PHOTOIONIZATION AND PHOTOABSORPTION IN QUANTUM-DOT NANOARRAYS AND SINGLE-ELECTRON TRANSISTORS: THEORETICAL RESULTS AND EXPERIMENTAL IMPLICATIONS

Ioan Baldea,[*] *H. Köppel, and Lorenz S. Cederbaum*

Theoretische Chemie, Physikalisch-Chemisches Institut, Universität Heidelberg, Im Neuenheimer Feld 229, D-69120 Heidelberg, Germany
ioan.baldea@pci.uni-heidelberg.de

In this contribution, we report results of the extensive recent and ongoing work done at the University of Heidelberg on nanoarrays of metallic quantum dots (QDs) and nanoelectronic devices.

Basically, regular nanoarrays of assembled QDs can be characterized by three parameters: the hopping integral t, the charging energy (self-elastance) U, and the mutual elastance V. They depend on the dot size $2R$ and the interdot spacing D, and can be tuned in broad ranges, especially because t exponentially decreases with $d=D/2R$ [1]. Our studies on QD-nanoarrays were mainly devoted to nanorings consisting of QDs of silver [2-7]. For potential applications, the broad tunability is important, because one can hope to fabricate nanodevices with designer specified functional properties. For the fundamental science, the tunability is important because it enables to *continuously* drive a nanosystem from a weak to a strong electron correlation regime by varying d from $d\approx1$ to $d\approx2$. In spite of the hard work in the last two decades, e.g., in connection with high-T_c-superconductivity, the latter regime is still confronted with numerous open issues, and tracing back continuously to the uncorrelated limit can offer very useful clues.

Our works on Ag-QD-nanorings demonstrated intriguing correlation effects: in spite of the strong correlations [2], the optical and ionization spectra are astonishingly scarce [3-7]. This points towards a hidden quasi-symmetry and suggests a generalization of the Landau theory of interacting many-electron system [4,6]. Besides, in this contribution we will emphasize a new aspect related to this issue, which has experimental implications: the scarce spectra are not confronted with the problem of resolving certain more or less intense signals from the background signal, and this can be exploited to accurately extract the parameters t, U, and V. This is schematically visualized in Figs. 1 and 2. At small d, correlations are weak, and the optical gap (Fig. 1) and the lowest (HOMO) ionization energy (Fig. 2) are determined by t, while at larger d, correlations become strong and they are determined by the electrostatic interactions (U, V). So, the parameters can be deduced from the limiting cases $d\approx1$ and $d\approx2$.

In addition to the aforementioned parameters, other parameters are also important for QDs embedded in a nanoelectronic device — e.g. single-electron transistor (SET) —, namely, the device-electrode coupling t_d and the energy of the dot level ε_d. The latter, which can be controlled by a gate potential V_g ($\varepsilon_d=\alpha V_g$ + const.), can be used to tune the number of electrons on the dot n_d. The values of the latter are important e.g., for the occurrence of the Kondo effect.

Based on our recent theoretical results, we proposed to investigate SETs by photoionization [8]. To avoid confusions, we note that the photoionization we consider amounts to eject an electron from the QD into vacuum, which is completely different from the widely studied photon-assisted tunneling through a QD. Importantly, the photoionization enables to *directly* determine the dot occupancy n_d (see Fig. 3), which is directly related to the total ionization intensity [8].

[*] Also at National Institut for Lasers, Plasmas and Radiation Physics, ISS, 077125 Bucharest, Romania

Moreover, photons with tunable frequency ω can be used to separately ionize from the lower ($\omega = \omega_l \approx -\varepsilon_d$) and the upper ($\omega = \omega_u \approx -\varepsilon_d - U$) Hubbard "bands" (see Figs. 3 and 4). As visible in Fig. 3, the spectroscopic factors $f_{l,u}$ [8] of the corresponding ionization signals are nonvanishing only in the ε_d–range where the corresponding band is occupied. The ionization energies $\omega_{l,u}$ can be employed to deduce the charging energy U and t_d. Noteworthy, this is a *direct* method to determine U. In the experiments proposed by us [8], the gate potential V_g must be also varied, like in dc-measurements, but the conversion factor α is not needed, in contrast to dc-transport experiments, where α is required, and its determination is affected by typical errors ~20% [9]. Besides the ZEKE-photoelectron spectroscopy, a combined photoionization–dc-transport can be conducted, which has the advantage that measuring the intensity of the ionized signals is *not* needed, a fact that makes the experimental task considerable easier [8]. We also suggest that far infrared absorption can be an even simpler method that ionization to investigate SETs [10].

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