Type-II GaSb/GaAs quantum rings: charging mechanisms and the bimolecular recombination approximation

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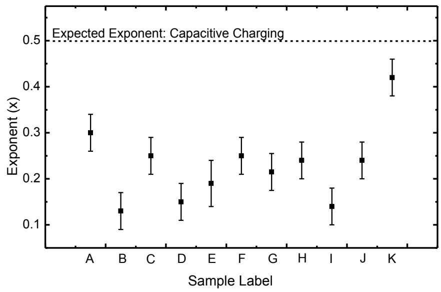
Type-II GaSb/GaAs self-assembled quantum dots (QDs) and quantum rings (QRs) have numerous potential applications including memories, solar cells and lasers. Blueshifts of QD emission energy, *E*, with increasing laser power, *P*, in photoluminescence (PL) measurements have been widely reported. This characteristic behavior has been attributed to either band bending effects [1] or capacitive charging of QD/QRs [2]. However, without careful analysis, it can be difficult to discern between the two mechanisms. Our results show that analyses based on the assumption that $P \propto I \propto n^2$, where $I \propto n^2$ is the bimolecular recombination approximation (BMRA), are flawed.

We studied the QR PL energy shift of eleven different samples. The observation of sub-peaks in Sample A [3], which correspond to ground state recombination of discretely-charged ring states, allowed us to conclusively show that capacitive charging dominates the blueshift and that the simplistic capacitor model describes our data. Furthermore, simple estimates show that the energy shift due to capacitive charging is an order of magnitude larger than that of band bending. Thus we confidently expect the laser power induced blueshift in all of our samples to be dominated by capacitive charging.



Exponents extracted by plotting log(ΔE) vs log(I) for each QR sample.

As Sample A is unique in showing charge quantized sub-peaks, a more general method using log(ΔE) vs log(I) was employed. This method uses emission intensity, I, as an indicator of carrier density rather than *P*, avoiding assumptions related to QR capture cross-section. Also, a log-log analysis enables the determination of the exponent, *x*, in $\Delta E \propto I^x$ without the need for *a priori* assumptions of *x*. It can be seen from the figure that all values are consistently lower than the 0.5 value expected for capacitive charging. This result illustrates that it is not possible to infer QD/QR occupancy, *n*, through the commonly used $I \propto n^2$ relationship, i.e. the BMRA breaks down when applied to type-II QD/QRs. This result has important consequences for the performance of type-II QD/QR devices; indicating benefits for the wavelength stability and emission intensity of lasers, but may also point to reduced efficiency in solar cells.

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[2] B. Bansal et al., Phys. Rev. B 80, 205317 (2009).
[3] R. Young et. al., Appl. Phys. Lett. **100**, 082104 (2012).

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