Time-dependent Theory of Laser-assisted Auger Decay induced by ultra-short Pulses

N. M. Kabachnik [1,2], A. K. Kazansky [3,4]

[1]*1. Institute of Theoretical Physics, Hamburg University, 20355 Hamburg, Germany*
[2]*Institute of Nuclear Physics, Moscow State University, Moscow 119991, Russia*
[3]*Fock Institute of Physics, the University of St.Petersburg, St.Petersburg, 198504, Russia*
[4]*Donostia International Physics Center, Paseo Manuel de Lardizabal, E-20018 San Sebastian/Donostia, Basque Country, Spain*
E-mail: nkabach@mail.ru

Abstract: A theoretical description of Auger decay induced by ultra-short pulses in the presence of a strong laser field is presented. It is based on a numerical solution of the time-dependent Schrödinger equations describing the Auger process. Appearance of the sidebands and their gross structure are discussed.

With the advent of attosecond physics, the time evolution of Auger relaxation processes in atoms and solids attracts ever increasing attention [1,2]. Typical Auger relaxation time is in the interval of a few femtoseconds - hundreds of attoseconds, which makes the Auger decay accessible for studying in time domain using attosecond technique. In pioneering experiments by Drescher et al. [1] the Auger process in Kr atoms has been investigated using a pump-probe approach. The inner atomic shell of Kr was excited by a subfemtosecond XUV pulse (pump) and the emission of Auger electrons was probed by a few-cycle infrared pulse of a strong laser field. Such technique implies that the Auger process is initiated by an ultra-short pulse with a duration comparable with the lifetime of the Auger state under consideration. This means that the excitation and the decay of the Auger state should be considered as a single process of resonant double ionization. Besides, the Auger decay occurs in the strong field of the IR laser which modifies the spectrum and angular distribution of the Auger electrons. Thus a consistent theoretical description of such an experiment should take into account both aspects: short-pulse excitation and autoionization in a strong laser field.

In this report a quantum mechanical theory of laser assisted Auger process in atoms excited by an ultra-short (attosecond) electromagnetic pulse in the field of a few-cycle strong laser pulse is presented [3]. It is based on the non-stationary Schrödinger equation, which describes the photoionization of an inner atomic shell and the decay of the created vacancy, while the Auger electron is treated in the strong field approximation. As an example, photoionization of the Ne 1s shell with the subsequent KLL Auger transition is considered. The spectra and angular distributions of photoelectrons and Auger electrons are calculated and discussed. The photoelectron spectra show a typical picture of streaking in the laser field. In contrast, the Auger electron spectrum contains sideband structure, however different from the conventional equidistant sideband structure, which had been discussed for longer pulses and smaller Auger-electron energies. The predicted sideband structure strongly depends on the delay time between the laser pulse and the X-ray pulse. It is very sensitive to the carrier-envelope phase as well. A simplified description of the Auger electron spectra in laser-assisted Auger decay, which gives the sideband structure in close agreement with the results of the exact theory, is suggested.

This description, which is similar to that developed in [4], is further used for the analysis of the sideband structure in angle-resolved Auger electron spectra [5]. We have shown that the structure strongly depends on the observation angle. The origin of this phenomenon is discussed, and it is demonstrated that the standard sideband picture appears after integration over all angles. We have shown that in angle-resolved measurements the sideband spectra exhibit a rather robust gross structure [6] which depends on the laser wavelength and intensity, but is practically independent of the laser pulse duration and of the delay time between the laser pulse and the x-ray pulse which induces the Auger transition. While the origin of the sidebands is the interference between the Auger electrons emitted at the same phase but at different periods of the laser field, the gross structure appears due to interference between electrons emitted during one period. The gross structure strongly varies with the observation angle. It disappears in angle integrated measurements.

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