Development of the Theory of Multicomponent Media for Describing Dynamic Processes in Materials of Complex Rheology

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Abstract. In the present paper we consider the problem of describing the dynamics of material with complex rheology, when it is necessary to take into account that it consists of several subsystems with different relaxation times. Such approach, in which the deformable solid is considered as a multicomponent medium, greatly expands the possibilities of continuum mechanics allowing to describe the processes, occurring at different scale levels. Here this problem is demonstrated by using the example of the interaction between the crystalline lattice and the electron gas. The experiments on different conductors demonstrate that their dynamic response on a laser pulse of nanosecond duration is different from the form predicted by classical theory of thermoelasticity. In this case it should be supplemented by equations describing kinematics of the electron gas, which may exert a serious influence on behavior of the lattice, resulting in significant increase of the stretching phase in comparison with the classical solution.

Keywords: Thermoelasticity · Dynamic response · Electron gas

Dynamic problems describing the mechanical processes in one of the components in materials with complex rheology are of great interest. In such materials, processes in one of the components are accompanied by relaxation processes, leading to significant changes in the structures of the other components [1, 2]. In an experimental study, such transformations are usually accompanied by a subsequent slow relaxation, characterized by responses with lower-frequency spectra.

As is well known, the main difference between multicomponent models of a continuous medium and the theory of mixtures is the possibility of considering the kinematics of each component without reducing the element of a continuous medium to a single velocity of the center of mass while maintaining the connection between the degrees of freedom through internal interaction forces and source terms contained in the balance equations masses for each component.

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This problem occurs when the laser is exposed to the surface of multicomponent materials. Among such materials, an important case is represented by conductive materials (metals, semiconductors). In addition to the dynamical processes in the lattice, kinematic processes in the electron gas are awakened in parallel. The interaction of electrons and lattice leads to the need to consider the processes in both subsystems of conductors simultaneously.

This approach becomes especially important in the study of dynamic processes under the action of laser radiation. In this case, the laser radiation energy, as a rule, is absorbed by the electronic subsystem in the first stage of the interaction and is transferred to the lattice only as a result of the subsequent interaction. When considering fast processes (femto-picosecond range), this situation leads to the need to use a two-temperature model in which the electron gas and lattice temperatures have different values [3].

In this case, the classical, coupled equations of thermoelasticity, taking into account the effect of laser irradiation only through thermal and thermoelastic phenomena in the crystal lattice, do not completely describe the formation of the acoustic pulse. Due to this fact, in this paper we study the problem of the influence of dynamic processes in the electronic subsystem on the deformation processes in the lattice. It is shown that accounting for the electronic processes can lead to a qualitative modification of deformation processes in conductors. In particular, they are significantly lengthen relaxation time in comparison with dynamic processes that take into account only the lattice component.

The development of modern methods for the diagnosis of defects in materials (first of all in metals) essentially depends on the physics of deformation processes in lattice. Their development is of paramount importance for acoustic methods, which are based on recording the deformation processes of the material lattice. Thus, the problem of describing the formation of a dynamic response in a lattice of conducting materials with allowance for the excitation of an electron gas is a fundamentally new fundamental problem.

The physical model developed for the first time which takes into account the impact of the heated electron gas on the dynamic of the crystal lattice not only due to the thermal expansion of the lattice, but also due to an additional reaction caused by the dynamic motion of the electrons themselves. In this case, the effects of excitation of the electron gas and electron-drag effects due to the motion of the thermal fronts are considered taking into account the interaction with the lattice component of the material.

In its essence, classical thermoelasticity is expanded by additional equations that take into account the dynamics of electrons, as well as their variable composition [4]. Within the framework of the proposed model, the features of deformation processes near certain model defects in conducting materials action are considered under laser irradiation.

The proposed model is implemented in the software product and tested in accordance with the experimental data. In particular, the experimental data obtained by laser ultrasonic methods for metals indented by Vickers and Rockwell test methods are given [5–7].

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