours

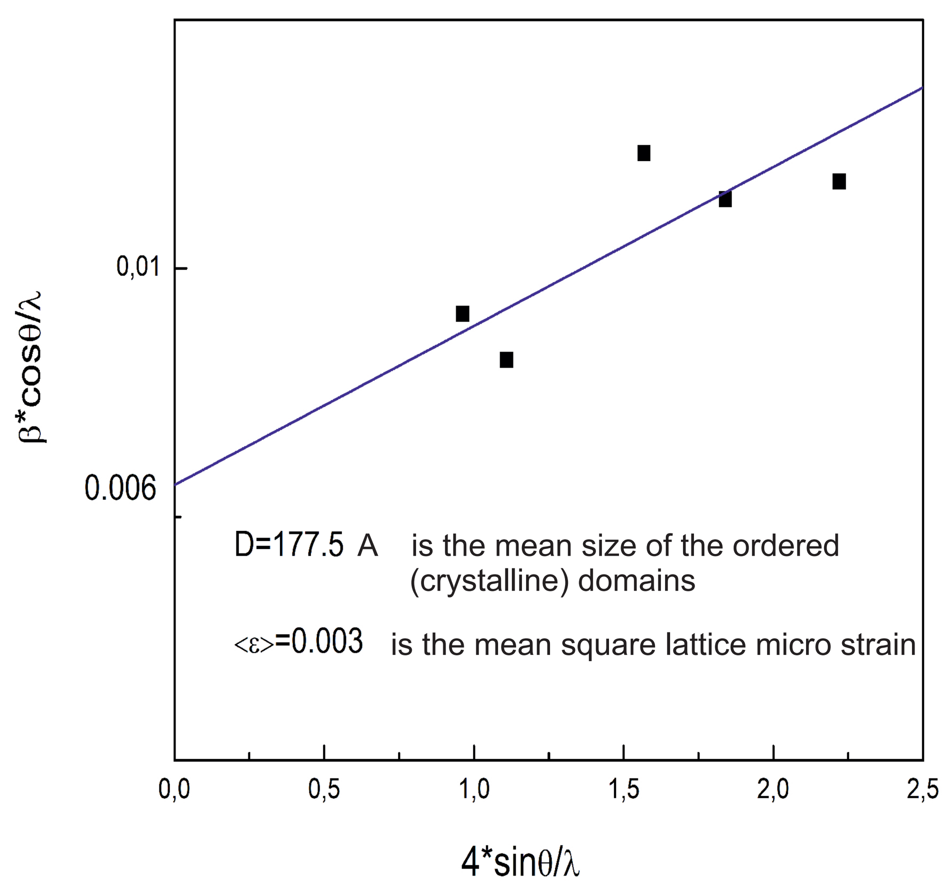
RESONANT MECHANICAL SPECTROSCOPY



Relaxation resonances in the $Al_{0.5}CoCrCuFeNi$ alloy in the structural state (II): a) temperature dependence of dynamic Young's modulus: ◆ is the experimental dependence $E_{exp}(T)$, ◇ - $E_R(T)$ resonant component; b) temperature dependence of internal friction: ● is the experimental dependence $Q^{-1}_{exp}(T)$, ○ – $Q^{-1}_R(T)$ resonant component. Solid lines show the background of the dynamic modulus $E_{BG}(T)$ and the absorption background $Q^{-1}_{BG}(T)$. T_p = 228 K is the peak temperature and T_{ps}=190K is the temperature of the absorption peak satellite.

