Towards deterministic photon sources in the short wavelength infrared

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Abstract: Optical study of PbS quantum dots emitting at 2 µm reveals strong temperature-dependent redshift, luminescence antiquenching, and anomalous increasing lifetimes, highlighting the role of phonon coupling and non-radiative recombination mechanisms.

Lead chalcogenides, in particular PbS, are extensively studied for the realization of quantum dots (QDs) with size-tunable optical properties. Despite PbS QDs are especially promising for near-infrared photonic applications [1,2], their photoluminescence (PL) at wavelengths covering the short-wave infrared remains experimentally challenging and relatively unexplored, despite its importance for sensing and communication technologies.
This work presents a systematic optical study of relatively large, non-shelled PbS QDs, exhibiting room-temperature emission around 2 µm. The PL properties, like peak position, intensity, and exciton lifetime, were analyzed as a function of excitation power, temperature, and excitation wavelength.
A pronounced temperature dependence of the emission is observed, with a redshift extending beyond 2.3 µm at 4 K, well described by Varshni and O'Donnell models [3,4] and attributed to electron–phonon coupling [5], as reported in the Fig.1. In addition, an anomalous decrease of PL intensity upon cooling (luminescence antiquenching, shown in the inset of Fig. 1), indicates the presence of surface-related non-radiative recombination channels.
Time-resolved PL reveals a transition from single- to multi-exponential dynamics with increasing temperature, consistent with the evolution of the relative recombination pathways and the observed antiquenching behavior.
This work provides an in-depth analysis of PbS QDs short-wavelenght range, offering new insight into recombination mechanisms and supporting their potential for infrared quantum photonic applications.

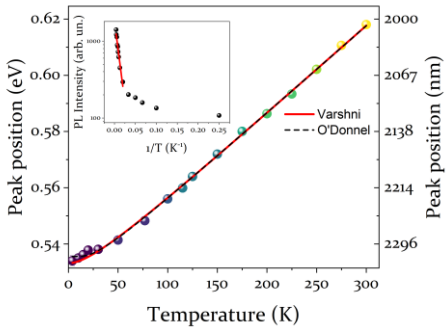

Fig. 1 Temperature dependence of the PL peak position, together with Varshni and O'Donnell fits; the inset shows the PL intensity as a function of temperature, highlighting the antiquenching behavior.

Example References

[1] P. Senellart, G. Solomon, and A. White, High-performance semiconductor quantum-dot single-photon sources, Nature nanotechnology 12, 1026 (2017).
[2] D. A. Vajner, L. Rickert, T. Gao, K. Kaymazlar, and T. Heindel, Quantum communication using semiconductor quantum dots, Advanced Quantum Technologies 5, 2100116 (2022)
[3] Y. P. Varshni, Temperature dependence of the energy gap in semiconductors, physica 34, 149 (1967).
[4] K. P. O'donnell and X. Chen, Temperature dependence of semiconductor band gaps, Applied physics letters 58, 2924 (1991).
[5] P. Dey, J. Paul, J. Bylsma, D. Karaiskaj, J. Luther, M. Beard, and A. Romero, Origin of the temperature dependence of the band gap of pbs and pbse quantum dots, Solid state communications 165, 49 (2013).