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The effects of annealing temperature on photoluminescence of silicon nanoparticles embedded in SiN_x matrix

Lihua Jiang, Xiangbin Zeng *, Xiao Zhang

Department of Electronic Science and Technology, Huazhong University of Science and Technology, Wuhan, Hubei 430074, China

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ABSTRACT

The effects of the annealing temperature on photoluminescence (PL) of non-stoichiometric silicon nitride (SiN_x) thin films deposited by plasma enhanced chemical vapor deposition (PECVD) using ammonia and silane mixtures at 200 °C were investigated. The optical property and the chemical composition of the films annealed at different temperatures were investigated by PL spectroscopy and Fourier transform infrared absorption spectroscopy (FTIR), respectively. Based on the PL results and the analyses of the bonding configurations of the films, the light emission is attributed to the quantum confinement effect of the carriers inside silicon nanoparticles and radiative defect-related states. These results provide a better understanding of optical properties of silicon nanoparticles embedded in silicon nitride films and are useful for the application of nanosize silicon semiconductor material.

1. Introduction

Recently, enormous attention has been paid to the PL of silicon nanoparticles due to its potential applications in the next generation of full-color flat panel displays, LED and other silicon based photoelectric devices [1]. Efficient room temperature PL has been realized in Si-in-SiO_2 and Si-in-SiN_x systems with silicon nanoparticles [2,3]. For silicon oxide systems, the too large band gap of the silicon oxide handicaps the injection of the carriers, and reduces the efficiency and reliability of the silicon-based photoelectric devices [4,5]. In comparison with silicon nanoparticles embedded in silicon oxide matrix, the silicon nanoparticles embedded in silicon nitride matrix show relatively lower barrier for carriers and more intense light emission [2,6]. Another major interest for using silicon nitride systems rather than silicon oxide systems is the possibility to get efficient light emission at shorter wavelength region [2,7]. Thus, silicon nitride thin films with silicon nanoparticles have the potential to produce full color emission devices. Although extensive work on the light emission properties of silicon nanoparticles embedded in SiN_x matrix has been done, the exact mechanism for the photoluminescence still remains controversial [6,8–10]. Furthermore, the PL spectroscopy technique is also one of the most commonly used tools to find the presence of silicon nanoparticles in SiN_x films [11,12]. Therefore, it is significant to clarify the detailed PL mechanisms to establish the correlation between the emission features and the structure traits of sample, to meet the need of the silicon-based photoelectric devices and to provide a convenient tool to judge the presence of silicon nanoparticles in a silicon-based sample. The purpose of this work is to get more insight into the PL mechanisms of silicon nanoparticles embedded in SiN_x films prepared by PECVD under the same deposition condition but different temperature annealing treatments. The changes of PL and FTIR spectroscopy of the films were investigated, searching for the effects of post-thermal annealing treatments on PL and FTIR from silicon nanoparticles embedded in SiN_x films.

2. Experiments

SiN_x films were grown on p-type crystalline silicon substrates (diameter 10 cm slice) from hydrogen-diluted 10% SiH_4 and NH_3 with the purity in excess of 99.999% in a conventional parallel plate radio frequency (13.56 MHz) PECVD system. The flow rates of silane and ammonia were maintained at 60 and 50 sccm, respectively. The pressure in the chamber was maintained at around 0.8 Torr and substrate temperature was maintained at 200 °C. The plasma radio frequency power of 80 W was used in the experiments. After deposition, the silicon wafers were cut into several smaller parts for different temperature annealing treatments. These smaller samples were annealed at temperatures of 500–1100 °C in nitrogen ambient. Each sample was annealed in a quartz tube furnace with a flowing environment of nitrogen (purity 99.999%) from room temperature to the settled temperature and was maintained at the settled temperature for 10 min, then was cooled down naturally to room temperature within the quartz tube furnace. A Fourier transform infrared spectroscopy with a resolution 4 cm^{-1} (model: VERTEX 70) was employed to examine the bonding configurations of the samples annealed at different annealing temperatures. The PL measurements were carried

* Corresponding author. Tel.: +86 27 87544760.
E-mail address: eexbzeng@163.com (X. Zeng).

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out using a FP-6500 fluorescence spectrometer at room temperature. A 75 W Xe lamp was used as the excitation source and the excitation wavelength was fixed at 325 nm. In PL measurements, a transmission filter of L38 was used to eliminate the influence of the strong overtone bands centered at 650 nm on the PL signal of each sample.

