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Semiconductor Quantum Dots in Metal Nanostructures[1]

MARK STOCKMAN, Department of Physics and Astronomy, Georgia State University, Atlanta, GA 30303, USA

We consider theory and available experimental data on optical and electronic properties of nanostructures containing semiconductor nanocrystal quantum dots (QDs) in a nano-proximity of metal surfaces and nanoparticles. Remarkable properties of such systems are due to a strong coupling between QD electrons and surface plasmons (SPs) and surface plasmon polaritons (SPPs) of the metal. Generally, the proximity to metal accelerates electronic transitions in the quantum dots. However, dependent on QD transition frequency ω and distance between QDs and the metal surface, and the size of the metal nanostructure, there may be different scenarios of such interactions with dramatically different effects.

1. For lower frequencies the QD transitions $\omega <\sim \omega_{SP}$, where ω_{SP} is a characteristic surface plasmon (SP) frequency, and $d \sim 1$ nm, the dominating interaction is that the excitation of localized SPs of the metal that undergo a strong Landau damping. This introduces a very fast Landau damping, efficiently damping the fluorescence of QDs.

2. For $\omega \sim \omega_{SP}$, $d >\sim 1$ nm and nanoscale size of the metal system, coherent excitation of SPs takes place. In this case, the metal system may work as a nano-antenna for QDs enhancing the dipole oscillator strength of QD transitions. In this case, one expect *enhanced* luminescence of QDs, opposite to what takes place in case (i). One can also expect the surface-enhanced Raman scattering (SERS) and strongly enhanced nonlinear effects such as CARS. One unique effect that is predicted in such systems is surface plasmon amplification by stimulated emission of radiation (spaser), which is similar to laser where the coherent accumulation of SPs in a single mode takes place.

3. For $\omega \sim \omega_{SP}$, $d >\sim 1$ nm, and macroscopic extension size of the metal system, besides SPs, the propagating modes of SPPs are excited. In this case, the metal system plays role of optical antenna that propagates the excitation of the quantum dots to the far zone. This leads to an increase of the fluorescence efficiency and intensity, and shortening of the fluorescence time.

There are numerous potential applications of the QD/metal nanostructures that we will be discussing.

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