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Modeling of ultrafast laser induced electron emission from a sharp tip[1]

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The emission mechanism of ultrafast laser induced electron emission from a sharp metallic tip has attracted considerable interest in recent years due to its applications, such as ultrafast electron-beam based imaging at nanometer scale, and also as high brightness short electron bunches for applications in future light sources such as x-ray free-electron lasers. The underlying electron emission mechanism is difficult to pin down as it occurs in the region of Keldysh parameter $\gamma \sim 1$, which is between the multiphoton ($\gamma >> 1$) and tunneling $\gamma << 1$) regimes. In this paper, we will present a consistent time-dependent quantum model that is able to combine the effects of (a) time-dependent tunneling, (2) ultrafast laser non-equilibrium excitation on metal, and (3) field gradient on the tip. It is found that the onset of the tunneling regime is given by a universal formula, depends only on the work function over a wide range of laser parameters. More interestingly, the classical concept of photoelectric effect for electron emission by absorption N number of photons is no longer valid at very short time scale for which the required N may be reduced by a photon by using a sub-10 fs ultrafast laser. The non-equilibrium electron distribution due to ultrafast laser excitation is also self-consistently included with good agreement with experimental findings. Due to the close correlation between the amount of electron emission and the phase of the ultrafast laser pulse, this model may provide a new way measure the phase of the laser. While the model is initially focused on metallic tip, it is ready to extend to novel materials such as single-layer graphene, for which a relativistic quantum model has been created to include the effect of Klein tunneling. These results show that traditional equilibrium models in the electron emission process will require a revision in the limit of ultrafast time scale, when the laser pulse length is comparable or shorter to the tunneling time, and also to the electron relaxation time. Dependence of laser parameters (wavelength, pulse length, phase) and material properties will be studied thoroughly.

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