# THE FORMATION OF NANO-DEFECT STRUCTURES IN PROCESS OF DOUBLE CROSS SLIP

**(This article is devoted to memory of M.B.Abdullayev)**

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It is shown that volume defects and slip bands form because of double cross slip (DCS). At small voltages the plastic deformation takes place in shift band area an it stays constant behind the wave area. On the base of crystal AFM-images it is shown that the formation of nano-islands (NI) can be considered on the base of conception of double cross slip. The possibility of synergetic approach for the analysis of concrete phenomena developing in dislocation ensemble in the forms of slip lines and slip bands, is demonstrated.

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## INTRODUCTION

The defect formation process on the base of the conception of double cross slip (DCS) are considered in work.

The plastic deformation in crystals begins at achieving of critical value by shear stress. Moreover the dislocation loops begin to move in slip plane and expand, in the result of which the shift bands appear [1]. At deformation increase the shift bands can join to packs forming the slip bands in macrolevel [2]. The slip bands play the important role in process of plastic deformation and they are intensively studied theoretically and experimentally. The expansion of shift band takes place as a result of *(DCS)* screw dislocation regions [3-7].

The crystal deformation takes place only in front of shift band. The velocity behind the band front strives to zero in the result of the internal stresses on accumulation of their dislocation, that's why the plastic deformation inside the band stays constant. The math models describing the expansion the shift bands in the result of *DCS* action are constructed in [4-6]. However, the approach realization suggested in [4-6] have disadvantages; the assumption on constancy of dislocation rate of motion contradicts to experiment data on dislocation deceleration inside shift band [3]. The math model of shift band distribution is constructed in [1]; the solutions describing the shift band structure considered in [3] are obtained. The scheme of slip band development in plane sample at uniaxial extension along $x_1$ axis (dislocation motion is along $x$ axis, the expansion of slip bands is along y axis) is given in [1]. Using the given scheme the plane sample which is extended along $x_1$ axis under $\sigma_1$ voltage action, is considered. The dislocation motion takes place in slip plane inclinated to $x_1$ axis on $\psi$ angle. The plastic deformation takes place because of motion of dislocation loops up to the moment of their deceleration on obstructions of different nature (impuritues and extractions). The screw region of dislocation loop can be put into neighbor slip plane under the influence of local voltages. The dislocation loop in initial slip plane rounds the obstruction and continues its motion. The time and distance of the screw segement surge has the occasional character, that's why the process of dislocation multiplication is described by kinetic balance equation [4]. Note that if the surge distance is $h < h_o$ then this segment doesn't move because of elastic interaction of surged segment with dislocation in initial plane and two edge dipoles appear in the result of surge [3]. In $h > h_o$ case the expansion of dislocation segment the motion of which leads to new *DCS* acts takes place in neighbor plane. The critical distance of segment surge is defined by formula given in [3]:

$$h_0 = \mu b / (8\pi(1-\nu)(\sigma - \sigma_f)),$$

where μ is shear modulus; $\nu$ is Poisson ratio; b is strength of dislocation; σ is voltage tangent lines; $\sigma_f$ is dry friction voltage.

In case when dislocation motion has thermoactivated character then dislocation rate of motion in slip plane is approximated b the following formula [3,7]:

$$u = u_0 \left(\frac{\sigma - \sigma_f - \sigma_\mu}{\sigma_0}\right)^m \qquad \sigma_\mu = \alpha \mu b \sqrt{\rho},$$

where $\alpha$, $u_0$, $\alpha_o$ are empirical constants; m = $H_o/(kT)$; $H_o$ is character activation energy; $k$ is Boltzman constant; T is temperature; $\alpha_\mu$ is voltage caused by interaction of given dislocation with nearest surrounding.

The plastic deformation begins from $\sigma > \sigma_*$ equation carrying out where $\sigma_* = \sigma_f + \sigma\mu$ is shift critical voltage. The dislocation velocity υ in direction perpendicukar to slip plane is defined by diffusion of point defects.

The deformation linearly increases at shift from wave front to band center. This solution can be interpreted as deformation localization taking place because of voltage increase in region of shift band development.

Our aim is the consideration of NI mechanism, their coalescence and coagulation on the base of DCS conception.

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## EXPERIMENT AND DISCUSSION

The samples are obtained by the method of directed crystallization at hot zone temperature 900K. The plates with surface orientation *(0001)* are cut from the samples. The mechanical treatment isn't carried out.

