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On the correct form of the nonlinear optical susceptibility in strongly-driven semiconductor quantum dots

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In recent years, significant attention has been given to nonlinear optical phenomena, such as nonlinear optical absorption and dispersion, derived from a driven quantum transition of semiconductor nanostructures, such as semiconductor quantum wells, quantum disks and mainly quantum dots. An important issue that is widely studied is the effect of probe electromagnetic field intensity on the total (nonlinear) absorption coefficient and on the total (nonlinear) index of refraction. Some of the phenomena that are commonly found for large electromagnetic field intensities are the creation of a strong dip in the absorption spectrum near or at resonance (the so-called bleaching effect), negative absorption near or at resonance that leads to optical gain and the change of the slope of the total index of refraction near or at resonance from negative to positive that changes the behavior of the system from fast to slow light. Unfortunately, these phenomena do not exist and are artifacts of a common abuse of the theoretical methodology for the study of the total absorption coefficient and the total index of refraction. The main error is that the total absorption coefficient and the total index of refraction was initially derived from density matrix equations using perturbation theory and includes first-order (linear) as well as third-order (nonlinear) terms. This method gives correct results for small electromagnetic field intensities and it leads to saturation of absorption and dispersion in this regime. However, for larger intensities it gives the misleading results mentioned above due to either failure of the order of perturbation theory considered in the derivation of the total absorption coefficient and the total index of refraction or even failure of perturbation theory at all in the treatment of the problem. In this work, we revisit the problem of the total absorption coefficient and the total index of refraction in a symmetric semiconductor quantum dot structure (we choose the example of a core-shell quantum dot) under a strong probe field excitation. We use the two-level model, solve the relevant density matrix equations under the rotating wave approximation and under steady state conditions, and obtain the correct form of the nonlinear optical susceptibility that is then used for the derivation of the formulae of the total absorption coefficient and the total index of refraction under the interaction with a strong probe field. Actually, the commonly used perturbation theory formulae can be obtained by our formulae using a series expansion and keeping terms up to second order in electric field amplitude. We also derive the electronic structure of the quantum dot system by solving numerically the time-independent Schrödinger equation, under the effective mass approximation, using the potential morphing method and obtain the energy difference and the electric dipole matrix element for the relevant transitions of the quantum dot system. Then, for the specific quantum dot system we compare the results of the total absorption coefficient and the total index of refraction for the two methodologies (the perturbation result and our result) for different electromagnetic field intensities.

Biography

John Boviatsis is a Professor of Physics at the Technological Educational Institute of Western Greece, Patras, Greece. He obtained his PhD from the Physics Department of the University of Patras in 1982. He then worked as a postdoctoral researcher at the Institute for Chemical Engineering and High Temperature Chemical Processes in Patras and at the Chemistry Department of the State University of New York at Buffalo, USA. He was also visiting scientist at the Department of Physics of the State University of New York at Buffalo. From 1991-2001 he was Assistant Professor at the Technological Educational Institute of Chalkis, Chalkida, Greece. In 2001, he became Associate Professor at the Technological Educational Institute of Patras (now merged into the Technological Educational Institute of Western Greece) and in 2010 was promoted to Professor. He also held various positions at the Technological Educational Institute of Patras, including Vice-Rector of the Institute, Chair of several Departments and Vice-Chair and Chair of the Research Committee of the Technological Educational Institute of Patras. His research interests in the past decade cover theory of coherent control and nonlinear optical properties of semiconductor quantum dots and semiconductor quantum wells as well as coupled quantum and photonic nanostructures. In this area he has published several articles in international refereed scientific journals and had several presentations in international conferences.

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