PECULIARITIES OF GENERATION AND TRANSPORT OF STRUCTURAL DEFECTS INDUCED BY THE LASER IRRADIATION

Alexander E. Pogorelov

G.V. Kurdyumov Institute for Metal Physics, NAS, Vernadsky 36, 03142, Kiev, Ukraine

ABSTRACT

In this work we discuss the peculiarities of generation and transport of the structural defects caused by external pulsed action on a crystal and, in particular, by a laser irradiation. The conditions for such processes to take place are defined and a novel approach is proposed for studying the kinetics of transport under the pulsed laser irradiation. Taking into account electronic character of a thermal conduction in metals a general model for the transport in pulse deformable crystals is presented.

Key words: crystal, structural defects, dislocations, mass-transport, thermal conduction, laser irradiation

INTRODUCTION

High-speed deformation of metals in the solid phase leads to the generation and migration of lattice defects at large distances. As shown in [1,2], dislocations are the most likely carriers, in particular of the mass. Their formation during pulsed laser irradiation has been confirmed experimentally in [3]. Direct study of concentration changes with the use of radioactive isotopes have shown that a region with a high content of dislocations (30 ÷ 40 micron) is several times larger then the area of mass transfer [4]. At the same time the mass-transfer occurs to the depths several times exceeding the area of thermal influence of a laser pulse.

CRITERIONS AND ANALYSIS

Processes of transport occurring in a crystal have a threshold nature and are determined by the criterion setting the boundary between the stationary state of the matter and its existance in highly nonstationary state [5]. This boundary can be set by comparing the time t_i the energy is supplied into the substance and time t_r of its relaxation. In a case if $t_i \geq t_r$ the relaxation processes occur in a stationary or quasi-stationary state. If $t_i <$ or $\ll t_r$, the state changes from the quasi-stationary to highly nonstationary.

Besides, for the dislocations to be generated in the crystal it is required that the portion of the energy supplied into it was sufficient to create stresses σ larger than the Young's modulus E. For the motion of dislocations it is sufficient that stresses developed by an energy pulse $\sigma > 10^{-4} \div 10^{-2}\,E \approx \sigma_p$ (Peierls stress). When selecting the mode it is important to remember that high portions of energy may result in crystal fracture.

When the region *d* is irradiated by axisymmetric laser beam the required criterion is in first approximation determined as

$$t_c = \pi d^2/4a, \quad (1)$$

Where *a* - a material thermal diffusivity. As follows from (1) the critical time t_c of the energy supply strongly depends on the size of irradiated area. When irradiating metals by laser impulses in a free generation mode ($\tau_i \approx 10^{-3}$ s) or by continuous irradiation the relaxation is limited only by the thermal conduction mechanism. The value of thermal gradient during such irradiation does not cause significant deformations, which could lead to the formation of excessive number of structural defects such as dislocations and interstitial atoms.

The irradiation of metals by huge laser pulses with $\tau_i \approx 10^{-8}$ s cannot restrict the energy drain only to the thermal conduction mechanism. This process causes a significant temperature gradient accompanied by the rapid thermal expansion of the irradiated area and occurrence of thermal stresses σ.

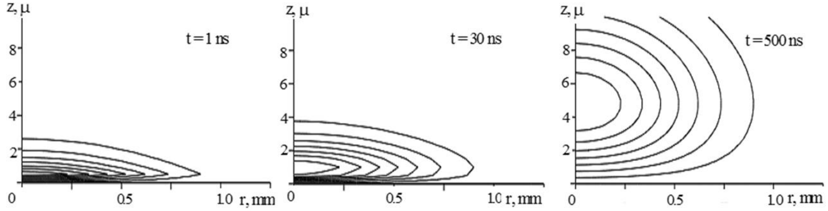

Fig. 1 – Maximum of the thermal stresses gradient is moving from laser irradiated surface deep into the crystal.

The relaxation of the energy by unrelaxed thermal conduction occurs through the appearance of a shock wave in a metal and generation of the excess number of structural defects of all types. The density of dislocations *ρ* arising as a reasult of these processes is determined from [1]

$$\rho_j(z,t) = \rho_{j-i} - \frac{2\alpha}{(1-\nu)b}\int_1^n \nabla T(0,z,\lambda\tau)d\lambda \quad (2)$$

where *α* – thermal expansion coefficient of the metal, *b* – Burgers vector, *ν* – Poisson's ratio, *n* – number of laser actions.