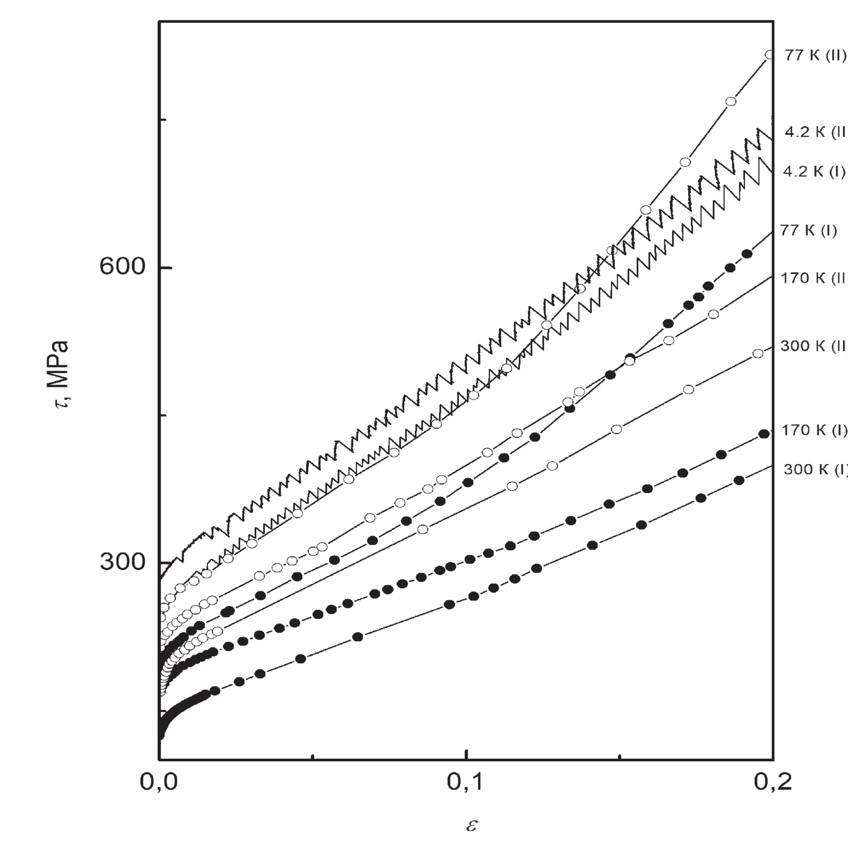
○

XRD PATTERNS ANALYSIS



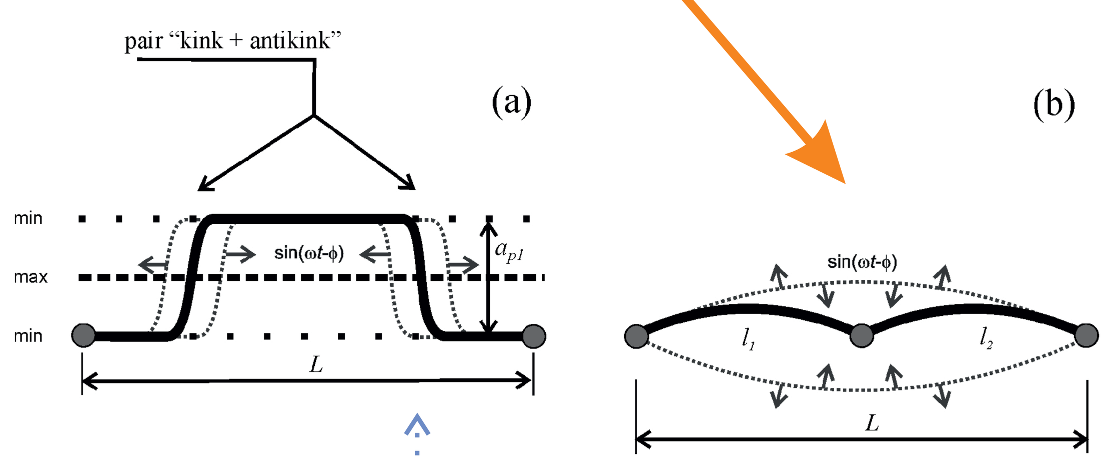
Williamson–Hall plot for the alloy $Al_{0.5}CoCuNiFe$
The average value of the dislocation density $\bar{\rho} = 4.97 \cdot 10^{15}\,m^{-2}$

ACTIVE DEFORMATION



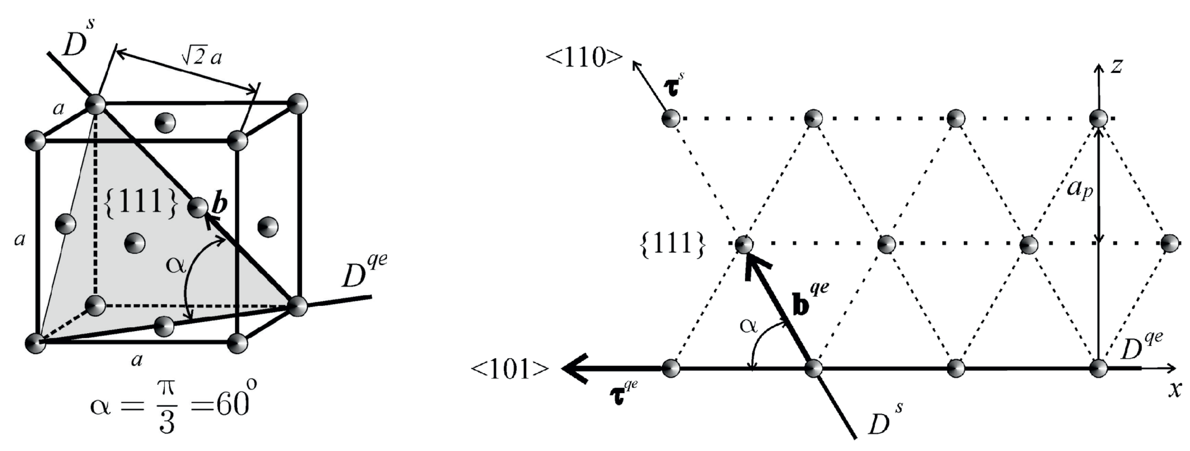
Diagrams of compression deformation of the alloy $Al_{0.5}CoCrCuFeNi$ in "τ–ε" coordinates at different deformation temperatures.