The electron-microscopic images are obtained on atomic-force microscope (AFM) of *SOLVER NEXT* mark.

NI of (0001) $A_2^V B_3^{VI}$ semiconductor surface and processes of heir localization taking place in the result of DCS are considered.

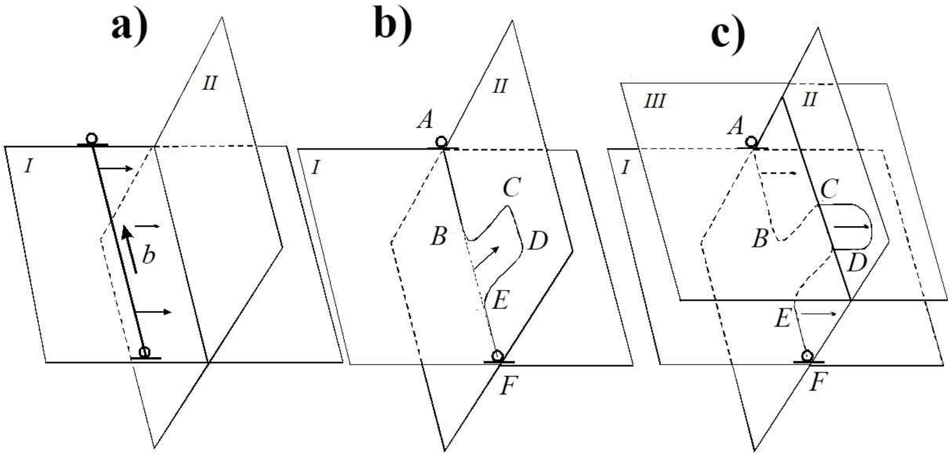


*Fig. 1. DCS* scheme.

*Fig.2. AFM*-images $Bi_2Te_3$*<Se>, NI* are ordered formed nano-islands on the places of dislocations on surface (0001).

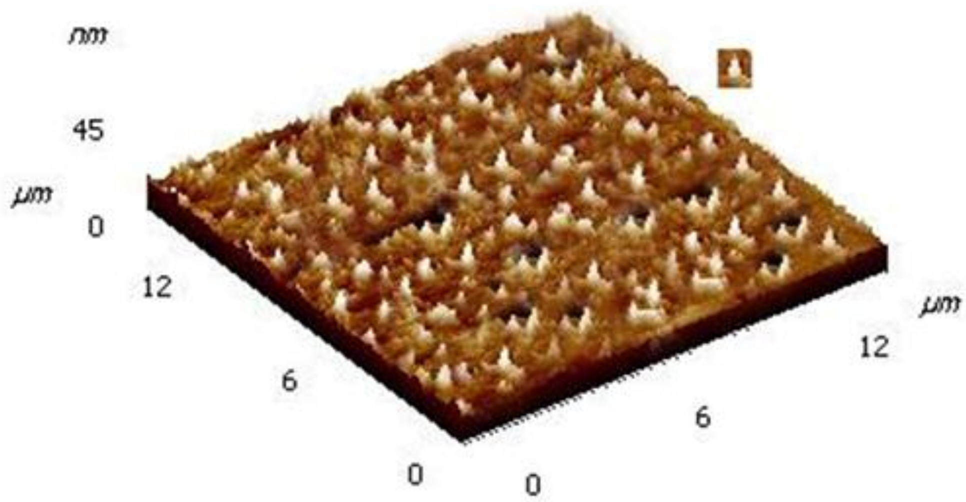


*Fig.3. AFM*-images in 3D-scale on surface $Bi_2Te_3$ *<Ni>*. Here the "smeared" nano-islands (NI) round, which the nano-islands (NI) of small sizes presenting the places of cross slip take place, are seen.

