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Superliner Photo Response in Colloids of Silicon Quantum Dots

Ujjwal Ghanta[1], Mallar Ray[2], Nil Ratan Bandyopadhyay[3], Syed Minhaz Hossain[4]

Research Scholar, School of Materials Science and Engineering, Bengal Engineering and Science University, Shibpur, Howrah, West Bengal, India [1]

Assistant Professor, School of Materials Science and Engineering, Bengal Engineering and Science University, Shibpur, Howrah, West Bengal, India [2]

Professor, School of Materials Science and Engineering, Bengal Engineering and Science University, Shibpur, Howrah, West Bengal, India [3]

Assistant Professor, Department of Physics, Bengal Engineering and Science University, Shibpur, Howrah, West Bengal, India [4]

ABSTRACT: In this work we have studied the photoluminescence (PL) properties of colloidal suspension of silicon quantum dots (QDs) surrounded by silicon oxide with 3.08 eV continuous wave (CW) laser and the effect of excitation power. The oxide coated silicon QDs shows strong visible PL at room temperature. The emission spectrum consists of two consecutive peaks in the visible region. A superliner increase in peak emission intensity accompanied by spectral narrowing of luminescent peak is observed. This phenomenon suggests the possibility of optical gain in the colloidal system.

KEYWORDS: Photoluminescence, silicon quantum dots, colloids, optical gain.

I. INTRODUCTION

The photon emission process form silicon is phonon assisted through indirect electronic bands, which limits its efficiency and makes it unsuitable for optoelectronic application. But the material is efficient as light emitter in low dimensional nanostructures [1]. Although the quantum confinement of excitons in the low dimensional crystalline silicon structures [2] and radiative recombination of localized carriers at Si/SiO_2 interface [3] play the key roles in the light emission process with reasonably high external quantum efficiency, the exact nature of the radiative recombination mechanism still remains an open issue.

Optical gain in low dimensional silicon system have been observed and reported by several groups via different techniques like amplified spontaneous emission [4, 5], variable stripe length [6], spatially coherent speckle patterns [7] etc. In this work we have studied the PL properties of silicon QDs in colloids by 3.08 eV CW laser radiation and the incident power dependence of PL emission peak. The emission peak intensity varies super linearly with excitation power. **A**lso the FWHM of the peak decreases with increasing excitation intensity. This phenomenon suggests the possibility of optical gain in the colloidal system.

II. EXPERIMENTAL

The core-shell nanostructure silicon QDs were prepared by mechanical milling of crystalline Si powder followed by thermal and chemical treatment. The entire process was carried out in the ambient atmosphere. The final colloidal suspensions of silicon QDs were formed by dissolving the powder in ethanol followed by successive sonication and centrifugation. The detail of the preparation route is reported elsewhere [8]. The room temperature emission spectra were recorded using a spectroflurometer (Horiba Jobin Yvon) and UV (3.08 eV) CW laser were used for excitation. For incident power measurement we used a spot meter with silicon detector.

III. RESULTS AND DISCUSSIONS

Figure 1 represents the room temperature PL emission spectra of silicon QDs in colloids for different incident power. The luminescence is intense and visible with naked eyes. The nature of the emission spectrum cannot be explained with a single Gaussian function. The Gaussian de-convolution (see inset of fig. 1) suggests that the spectrum consists of two consecutive peaks at 435 and 465 nm respectively. The later low energy high intense peak is associated with radiative recombination between conduction band (CB) and interface states of silicon QDs [9].

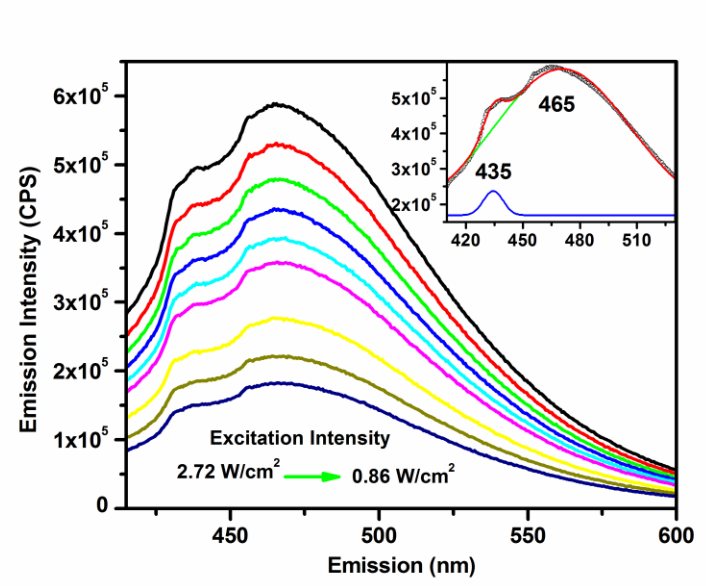

Fig. 1 Room temperature PL emission spectra of the sample for different incident power of 3.08 eV laser excitation. The incident power decreases from top to bottom in sequence (2.72, 2.47, 2.3, 2.13, 1.95, 1.89, 1.21, 1.02, 0.86 W/cm^2). The inset represents the de-convolution of the spectrum for excitation intensity 2.72 W/cm^2 and the numbers represents the peak positions in nm.