DISLOCATION MODEL



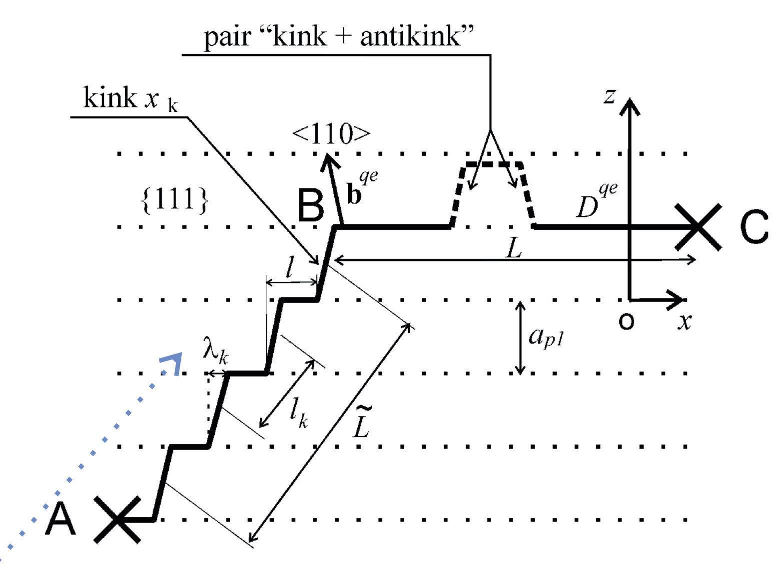
Schematic representation of an elementary relaxer:
(a) – Seeger relaxation; (b) – relaxation Koiwa and Hasiguti;

● – local defects on the dislocation string; the symbol L denotes the length of the dislocation segment, the activation of which determines the elementary contribution of the dislocation to the acoustic resonance or the rate of plastic deformation.



{111}<110> slip system and straight dislocations in an fcc crystal:
(a) – unit cell; (b) – one of the sliding planes {111}.

$a_p = \frac{\sqrt{3}}{2} a_0 = \sqrt{\frac{3}{8}} a$ Peierls relief period in the direction of easy sliding



Configurations of dislocation lines in the {111}<110> slip system in an fcc crystal: ***ABC*** – curved segment of a quasi-edge dislocation D^{qe} with a Burgers vector $\mathbf{b}^{qe}$, the dotted line indicates the close packing directions; a_{pl} - period of the first kind Peierls relief in the direction of the axis oz; $a_0=b$ - period of secondary Peierls relief; L - length of straight segment ***BC*** in the relief valley; $\tilde{L}$ - length of the chain of ***AB*** kinks between relief valleys; x_k - coordinate of a separate kink along the axis ox; λ_k - kink width; l – distance between the centers of neighbouring kinks.

THEORETICAL ESTIMATES

$m_k \approx 5 \cdot 10^{-3} m_a \approx 5 \cdot 10^{-28}$ kg - mass of the kink

$\lambda_k \approx 40 a_0 \approx 1 \cdot 10^{-8}$ m - width of the kink

$M \approx 1.1 \cdot 10^{-15}\ \frac{kg}{m} \approx 2.1 \rho b^2$ - linear mass density

$\Gamma \approx 12.4 \cdot 10^{-9}\ \frac{J}{m} \approx 2.1 G b^2$ - energy per unit length of a dislocation

$c_t = \sqrt{\frac{G}{\rho}} \approx 3.4 \cdot 10^3\ \frac{m}{s}$ - speed of sound

$\tau_{p1} \approx 3.6 \cdot 10^6$ Pa $\approx 4 \cdot 10^{-5} G$ - Peierls critical stress

$\Lambda_d \sim 4 \cdot 10^{13}\ m^{-2}$ - the density of dislocation which effectively interact with elastic vibrations of the sample

$\tau_{0.2}, \tau_2 \approx (2 \div 3) \cdot 10^8\, Pa \approx 50 \cdot \tau_{p1}$

$L = 2l \approx 10\ nm$

CONCLUSION:

Based on the proposed dislocation model, quantitative estimates have been obtained for the most important characteristics of dislocations and their interaction with barriers (distance between local obstacles in the slip plane 4.1 nm, the Peierls stress for dislocations in an easy slip system $4 \cdot 10^6$ Pa and others). The estimate for speed of sound $3.4 \cdot 10^3$ m/s obtained within the framework of our proposed model is in good agreement with the experimental data of the work [3]. It has been established that the obtained empirical estimates for the energy per unit length of a dislocation $12.4 \cdot 10^{-9}$ J/m and the linear mass density $1.1 \cdot 10^{-15}$ kg/m do not contradict their estimates in the modern continuum theory of dislocations.

It was found that the value of the dislocation density obtained by X-ray structural analysis methods correlates with estimates for the density of dislocation which effectively interacts with elastic vibrations of the sample (the total length of dislocation segments per unit volume) 4 10^{13} m^{-2}, obtained within the framework of the dislocation model proposed by us.

Analysis and physical interpretation based on modern dislocation theory of the results of a comprehensive experimental study of the processes of plastic deformation and acoustic relaxation in HEA $Al_{0.5}CoCrCuFeNi$ made it possible to establish:

- the most important types of dislocation defects in the lattice structure of the alloy;
- types of barriers that prevent the movement of dislocation lines (strings);
- adequate mechanisms of thermally activated movement of various elements of dislocation strings through barriers under conditions of moderate and deep cooling;
- quantitative estimates for the most important characteristics of dislocations and their interaction with barriers.

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