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NONTHERMAL MECHANISM RESOLVED A PARADOX OF SLOW ELECTRON-PHONON COUPLING VS. FAST ION TRACK HEATING*

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For over two decades, there has been a puzzling discrepancy between slow electron-phonon coupling and creation of tracks swift heavy ions (SHI) decelerated in the electronic stopping regime. Due to fast cooling down of excited electrons (less than 100fs), track formation requires extremely fast energy transfer from the excited electrons to atoms [1]. In contrast, laser-irradiation experiments measured much too slow electron-phonon energy exchange rate, which is supported by various calculations [2]. This paradox lead to a widespread use of electron-phonon coupling as a fitting parameter in calculations of SHI track creation.

We resolve this contradiction noticing that electron-phonon coupling is not the sole mechanism of energy exchange between electrons and atoms in solids. Heating of electrons alters potential energy surface of atoms. Appearing forces due to modification of the interatomic potential accelerate atoms increasing their kinetic energy (”nonthermal heating”) [2]. This nonthermal mechanism may be extremely fast, significantly faster than the electron-phonon coupling. At high deposited doses it may even lead to ultrafast nonthermal structure transformations.

It suggests that the estimates of the ”electron-phonon coupling parameter” extracted from the data on SHI track sizes with help of the two-temperature (inelastic thermal spike) model do not reflect the electron-phonon coupling per se, but must be interpreted as a quantity reflecting the nonthermal heating of atoms (with a contribution of phononic and non-phononic elastic scattering of hot electrons and valence holes) [2]. This notion reconciles the much debated problem of extremely fast atomic heating in swift ion impacts (at hundred femtosecond timescales) with slow electron-phonon coupling (acting at picosecond timescales).

Our results suggest that the nonthermal heating of atoms is a universal effect in nonmetallic crystalline materials under ultrafast energy deposition, and thus must be taken into account in appropriate models and interpretation of experiments [2].

REFERENCES

[1] [A.E. Volkov, V.A. Borodin, Nucl. Instruments Methods Phys. Res. B. 146 (1998) 137–141

[2] [N. Medvedev, A.E. Volkov, (2021) https://arxiv.org/abs/2109.04401v1

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