

# Semiconductor quantum dots: From synthesis to photonic applications

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## I. INTRODUCTION

Interest in semiconductor colloidal nanocrystals synthesized using chemical methods, has grown considerably due to the many advantages they offer. They are made as a colloidal suspension,[1] enabling the production of a wide variety of materials and sizes. As the diameter typically equals 1–15 nm, bulk semiconductor bands are transformed into discrete energy levels and the optical properties become size-dependent. Furthermore, nearly all materials have a high band-edge luminescence, opening pathways for lasing applications.[2]

In this paper we will focus on yet another promising property of these quantum dots: the nonlinear refractive index  $n_2$  is expected to be enhanced with respect to the bulk material.[3] Combined with the facile nanocrystal processing in for instance polymer thin films, this might eventually lead to all-optical applications on a silicon platform.

## II. OPTICAL PROPERTIES OF Q-PbSe

For applications in the near-infrared (NIR), Q-PbSe are excellent candidates. Due to the small bulk band gap (0.28 eV), optical properties can be tuned from 1  $\mu\text{m}$  to beyond 2  $\mu\text{m}$ ,

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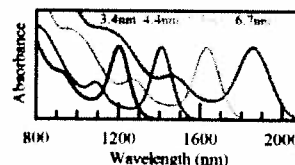


Figure 1. Absorbance spectra of different Q-PbSe suspensions. A blue shift of the transitions with decreasing Q-PbSe size is observed.

covering the entire telecom spectral range (figure 1). The exciton Bohr radius (46 nm) is much larger than the typical nanocrystal size (3–8 nm), leading to strong quantum confinement and the appearance of sharp peaks in the absorption spectrum. These are the result of transitions between the discrete energy levels of the quantum dot.

## III. THE NONLINEAR REFRACTIVE INDEX

The nonlinear refractive index  $n_2$  of Q-PbSe suspensions was studied with the Z-scan technique.[4], [5] This technique is well suited to determine both the sign and magnitude of  $n_2$ , given that the laser beam intensity  $I_0$  is known. Figure 2(a) shows a typical  $n_2$ -spectrum for a Q-PbSe suspension ( $I_0 = 12 \text{ MW/cm}^2$ ). A strong resonance in  $n_2$  occurs in the vicinity of the absorption peaks, indicating that it originates from electronic transitions within the

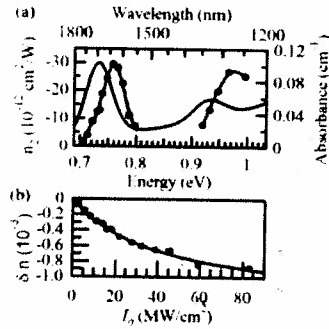


Figure 2. (a)  $n_2$ -spectrum (blue) compared to the absorbance spectrum (black). (b) Intensity dependence of  $\delta n$ . A clear saturation is observed.

nanocrystal. Further evidence follows from the change in refractive index  $\delta n = n_2 \cdot I_0$  (figure 2(b)). At high  $I_0$ , saturation is observed, which can be explained by the existence of discrete energy levels. As  $I_0$  increases, more electrons will be promoted to the first excited state, until this level is completely filled. Further increasing  $I_0$  will then no longer promote more electrons, leading to a saturation in  $\delta n$ .

#### IV. HYBRID NANOCRYSTAL - SOI RING RESONATORS

Following the promising Z-scan results, the interaction of Q-PbSe with the evanescent wave of a Silicon-on-Insulator (SOI) ring resonator was studied. Q-PbSe were mixed with a polymer and spincoated on SOI rings. Figure 3(b) shows a typical transmission spectrum of a coated ring. To gain insight in the interaction between the Q-PbSe doped thin film and the SOI ring, the loss per circulation  $\alpha$  of the ring was calculated based on the linewidth and depth of the resonances.  $-2\log(\alpha)$  is compared to the Q-PbSe absorbance spectrum in

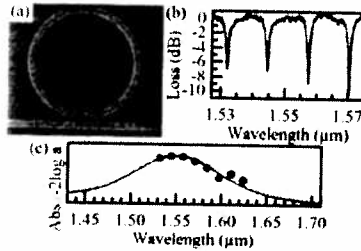


Figure 3. (a) SOI ring resonator. (b) Transmission spectrum for a Q-PbSe coated ring. (c) Comparison of the loss per circulation  $\alpha$  with the Q-PbSe absorbance spectrum.

figure 3(c). The excellent agreement confirms a strong coupling of the light in the ring resonator to the Q-PbSe doped thin film.

#### V. CONCLUSIONS

Q-PbSe show strong NIR, size-dependent absorption peaks. A negative  $n_2$  is observed and the electronic origin is established. After depositing Q-PbSe on a SOI ring resonator, the transmission spectrum is determined by the Q-PbSe absorption. The results hold considerable promise for further investigations of the nonlinear optical properties of hybrid SOI devices.

#### ACKNOWLEDGMENTS

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#### REFERENCES

- [1] C. B. Murray et al. *IBM J. Res. Dev.*, 45(1):47, 2001.
- [2] A. L. Rogach et al. *Small*, 3(4):536, 2007.
- [3] E. Hanamura. *Phys. Rev. B*, 37(3):1273, 1988.
- [4] M. Sheikbahaie et al. *IEEE J. Quantum Electron.*, 26(4):760, 1990.
- [5] I. Moreels et al. *Appl. Phys. Lett.*, 89(19):193106, 2006.
- [6] A. Yariv. *Electron. Lett.*, 36(4):321, 2000.

