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Localized Surface Plasmon-enhanced Light Emission Output of Amorphous Silicon Quantum Dots Light-Emitting Device with Plasmonic Subwavelength Ag grating structure

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Abstract

We investigated experimentally the enhanced emission output of the amorphous silicon quantum dots (a-Si QDs) light-emitting devices (LEDs) with plasmonic subwavelength Ag grating, through strongly coupling a-Si QDs into localized surface plasmons (LSPs) modes.

1. Introduction

Silicon quantum dots (Si-QDs) light-emitting devices (LEDs) have been widely studied as a novel light source in recent years for the next generation Si-based optoelectronic integrated circuits (OEICs) [1]. To achieve the goal of the practical applications in future OEICs, high emission intensity and low temperature growth for Si-QDs are required. In this research, we focus on the localized surface plasmons (LSPs)-enhanced spontaneous emission of a-Si QDs LEDs with the Ag/SiO_x:a-Si QDs/Ag nanostructures, by tuning the one-dimensional (1D) subwavelength Ag grating on the top, through the strong a-Si QDs–LSPs coupling based on the Fermi's golden rule.

2. Experiment

The devices with the Ag/SiO_x:a-Si QDs/Ag sandwich nanostructures were fabricated as follows. First, a 100 nm Ag film was deposited on the Si substrate by thermal evaporation, followed by the Si-rich SiO_x (SRO, $x < 2$) film deposited, using plasma enhanced chemical vapor deposition (PECVD) system with SiH_4 and N_2O reactant gas. Then, the SRO film was annealed at 300℃-700℃ for 1 hr in a quartz furnace with flowing N_2 gas to form SRO film with embedded a-Si QDs (SiO_x:a-Si QDs film) as a light emitter. Then, electron-beam (e-beam) lithography, thermal evaporation, and lift-off process are used to fabricate 1D Ag grating on the top of SiO_x:a-Si QDs film. Fig. 1 shows the device structure with 1D Ag grating on the top. And the structural parameters of 1D Ag grating for samples A-D with Ag wire width d and pitch p are listed in Table I.

3. Results and Discussions

Fig. 2 shows the top-view scanning electron microscopy (SEM) images of the 1D Ag grating for samples B-D. Fig. 3 shows the depth profiles of Si, O, and Ag elements for SiO_x:a-Si QDs film by X-ray photoelectron spectroscopy (XPS) analysis. It is found that the average Si concentration of SiO_x:a-Si QDs film up to 48.27 at.% since high SiH_4/N_2O gas flow ratio during the PECVD process.

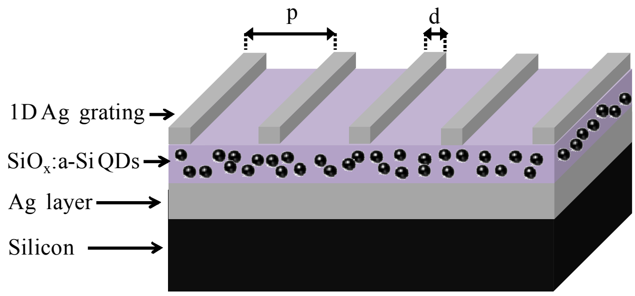

Fig. 1. The device structure of a-Si QDs LEDs with tri-layer Ag/SiO_x:a-Si QDs/Ag nanostructures.

Table I. The structural parameters of 1D Ag grating for samples A-D.

Sample	p	d	d/p
A	-----	-----	-----
B	500 nm	125 nm	0.25
C	600 nm	150 nm	0.25
D	700 nm	175 nm	0.25

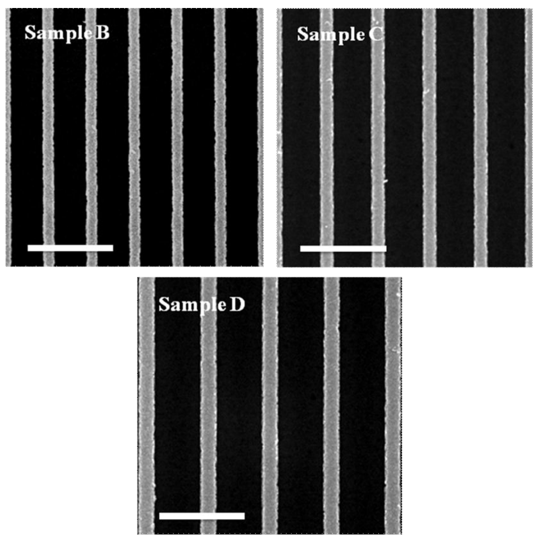

Fig. 2. The top-view SEM images of the 1D Ag grating for samples B, C. and D. Scale bar is 500 nm.

