Electronic and Excitonic Properties of [111]-oriented site-controlled GaAs Quantum Dots

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Scaling laboratory systems for quantum information processing (QIP) and quantum computing to accommodate large numbers of qubits is challenging. Photonic cluster states (PCS) offer a potential solution to this issue when used as a substrate for quantum computation [1]. However, generating these cluster states on-demand and at large scales faces significant challenges and strongly benefits from theory guidance to maximize chances of success especially when targeting multi-dimensional PCS [2].

Recent literature has targeted semiconductor quantum dots (QDs) for production of PCS. In experimental settings, generation of linear PCS using QDs [3] has been successful and fusion protocols (probabilistic at their core) have been used to create multi-dimensional PCS [4]. A key roadblock facing widely exploited QD systems (e.g., Stranski-Krastanov (SK) QDs) for producing multi-dimensional PCS stems from the lack of deterministic control over electronic and optical properties of these systems [5]. On the other hand, site-controlled [111]-oriented GaAs QDs provide an attractive option for PCS generation as they possess the significantly enhanced ability to control their structural properties [6]. In comparison to SK QDs grown along the [001]-direction, far less attention has been directed to the electronic and optical properties of the [111]-oriented dots. Due to changes in symmetry, understanding from [001]-oriented dots cannot necessarily be carried over to these site-controlled structures. In this work we target this question and present results on electronic and excitonic properties of [111]-oriented site-controlled GaAs QDs from a symmetry-adapted framework and compare our results with experimental data.

We employ an 8-band **k**.**p** model [7] to simulate the electronic structure of experimentally relevant triangular prism shaped GaAs/$Al_{0.45}Ga_{0.65}As$ QDs embedded in a vertical $Al_{0.08}Ga_{0.92}As$ quantum wire (VQW). Our model accounts for strain and polarization fields and preserves the C_{3v} symmetry of the combined system of the underlying [111]-zincblende lattice and the dot geometry, which is important for an accurate description of electronic and excitonic properties. Our calculations reveal several bound hole states and, when limited to single particle solutions, almost no confinement for electrons in the QDs. In contrast to widely studied [001]-oriented SK dots, we find the first excited hole state exhibits a significant p_z-like orbital character, indicative of a light-hole like state.

To gain insight into the excitonic and biexcitonic properties of the [111]-oriented QDs, the calculated electronic structure serves as an input for configuration interaction calculations, allowing us to account for exchange and correlation effects in the many body states. We find signatures of both "heavy-hole" excitonic states (X_{10}) and states with "light-hole"-like excitonic (X_{01}) features. Figure 1 shows an example of the calculated excitonic spectrum. Overall, the obtained excitonic features align well with experimental studies, serving as an ideal starting point for exploring the properties of site-controlled QDs for multi-dimensional PCS generation.

References

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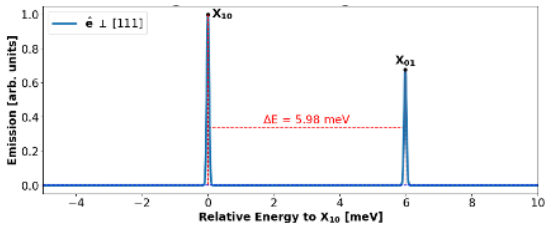

Fig.1. Calculated Excitonic Emission Spectrum GaAs/$Al_{0.45}Ga_{0.65}As$ in $Al_{0.08}Ga_{0.92}As$ VQW. Light polarization in the (111) plane, thus light polarization vector perpendicular to [111]-direction.