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Photoluminescence from C^+ ion-implanted and electrochemical etched Si layers

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Abstract

The microstructural and optical analysis of Si layers emitting blue luminescence at about 431 nm is reported. These structures have been synthesized by C^+ ion implantation and high-temperature annealing in hydrogen atmosphere and electrochemical etching sequentially. With the increasing etching time, the intensity of the blue peak increases at first, decreases then and is substituted by a new red peak at 716 nm at last, which shows characteristics of the emission of porous silicon. C=O compounds are induced during C^+ implantation and nanometer silicon with embedded structure is formed during annealing, which contributes to the blue emission. The possible mechanism of photoluminescence is presented.

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Keywords: Ion implantation; Annealing; Chemical etching; Photoluminescence

1. Introduction

Considering the relative maturity of silicon IC technique, people always want to realize Si-based optoelectronic integration in order to provide a new path for modern optical communication and optoelectronic computing. Silicon is the basic material of modern microelectronic technology, whereas silicon cannot emit light effectively for its indirect-band property. Therefore, to fabricate nanometer Si-based materials with strong luminescence will be of great significance for optoelectronic integration. Since Canham successfully prepared the red emission porous Si [1] in 1990, the luminescent properties of the nanometer Si [2], the C^+ implanted Si [3], doped Si [4–5] and the Si/SiO_2 superlattice [6] have been sequentially studied, and the emissions from infrared to ultraviolet in the spectrum have been all realized. Among them the blue, violet and ultraviolet emissions are especially vital to optoelectronic integration because of their short-wavelength properties. Furthermore, they can also increase the memory density of memory devices and resolution of the laser scanner and printer.

In recent years, ion implantation technique has been extensively applied to synthesize Si-based luminescent materials. In this work, we observe blue emission at about 431 nm from C^+ ion-implanted and etched silicon layers. We think that C=O compounds are implanted into along with C^+ ions, and embedded in the surface of nanometer silicon particles, nanometer silicon with embedded structure are formed during high-temperature annealing. Electrochemical etching makes the embedded layers exposed, which contributes to the blue emission. This material has great application potential in the fields of violet and ultraviolet light-emitting devices and ultraviolet detectors.

2. Experiments

In our experiment, a 50 keV C^+ ion implantation with the dose of 2×10^{16} ions/cm^2 was performed at room temperature into n-type epitaxial Si$\langle 1\,1\,1 \rangle$ wafers with resistance of 2–3 Ω cm and thickness of 30 μm. The samples were annealed under hydrogen atmosphere at 1050 °C for 1 h. Subsequently, electrochemical etching was carried out on the samples with the

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current density of 40 mA/cm^2. The etching solution was a 2:1 mixture of HF and $C_2H_5O_2$ and etching lasts 5 min, 10 min and 20 min, respectively.

Photoluminescence (PL) measurement was carried out on an FLS920 PL spectrophotometer with an excitation wavelength of 360 nm from a 300 W Xe lamp excitation source. Infrared spectra (FTIR, Nicolet710) and scanning electron microscopy (SEM, HITACHI H-8010) were employed to study the structure, composition and morphology of the samples. All measurements were carried out at room temperature.

3. Results and discussions

The surface morphology of the as-annealed sample and etched samples for different time were imaged by SEM. Fig. 1(A) shows that the as-annealed sample has a relatively smooth surface without any porous structure. Fig. 1(B) is an SEM image of the same surface following electrochemical etching in the acid mixture at room temperature, with parameters of 40 mA/cm^2 for 5 min. Faveolate porous structures are formed, which is beneficial to the exposure of C^+ ion-implanted layer. It can be seen from Fig. 1(C) that, when the etching time lasts 10 min, porous structures become denser and more obvious. Scalelike structures with many nanometer scale size linear fringes can be observed in the surface of the sample etched for 20 min, as shown in Fig. 1(D). These structures, we think, are exposed porous silicon formed when C^+ ion-implanted layers are removed due to excess etching.