3. Results

To investigate the effect of the annealing treatments on the luminescence properties of SiN_x films, room temperature PL measurements were performed on the as-grown and the post-annealed samples. Fig. 1(A) to (F) depicts the variations in PL spectra for the as-grown and the annealed samples with the annealing temperatures of 500, 650, 800, 950 and 1100 °C, respectively. It can be seen that the intensity, position, and shape of each global PL peak change with increasing annealing temperature. Furthermore, the PL spectra were decomposed into four main peaks (P1, P2, P3 and P4) with the best Gaussian fit to understand the emission mechanism of the samples. Fig. 2 shows the position of the four PL peaks (P1, P2, P3 and P4) obtained from Fig. 1(A) to (F) by Gaussian fit as a function of annealing

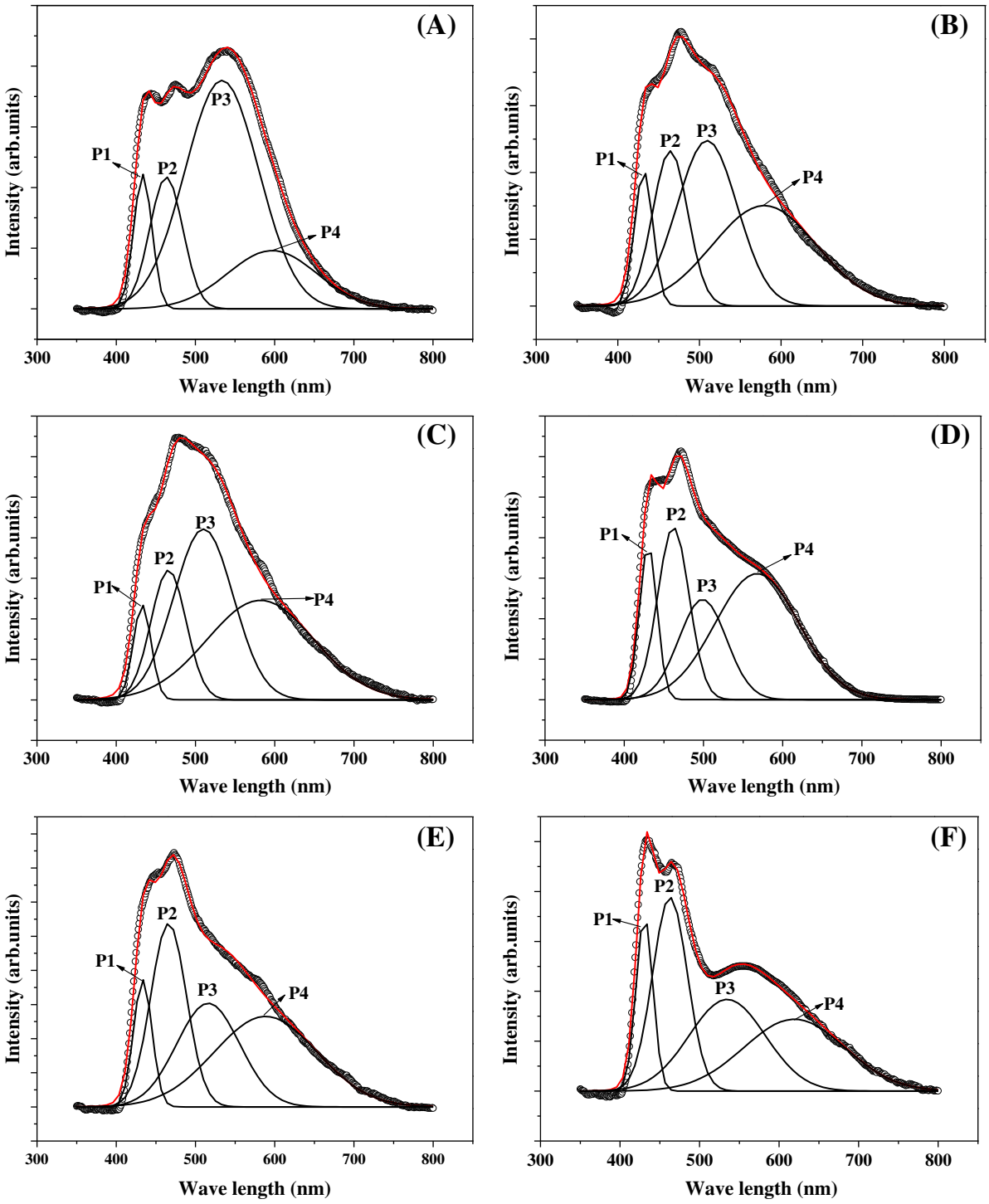

Fig. 1. Room temperature PL spectra (open circles) of the as-grown sample (A), and the samples annealed at 500 °C (B), 650 °C (C), 800 °C (D), 950 °C (E), and 1100 °C (F) together with the fitting results (solid curves) using four Gaussian peaks.