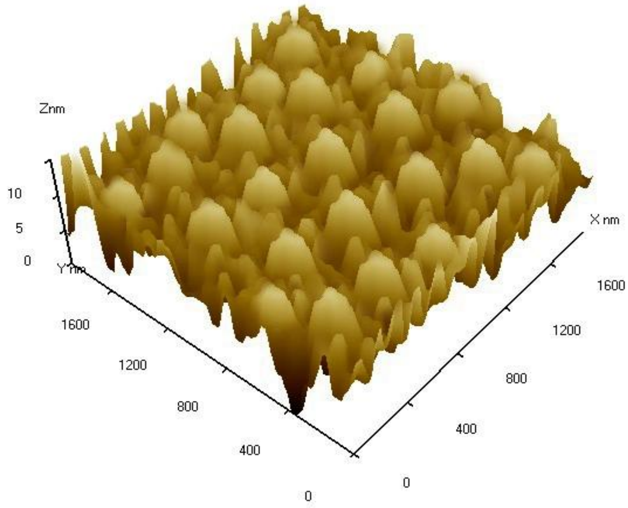


*Fig.4. AFM*-images by height 10nm of big and small NI on surface $Bi_2Se_3$. The aligning arrangement of such NI can be evidence of their redistribution in process of cross slip of screw dislocation.

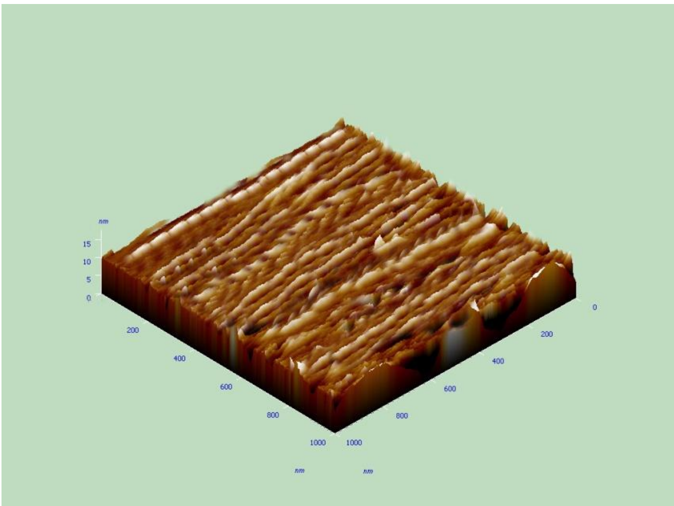


*Fig.5.* Line defects in solid solution $Bi_2Te_3$ *90mole%*- $Bi_2Se_3$ presenting the localized slip lines in layered semiconductors of $A^V{}_2B^{VI}{}_3$ type.

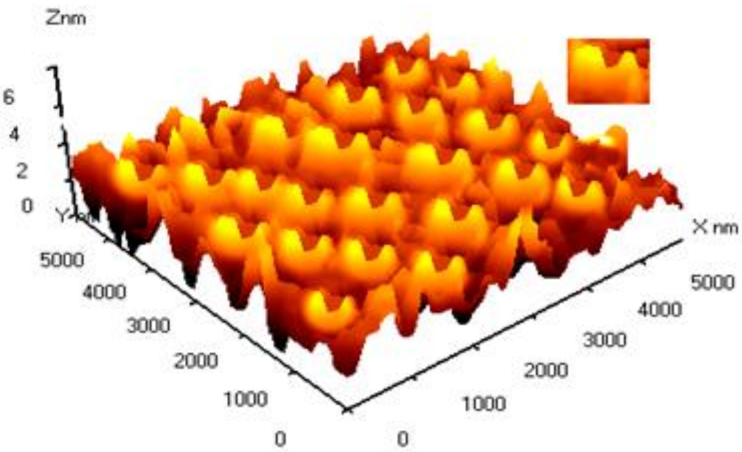


*Fig.6.* Double *AFM*-images $Bi_2Te_3$ *<Ni>* characterising *DCS* mechanism. The double nano-islands with the saddle characterising the transition of slip lines is emphasized in right in insertion.