Fig. 2 shows the PL spectra obtained at room temperature from the as-annealed sample prior to etching and the etched samples with different etching condition. It can be seen from Fig. 2 that there is no apparent peak for the as-annealed sample, while a weak blue emission band at 431.2 nm is obtained from the sample etched for 5 min. The intensity of blue emission peak increases significantly with the etching time increasing from 5 min to 10 min. Moreover, there is no apparent sign of blue-shift. However, when the etching time lasts 20 min, the blue emission band disappears whilst a new strong red emission band at about 716.3 nm emerges showing characteristics of the optical emission of porous Si, which is consistent with results of SEM.

The FTIR spectra measured in the 750–1900 cm^{-1} spectral region of the as-annealed sample (a) and the sample etched for 10 min (b) are displayed in Fig. 3. The 980 cm^{-1}, 1131 cm^{-1}, 1251 cm^{-1} and 1449 cm^{-1} bands shown in Fig. 3(a) correspond to O=Si–O, Si–O–Si and Si–O (or O≡Si–Si≡O), CH_x,

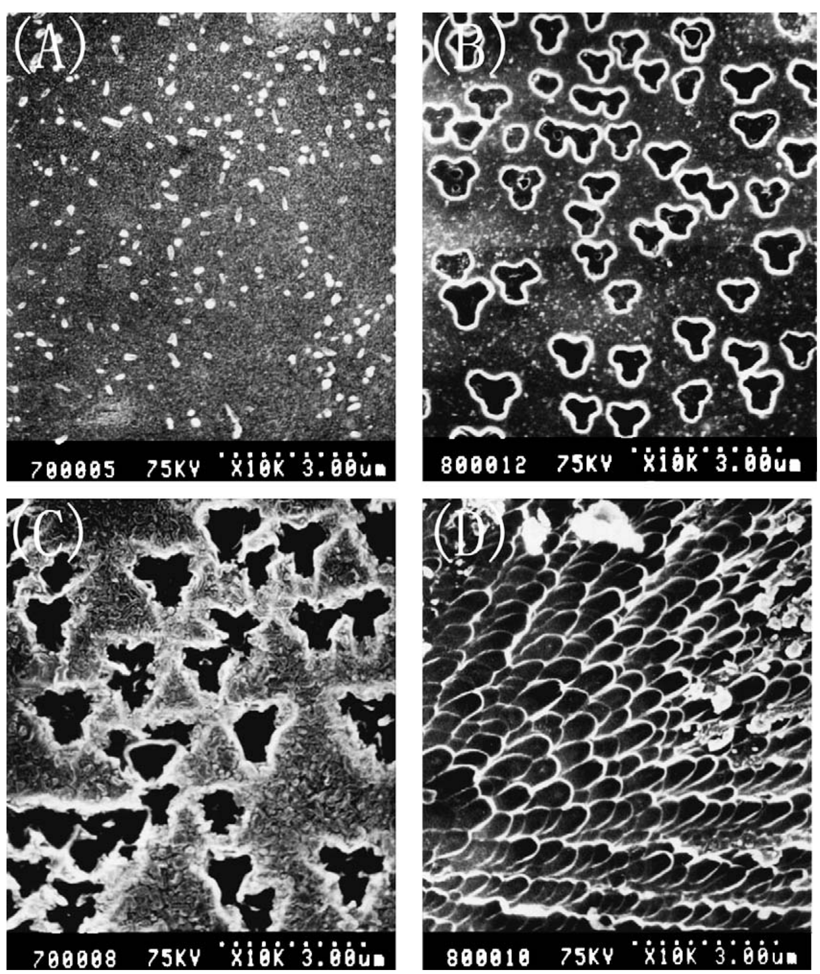

Fig. 1. SEM images of the as-annealed sample and the etched samples for different time: (A) as-annealed; (B) etched for 5 min; (C) etched for 10 min; (D) etched for 20 min.