There are excessive Si atoms in SiO_x:a-Si QDs film lead to the Si atoms could move simply and accumulate to form Si-QDs during post low annealing process. Fig. 4 shows the change in PL peak position of SiO_x:a-Si QDs film depending on the annealing temperature, and exhibits that the main PL peak is shifted to the long wavelength side when annealing temperature is increased from 300℃ to 700℃. It can be seen the main PL peaks of these samples were not located at the PL range of oxygen related defects [2]. And the more beneficial for quantum confinement effect (QCE) surpass the carriers recombination of interface states for the smaller size of a-Si QD (~1.7 nm) [3]. Hence, we consider that the emission spectra of these devices originated from the QCE of a-Si QDs. Fig. 5 shows the reflection spectra of samples B-D, and shows the reflection dips contributed to the excitation of LSPs mode on the Ag grating. Fig. 6 shows the PL spectra of samples A-D. The significantly enhancement of PL intensity is found for sample B with optimized 1D Ag-grating, through the strong a-Si QDs–LSPs coupling.

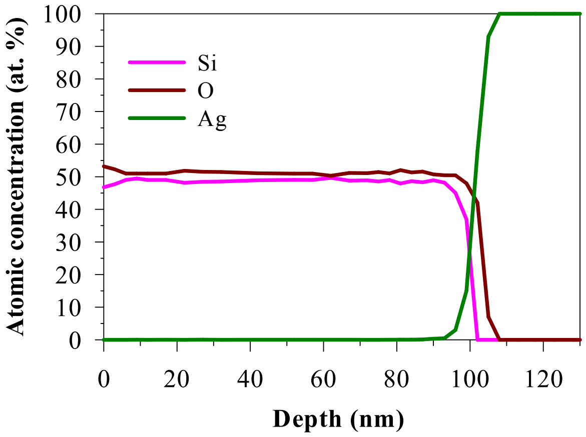

Fig. 3. The concentration-depth profiles of Si, O, and Ag atoms for SiO_x:a-Si QDs film, and at SiO_x:a-Si QDs/Ag film interface by XPS analysis.

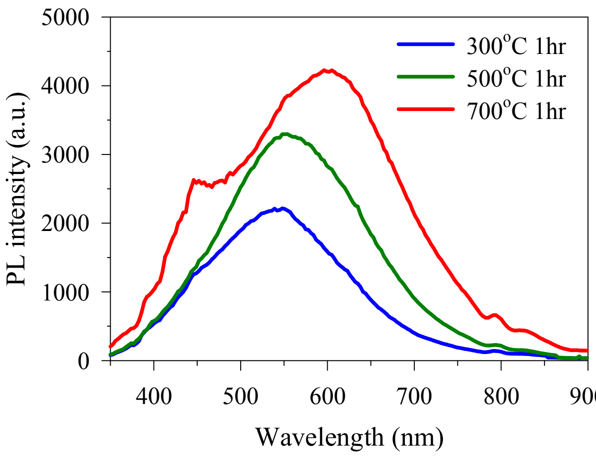

Fig. 4. The PL spectra of SiO_x:a-Si QDs films with different annealing temperatures.

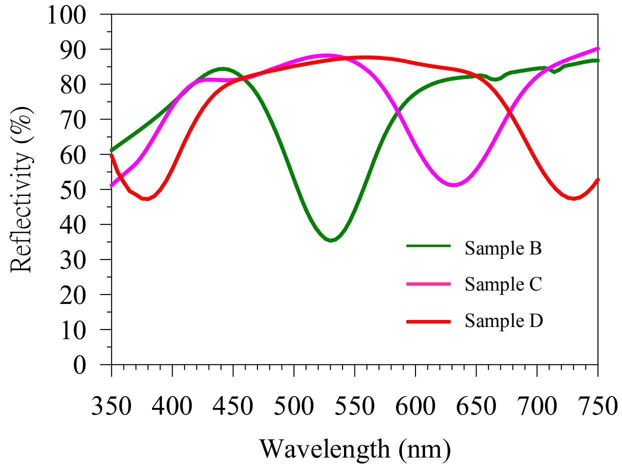

Fig. 5. The measured reflection spectra of the samples B, C, and D.

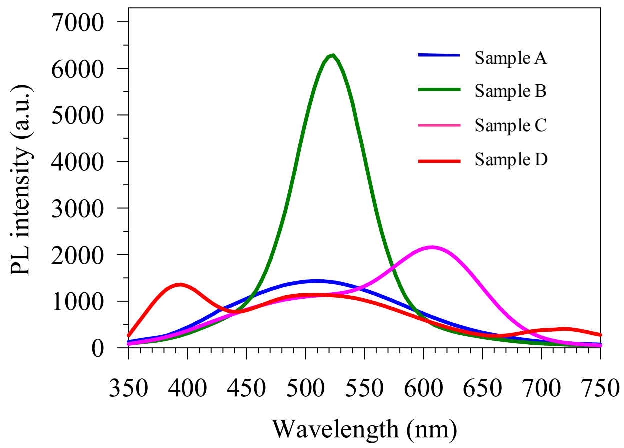

Fig. 6. The PL spectra of the samples A-D.

4. Conclusions

In this work, we focus on the plasmon-induced emission enhancement of a-Si QDs LEDs with plasmonic Ag grating on the top, through the strong a-Si QDs–LSPs coupling. A maximum of 2.46-fold enhancement of the PL integrated intensity and a minimum of spectral bandwidth of 67 nm for sample B are found, due to the close match between the center emission wavelength of a-Si QDs (510 nm) and the LSPs resonance (526 nm).

Acknowledgements

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