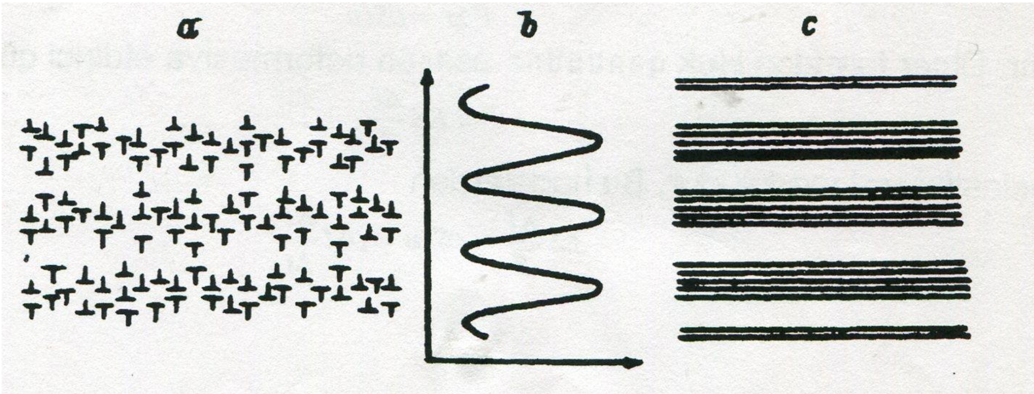


*Fig.7.* Microscopic (a) and mezoscopic (c) levels of self-organization>dislocation in slip lines. Such lines are experimentally revealed and presented in fig.5. This circumstance is revealed in the form of thin and more rude slip lines visible in optic microscope on crystal surface. The heterogeneity of deformation redistribution in crystal is the result of space-heterogeneous distribution (in the fiven case layered one) of mobile dislocation density in it.

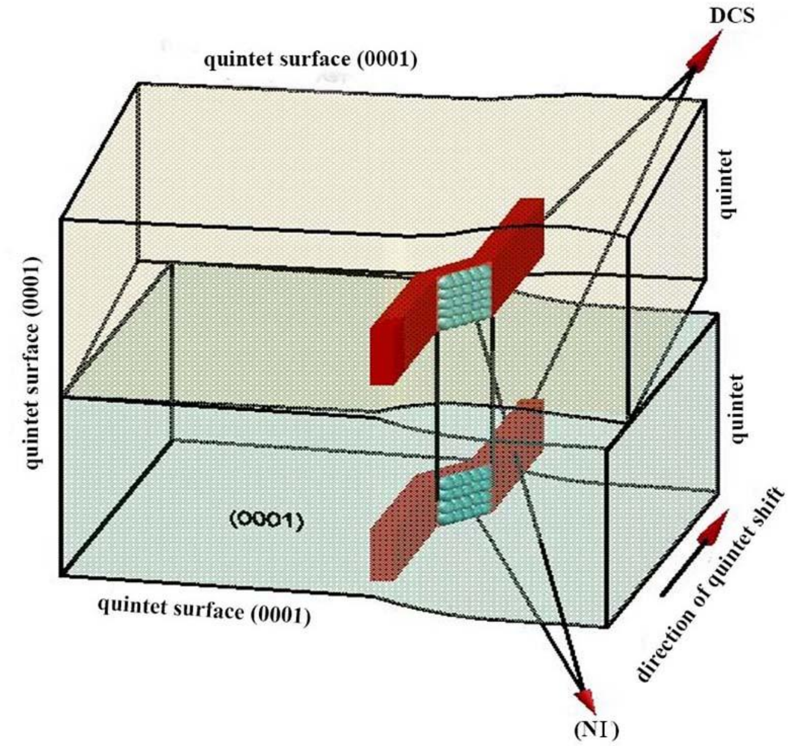


*Fig.8. DCS* scheme with screw dislocation between two quintets $A_2^V B_3^{VI}$.

## CROSS SLIP IN $Bi_2Te_3$

The multiplication of dislocations and the precipitation of impurities in dislocation pits can be considered in limits of cross slip of screw dislocations. Note that the screw dislocations (SD) in $Bi_2Te_3$ and $Sb_2Te_3$ compounds have the ability to cross slip.

Let's consider the slip circuit including *DTS* in which screw dislocations *AF* (see fig.1a) have the main (I) and additional (II) plane of cross slip.

If the obstruction in the form of impurity or defect appears in plane of primary slip in *CE* direction (see fig.1b) then *AF* dislocation can change the direction and conntinues the slip by plane *II* showing *BCDE* double kink in this plane.

Such transition of dislocation part from one plane to another one for $Bi_2Te_3$ can be cross slip. (0001) is the main plane of slip in layered crystals of $Bi_2Te_3$ type. The plane perpendicular to (0001) $Bi_2Te_3$ one (fig.1b) should be the plane (*II*) of cross slip; it presents itself *BCDE* kink; the motion directions in all planes are shown by arrows.

The first kink *BCDE* moving in *II* plane can carry out the cross slip moving to *III* plane parallel to main plane (fig.1.c).

Such two consistent acts of cross slip can form as *DTS*. The localized *NI* are their example (see fig.2-5). Burger vector change in II plane for bismuth telluride is shown by arrorw (see *DTS* circuit, fig.1). Moreover, the dislocation changed the slip plane for the second time transits into parallel surface level or on surface of nearest quintet of crystal lattice.

