Evolution of the microstructure of the near-surface copper layer during thermal cycling by nanosecond laser pulses

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The mechanisms of surface relief formation on bulk copper samples under the influence of laser pulses (duration 10 ns, wavelength 355 nm) in the preablation mode are investigated. It has been experimentally established that during irradiation at energy densities of 0.60–1.05 J/cm^2, a characteristic system of protrusions/depressions is formed on the surface of samples in local areas near grain boundaries, the height/depth of which reaches 500 nm. Using optical profilometry, confocal scanning laser microscopy, and transmission electron microscopy, the deformational nature of the emerging relief has been established. At the same time, traces of plastic deformation development are found in the thin surface layer near the grain boundaries: nanoscale twin plates, dislocations, and small-angle dislocation boundaries. Molecular dynamic modeling has shown that the main physical reason for the development of the considered relief is the anisotropy of thermal expansion of variously oriented grains (crystallites) during cyclic heating to pre-melting temperatures. It is established that thermomechanical stresses arising in the subsurface layer exceed the yield strength of the material, which leads to irreversible plastic deformation. The accumulation of structural changes with an increase in both energy density and the number of pulses is shown. The results obtained are important for understanding the mechanisms of degradation of the metal structure under cyclic pulsed thermomechanical loading and can be used, in particular, to develop methods to increase the operational resistance of metal optics.