Strong photoluminescence enhancement of Si and SiC quantum dots by their resonant coupling with multi-polar plasmonic hot spots

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Since the observation in 1990 of strong room-temperature photoluminescence (PL) from nanostructured porous Si [1, 2], significant scientific interest has been focused on Si-based nanomaterials (quantums dots (QDs), nanowires, nano-porous layers, etc.) emitting light in a wide spectral range from near infra-red up to ultra-violet regions [3]. However, even for Si QDs of few nanometers with sufficiently broken-down wave-vector selection rules due to spatial and quantum confinements of charge carriers, the luminescence quantum efficiency is rather low (1-10% [4, 5, 6]) compared to direct band-gap semiconductors [7, 8, 9], and its considerable enhancement remains an important challenge.

Currently, one of the most intensely studied approaches allowing a significant enhancement of the photo-stimulated emission of various QDs is their localization in the vicinity of metal nanoparticles (NPs) [10, 11, 12]. Indeed, optically excited collective oscillations of conducting electrons (known also as localized plasmons [13]), appearing in the metal NPs at the spectral ranges corresponding to the plasmon resonance bands allow strong increase of: (i) effective absorption cross-section of the QDs and (ii) their radiative recombination rates. Both reasons provoke an important luminescence enhancement. Moreover, to render much stronger the electrical field in the vicinity of the photoexcited metal NPs and thus to ensure enhancement of the QD photoluminescence intensity by several orders of magnitude, the QDs must be localized in the regions (called hot spots) where the photo-induced electrical fields from several metal NPs are superimposed [14].

Plasmon induced PL amplification was mainly reported for II-VI core/shell QDs [15, 16]. In particular, using various configurations of metal (most often: gold and silver) nanostructures, the obtained PL amplification gain varied from 30 to 240 [15, 16]. Despite these important recent advances achieved on II-VI QDs, only a seven-fold photoluminescence enhancement was reported for Si QDs [17].

In our present work we show that the plasmon-induced strong local photoluminescence enhancement of Si QDs in SiN matrix can reach 60-fold gain level. This important result was achieved by our team developing original tunable “nano-Ag/SiNX” plasmonic structures. In particular we show that, (i) localization of Si QDs in hot spot regions created by several randomly arranged Ag nanoparticles and (ii) careful tuning of the multi-polar plasmon bands of Ag nanoparticles to match resonantly absorption and emission wavelengths of Si QDs, lead to the important enhancement of their photoluminescence intensity**.** By exploiting the same physicals mechanisms we were also able to achieve high values of PL enhancement of SiC QDs coupled with plasmonic nanostructures, reaching 20-fold level.

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