In principle, the multiple cross slip when dislocation changes the quintet planes many times with more profitable thermodynamic conditions of slip and formation of *(NI)* nano-islands on dislocations, is possible.

The nano-islands settled in places of *ABCDE* paired kink are shown in fig.2-6.

Such paired kinks can be in interplanar space in planes of cross slip.

Earlier such places of accumulations in (0001) $Bi^V{}_2Te^{VI}{}_3$ plane form the different volume defects [8,9]. *NI* and their accumulations are especially interest ones, AFM-images of such structures are presented in fig.3-6.

The wide diversity of forms and sizes including the linear defects (see fig.5) are seen in fig.5-6.

If one can consider *NI* as settling impurities on dislocation surface (0001) $Bi_2Te_3$ then cross slip area can be considered as places of formation of different nano-islands.

Moreover, one can consider *DCS* character on interlaminar surface (0001) $Bi^V{}_2Te^{VI}{}_3$ by density and line dislocation.

The scheme of short-wave thin slip lines is given in fig.7. This demonstrates the corresponding layered distribution of dislocations on microscopic level.

The existing of several scale levels of slip localization is the character feature of plastic deformation.

**SLIP BANDS**

The appearance and widening of slip bands in crystals is the another character element of initial degree of crystal deformation. The kink bands causing the lattice disorientation between neighbor crystal volumes are the special case of deformation localization on its initial degree. The theoretical analysis of formation mechanism of both type bands is based on nonlinear equations of dislocation local density evolution. The solution examples of these equations in the form of stationary moving fronts are in [3] (in case of slip bands), in [6] (in case of kink bands), in [7] (in case of Luders bands in polycrystals).

The another difference of present approach to the problem is in the fact that formation of slip of lines and bands can be considered in the limits of one system of initial dislocation equations using the slip lines.

The density of dislocation sources also defines the conditions of appearance and stable expansion of slip bands. For band appearance it is necessary that dislocation source density is less than some critical value.

The interaction of such system open to each other and external influence leads to formation of essentially nonequilibrium space and time structures with thermodynamic point of view.

The formation mechanism scheme of other heterogeneous dislocation structures in more late deformation stages from the given positions is given in fig.8.

**CONCLUSION**

The math development model of plastic deformation because of action of DCS mechanism and also the solution of running wave type and its structure are analysed. The stability of single crystal heterogeneous state has been investigated. It is seen that if the disturbance is in instable region then its growth takes place after that two shift bands each of which is described by solution of running wave type propagate in opposite directions.


[1] *S.P. Kiselev.* Prikladnaya mexanika I texnicheskaya fizika. 2006. T. 47, № 6, s. 202-113. (In Russian).

[2] *A. Chiqenbayn, Y. Plessinq, Y. Noyxayzer.* Fiz. mezomexanika. 1998. T. 1, № 2. s. 5-20. (In Russian).

[3] *B.M. Smirnov.* Dislokachionnaya struktura I uprochnenie kristallov. L.: Nauka. Leninqr. otd-nie, 1981, s 323. (In Russian).

[4] *G.A. Maliqin.* Uspexi fiz. nauk. 1999. T. 169, № 9. s. 979-1010. (In Russian).

[5] *P. Hahner.* Theory of solitary plastic waves. 1. Luders bands in polycrystals. Appl. Phys. A.1994. V. 58. P. 41-48.

[6] *P. Hahner.* Theory of solitary plastic waves. 2. Luders bands in single glide-oriented crystals. Appl. Phys. A. 1994. V. 58. P. 49-58.

[7] *S.P. Kiselev.*Vnutrennie napyajeniya v tverdom tele s dislokachiyami PMTF. 2004. T. 45, № 4. s. 131-136. (In Russian).

[8] *F. K. Aleskerov, S.Sh. Kaxramanov, K.Sh. Kaxramanov, E.M. Derun, M.G. Pishkin.* J. Fizika. tom XII, № 4, 2006, s. 33-40. (In Russian).

[9] *A.P. Alieva, S.Sh. Kaxramanov, F.K. Aleskerov, S.A. Nabieva, K.Sh. Kaxramanov.* J. MNPK «Sovremennie informachionnie I elektronnie texnoloqii».2015, s. 287-288. (In Russian).


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