Quantum effects in optical spectra line shapes and electronic relaxation in quantum dots

Karel Král

***Index Terms*—electron-phonon interaction, electronic relaxation, optical spectra, quantum dots.**

Attention is paid to the line shape of the optical transitions which are sometimes measured on individual quantum dots of polar semiconductors.

It has been shown a time ago that one of the strongest electron-phonon scattering mechanism in bulk polar semiconductors, like GaAs, is the coupling of charge carriers to the longitudinal optical (LO) phonons. This electronic scattering mechanism was shown to have a strong influence on the electron energy relaxation intensity in the bulk materials. In an analogy with this role of the LO phonons one can expect that also in zero-dimensional structures, like quantum dots, in which a charge carrier moves in a material of the type of polar semiconductor, and in which the charge carrier motion is confined in all three dimensions, the interaction of charge carriers will be strongly influenced by the coupling to the LO phonons.

Earlier the line shape of the optical transitions, represented by spectral line profiles given by electronic spectral densities calculated from electronic Green's functions, were presented to show that these line profiles have a shape of narrow lines having one broad shoulder [1]. The line shapes were shown to have the functional dependence, on the frequency variable, or on the energy variable E, as 1/sqrt(E). This theoretical result was obtained in the self-consistent Born approximation to the electronic self energy in individual quantum dots.

In the present work the theoretical analysis will be extended beyond the two-electronic-levels theoretical model of the quantum dot and the electron-LO-phonon coupling will be again given the principal role in the calculation. The calculated electronic spectral densities will be compared with the available experimental and theoretical data on the optical line shapes and on the electronic spectral densities in individual quantum dots.

Manuscript received February 8, 2007. This work was supported in part by the grant of MSMT ME 866 OS.

K. K. Author is with the Institute of Physics of ASCR, v.v.i., Na Slovance 2, 18221 Prague 8, Czech Republic (phone: +420 2 66052772; fax:+420 2 86890527; e-mail: kral@fzu.cz).

Basing on the above mentioned line of the theoretical interpretation of the rapid electronic kinetics, we can also detect certain shortcomings of this theory, namely those connected with the effect of an excessive LO phonon heating introduced in paper [2]. We shall briefly summarize the proposed origin of the effect, together with describing the way how this undesired and in some sense artificial effect may be eliminated from kinetic equation description of electrons in quantum dots.

The electronic overheating effect has been analyzed numerically for the case of one electron in a single quantum dot. It has been shown that in the case of a single electron per quantum dot the electron kinetics is not much influenced by the theoretical procedure of suppressing the overheating effect. In the present work we would like to show how much the electronic optical line shape properties and the electronic transport properties, like the electron energy relaxation, at low densities of electrons per single molecule are influenced by the theoretical procedure of removing the overheating effect.

The problem of the rapidity of the electronic relaxation in a single dot in the case of low number of electron per dot may be related to the interpretation of the recent experimental detections of the electronic relaxation rate under the condition of very weak excitation of the samples, when the number of electrons per dot is expected to be very low. In some of these experiments even in this low-excitation limit the effect of the up-conversion may seem to depend on the intensity of exciting the sample and may thus lead to the interpretation of the experimental observations with help of an Auger effect mechanism, although the average density of electrons in the sample is low. Keeping this question in mind we can therefore present the numerical data on the dependence of the relative electronic relaxation rate at low electronic densities and see how this rate depends on the procedure of suppression of the overheating. It is certain that we present only an estimate of effects under consideration and the problem deserves a much deeper analysis in future.

Conclusions about the role of the electron-LO phonon coupling in quantum dots will be drawntogether

with the implications for the theory of application of quantum dots in electronic nanodevices.

REFERENCES

[1] K. Král, Z. Khás, Phys. Rev. B **57**, R2061-R2064 (1998).