RESULTS AND DISCUSSION

Figure 2 shows the dislocation density as a function of the depth z of the pulsing laser influenced *Armco-Fe*, calculated using the formula (2) and compared with the experimental data obtained in [3].

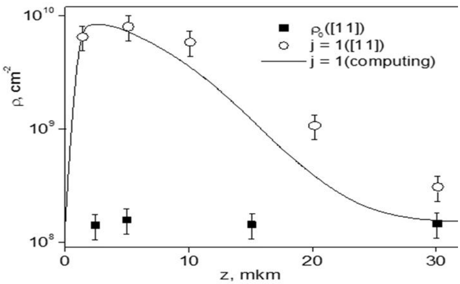

Fig. 2 – Dislocation density vs. depth z of pulsing laser influenced Armco-Fe.

Figure 3 presents schematics of generation and transport of the structural defects caused by a laser irradiation.

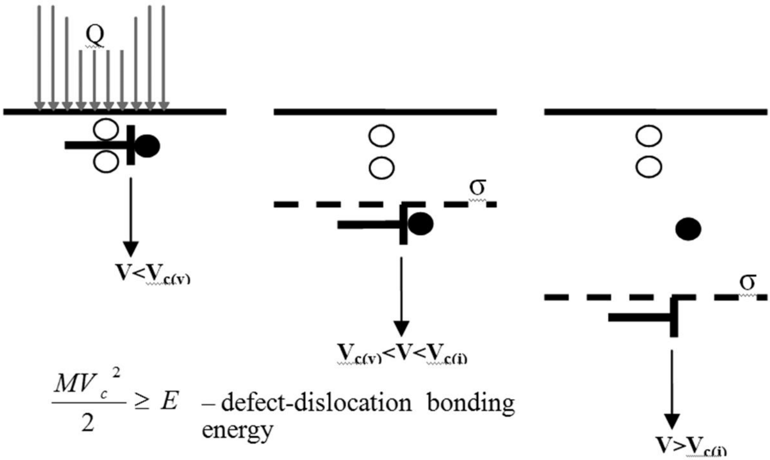

Fig. 3 – Generation and transport of structural defects caused by a laser irradiation

The particular interest in studying of the structural defects generated and migrating under the influence of a laser irradiation is their detection in real time. It has been noted that when measuring a thermal diffusivity by the laser flash method [6], the increase of temperature *T* on the opposite side of the flat sample of the given thickness reaches values *T/2* for different time $t_{1/2}$ for a different pulse length. Moreover, the value of $\Delta t_{1/2}$, which is the determining parameter in the calculation of *a*, does not exceed the time required for the acoustic wave to pass through the sample. Considering the electronic nature of a thermal conduction in metals and above discussions, a general model for the transport in pulse deformable crystals is proposed. Also proposed is the technique to study a kinetics of transport under specified conditions.

CONCLUSIONS

Under conditions of pulsed deformation of crystals a directed transfer of point defects (PD) is carried out. These defects are produced due to displacement and interaction of dislocations, which are trapping and transporting PD during directional movement in the field of dynamically varying stresses σ. Movement of such a complex «dislocation + PD» is happening until its kinetic energy $\mathbf{V_c}$ becomes higher than the defect-dislocation bonding energy **E**. When moving with the speed higher critical value the dislocation is dropping an atmosphere containing vacancies while its core is continuing the movement together with trapped interstitial atoms. As a result the near-surface layers are being saturated with vacancies. At the same time the deeper layers are saturated with interstitial atoms, entrained by dislocations to larger depth from the near-surface layer.

REFERENCES

[1] A. Pogorelov, A. Zhuravlev. Defect and Diffusion Forum. Switzerland, Scitec Public., V.194-199, 2001, P. 1247-1252.
[2] A.E. Pogorelov, K. P. Ryaboshapka, A. F. Zhuravlev. JAP, 92(2002), p. 5766-5771.
[3] P.Yu. Volosevich, A.E. Pogorelov. Poverhnost. Fizika, himia, mehanika, 9(1986), c. 126-130.
[4] A.E. Pogorelov. PhD Theses, Kiev, 1985.
[5] A. Pogorelov. International Conference NANO-2010, Ukraine, Kiev, October 19-22, 2010, P. 162.
[6] M.E.Gurevich, A.E. Pogorelov. – In: «Fizicheskie metody issledovania metallov». Kiev, Naukova dumka, 1981, P. 3-23.