Figure 2 shows the power dependence of the PL emission peak intensities in a log-log plot. The solid straight line represents the linear fit of the data points. It is obvious from the analysis of the intensity variation of emission spectra that both of the closely spaced peaks exhibit a nonlinear dependence with power (from the slope of output intensity vs. Input intensity) and there is a sharp threshold of incident power. Below the threshold value (closer to 1.92 W/cm^2) the curves are sub-linear with a slope of 0.84. But above the threshold it is super-linear with a slope of 1.32 & 1.36 for high (465 nm) and low intense peak (435 nm) respectively. Above the threshold value the low intense peak shows more dependence on incident power compared to the higher one.

From the de-convolution analysis it is clear that the position of the peaks does not changes with incident power. On the other hand the FWHM of the high intense peak (465 nm) gets narrower with increasing power (from 60 nm at 0.86W/cm^2 to 56 nm at 2.3 W/cm^2), while FWHM for the low intense peak (435 nm) remains almost unaltered (see inset of fig. 3). The changes in FWHM of emission peaks with incident power are represented in figure 3.
The above mentioned results suggest that the emission peak intensities follow a sub-linear relationship with the incident power which changed abruptly to super-linear behaviour beyond a threshold value as expected when stimulated emission dominates over Auger recombination. The nonlinear behaviour and the narrowing of FWHM of the high intense peak indicates the origin of optical gain and stimulated emission, possibly due to recombination of exciton within the bands and the interface states of silicon QDs. However, the threshold value of power is quite low for achieving optical gain in such system. For detail understanding of the stimulated emission and consequently the optical gain, we need to investigate the dynamics of PL emission.

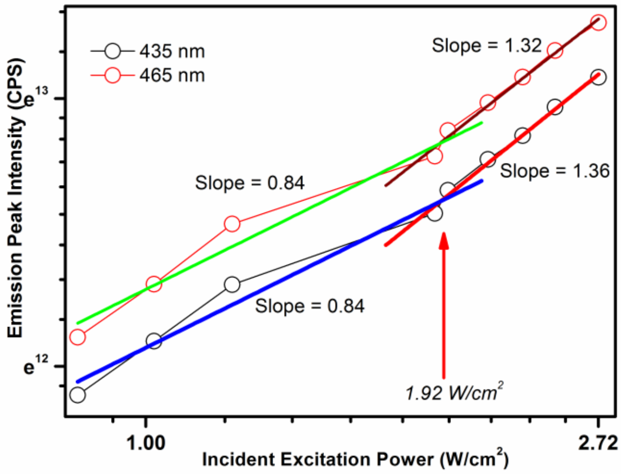

Fig. 2 Peak emission intensity variation with incident laser power. The peak intensity varies super linearly with the incident power for both the peaks. The high intense peak is more sensitive to incident power. The solid lines are power –law fitting. A clear threshold is observed near 1.92 W/cm^2.

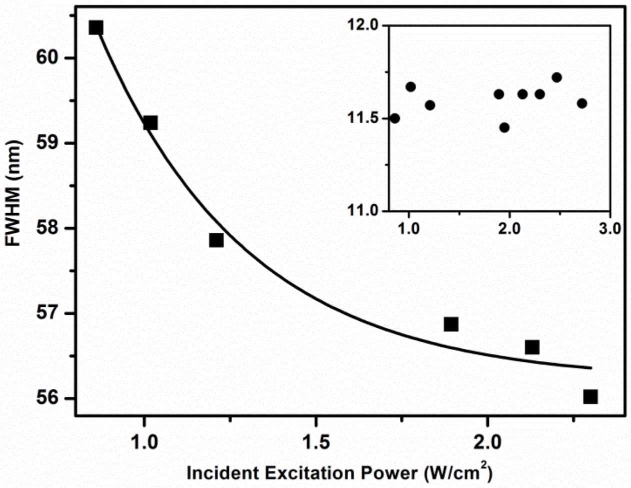

Fig. 3 FWHM narrowing of the high intense peak (465 nm) with increasing excitation power.
The inset represents the same for low intense peak (435 nm) which remains unaffected by laser power.

IV. CONCLUSIONS

Silicon QDs in colloids shows strong PL under CW laser illumination. The emission spectrum consists of two peaks at 435 and 465 nm respectively. The intensity of 465 nm peak, associated with radiative recombination of excitons within bands and interface states of silicon QDs, varies superlinearly with the incident power and the FWHM decreases with increasing power. This phenomenon suggests the possibility of optical gain in the colloidal system.

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