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Recent advances in quantum dot physics / Nouveaux développements dans la physique des boîtes quantiques

Foreword

The purpose of this thematic issue is to present a non-exhaustive survey of recent advances in quantum dots physics. Semiconductor quantum dots (QDs) are nanometer-sized structures which confine electrons and holes in all three directions, thus giving rise to a discrete electron energy spectrum. Since the first publications confirming experimentally the specificity of the optical and electronic properties of QDs in the early 1990s, this field has flourished and evolved at a very fast pace. Spectacular and often unforeseen advances have been achieved for QD nanofabrication processes, fundamental physical studies, as well as for the exploitation of the unique QD properties for applications in optoelectronics, spintronics, as well as quantum information processing and quantum communications.

When preparing this special issue of Comptes rendus Physique, our aim has been to highlight some of the most lively and exciting topics in semiconductor quantum dots physics with pedagogical articles prepared by world-renowned specialists in the field.

Many types of QDs have been developed, but in this issue emphasis will be put on the properties of epitaxial self-assembled QDs. The first paper reviews however the properties of the chemically synthesized QDs, i.e. colloidal semiconductor QDs, and highlights some important differences with the self-assembled epitaxial QDs.

The second paper deals with a very important challenge, which is the ordering of epitaxial QDs on predetermined site-positions. Such issue is in particular a prerequisite for the reproducible fabrication of quantum devices using one/few QDs with a high yield in the future.

The next article presents a new type of epitaxial QDs, namely made of a slice of a semiconductor nanowire. This novel bottom-up fabrication process looks very promising, since it allows building QDs in lattice-matched systems (unlike standard approaches based on the Stranski–Krastanow growth mode) and provides potentially a much better control over the fabrication of individual QDs or coupled QD structures.

The next three papers are focused on the fundamental optical properties of isolated QDs. The peculiarities of GaN QDs are first presented, with an emphasis on the impact of the huge internal electric field for QDs grown along a polar axis, leading to complex dynamical behaviour. The second paper sheds new light on the dephasing mechanisms which limit the excitonic coherence inside the dot, namely the exciton-acoustic phonon coupling and the fluctuations of the QD electrostatic environment. Finally, some key optical QD properties related to their intraband transitions are described, with an emphasis on the strong coupling regime between electron excitations and optical phonons. Besides appealing for a description of electron excitation and relaxation in terms of polaron formation and decay, it also offers very novel development opportunities for mid-infrared optoelectronic devices.

The next chapter is dedicated to quantum optics experiments with isolated quantum dots. Thanks to impressive advances in the deterministic positioning of a single quantum dot within a photonic crystal optical microcavity, new light is shed on the quantum properties of QD/cavity systems in the strong coupling regime.

Finally the last three articles are focused on spin related phenomena in QDs. The first one gives a theoretical overview of the original properties which can be expected from magnetic QDs (such as new order of filling the electronic shells) and magnetic QD molecules (such as spontaneous breaking of symmetry and phase transitions). Next, recent investigations are presented, which evidence the key role played by the electron-nuclei coupling (hyperfine interaction) in the spin physics of an electron confined in a QD. This coupling can either give rise to large electron spin dephasing, or to high polarization of nuclei spins. Last but not least, some optical experiments are reported on

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isolated QDs doped with a single Mn magnetic ion, which demonstrate the optical probing and manipulation of the Mn spin. These results are the first step towards the development of new memories in which classical or quantum bits of information would be stored on the spin state of a single atom.

Finally, we warmly thank all the corresponding authors for their contributions, and especially for the efforts they have successfully made to prepare comprehensive and pedagogic papers. Grateful thanks are also due to our colleagues from the CEA-CNRS group "Nanophysique et Semiconducteurs" who have helped us reviewing the manuscripts.

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