Evidence for Inter-Valley Coupling from a charge tunable GaAs/AlAs Quantum Dot

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With the ongoing advances in quantum information technologies and semiconductor fabrication processes, semiconductor quantum dot molecules (QDMs) are of great interest as a system allowing for the existence of both delocalized indirect excitons[1], where the hole and electron are confined in two different dots, and direct excitons, where the hole and electron are localized in the same dot. While direct excitons exhibit strong interaction with light, indirect excitons typically have weaker radiative coupling, but benefit from a stronger interaction with an external electric field because of their larger dipole moment. This tunability allows indirect excitons to bring electronic states into resonance and control their coupling, paving the way for the design of quantum logic gates.[2, 3].

We here present an architecture for type-II GaAs QDs embedded between two AlAs barriers [4], offering an alternative way to generate indirect excitonic states, where the electron is either confined within the dot itself or in the AlAs barrier. The AlAs layer provides a barrier potential for the Γ-valley, allowing the electron to be confined in the GaAs QD, while simultaneously lowering the X-valley energy of the structure, making it possible to confine conduction states inside the barrier. The interaction between the spatially separated electronic state is allowed through Γ-X intervalley interface coupling [5], replacing the tunnel coupling present in QDMs.

We study this interface coupling using the large dipolar moment of the indirect exciton, making its emission energy highly sensitive to an external electric field. When the energy of the indirect exciton crosses that of the direct one, an anticrossing appears, evidencing coherent coupling between the two eigenstates of the system.

In addition, under the influence of an external magnetic field, the indirect and direct branches of the excitonic lines exhibit distinct magnetic properties, characterized by opposite signs of their effective Landé factors for the X-valley electron in the AlAs barrier and the Γ-valley electron in the GaAs dot. This enables the realization of a fully electrically tunable effective g-factor, which can be continuously adjusted from negative to positive values.

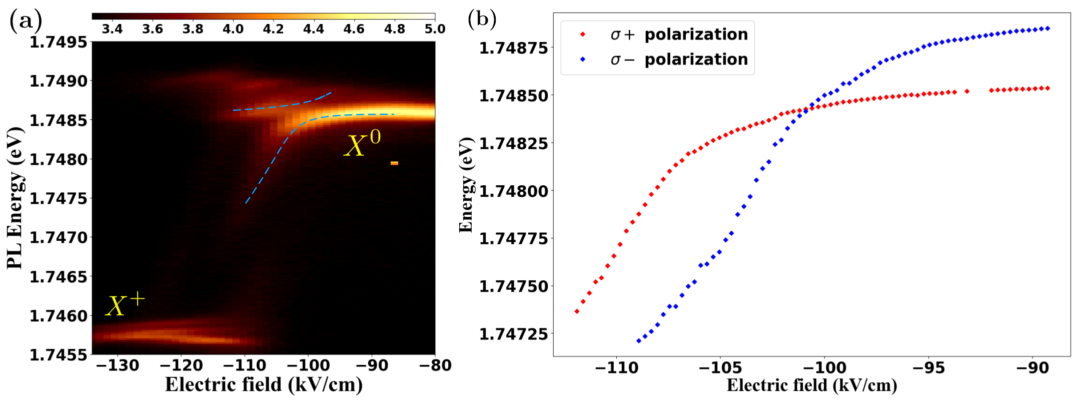

Figure 1: (a) Stark spectroscopy of the GaAs quantum dot, with an anticrossing visible on the netural exciton emission line, demonstrating coherent coupling between the direct and indirect excitonic branches. (b) Fitted emission energy at a magnetic field of 4T for the lower branch of the anticrossing, for the $\sigma+$ and $\sigma-$ polarization components. The Zeeman splitting is positive at lower values of the electric field, where the exciton is indirect, and negative at higher values, showing a sign inversion of the effective Landé factor of the exciton as the state changes from indirect to direct.

References

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