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Effects of thermal annealing on photoluminescence of Si^+/C^+ implanted SiO_2 films

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ABSTRACT

The mechanisms of photoluminescence (PL) originating from Si^+/C^+ implanted SiO_2 are still unclear and need to be clarified. Thus, the purpose of this study is to thoroughly investigate the effects of ion implantation and post-annealing temperature on microstructures and PL characteristics of the Si^+/C^+ implanted SiO_2 films. A comparative analysis was also conducted to clarify the different optical properties between the Si^+ and Si^+/C^+ implanted SiO_2 films. In this study, thermally-grown SiO_2 films on Si substrates were used as the matrix materials. The Si^+ ions and C^+ ions were separately implanted into the SiO_2 films at room temperature. After ion implantation, the post-annealing treatments were carried out using the furnace annealing (FA) method at various temperatures (600–1100 °C) for 1 h in a N_2 ambient. The PL characteristics of the implanted SiO_2 films were analyzed using a fluorescence spectrophotometer. The results revealed that the distinct PL peaks were observed at approximately 310, 450 and 650 nm in the Si^+-implanted SiO_2 films, which can be attributed to the defects, the so-called oxygen deficiency centers (ODCs) and non-bridging oxygen hole centers (NBOHCs), in the materials. In contrast to the Si^+ ion implantation, the SiO_2 films which were sequentially implanted with Si^+ and C^+ ions and annealed at 1100 °C can emit white light corresponding to the PL peaks located at around 420, 520 and 720 nm, those can be assigned to the Si–C bonding, C–C graphite-like structure (sp^2), and Si nanocrystals, respectively. Moreover, a correlation between the optical properties, microstructures, and bonding configurations of the Si^+/C^+ implanted SiO_2 films was also established in this study.

1. Introduction

Visible photoluminescence (PL) emitted from porous silicon at room temperature was first reported in 1990 [1]. Variable energy bandgap of porous silicon could be induced by the quantum confinement effect, leading to the radiative recombination of carriers that can emit multiple luminescence spectra. From then on, the research of silicon-based nanostructure materials has been prosperous due to such the special optoelectronic property.

Plenty of processes have been adopted to manufacture low-dimensional silicon-based materials where silicon nanocrystals embedded, e.g. ion beam synthesis [2–9], physical sputtering [10,11], and plasma-enhanced chemical vapor deposition (PECVD) [12–14]. Especially, ion beam synthesis possesses a distinctive feature of adjustable implantation fluence and accelerated ion energy such that the size and distribution of the ion beam synthesized nanoparticles can be well controlled. This is also the reason why the process has been widely used to synthesize specific nanoparticles in some matrix materials. Luminescence properties of group-IV nanoparticles formed by ion beam synthesis have been reported to be dominated by the defect states located at the interface between nanoparticles and matrix material. For example, high-energy Si^+ ions implanted into SiO_2 would congregate together after thermal annealing and thus produce some silicon- and oxygen-related defects at the Si/SiO_2 interface. These defects may trap carriers and create energy levels within the energy bandgap of Si and eventually become a radiation recombination center for light emission [15–18]. In contrast to the single-element implantation, the co-implantation method that two or more ions are sequentially implanted into the same matrix has been also proposed in recent years. Multiple ions implanted into the same matrix may generate different types of defect configurations and also enhance the interaction between the ions and defect states,

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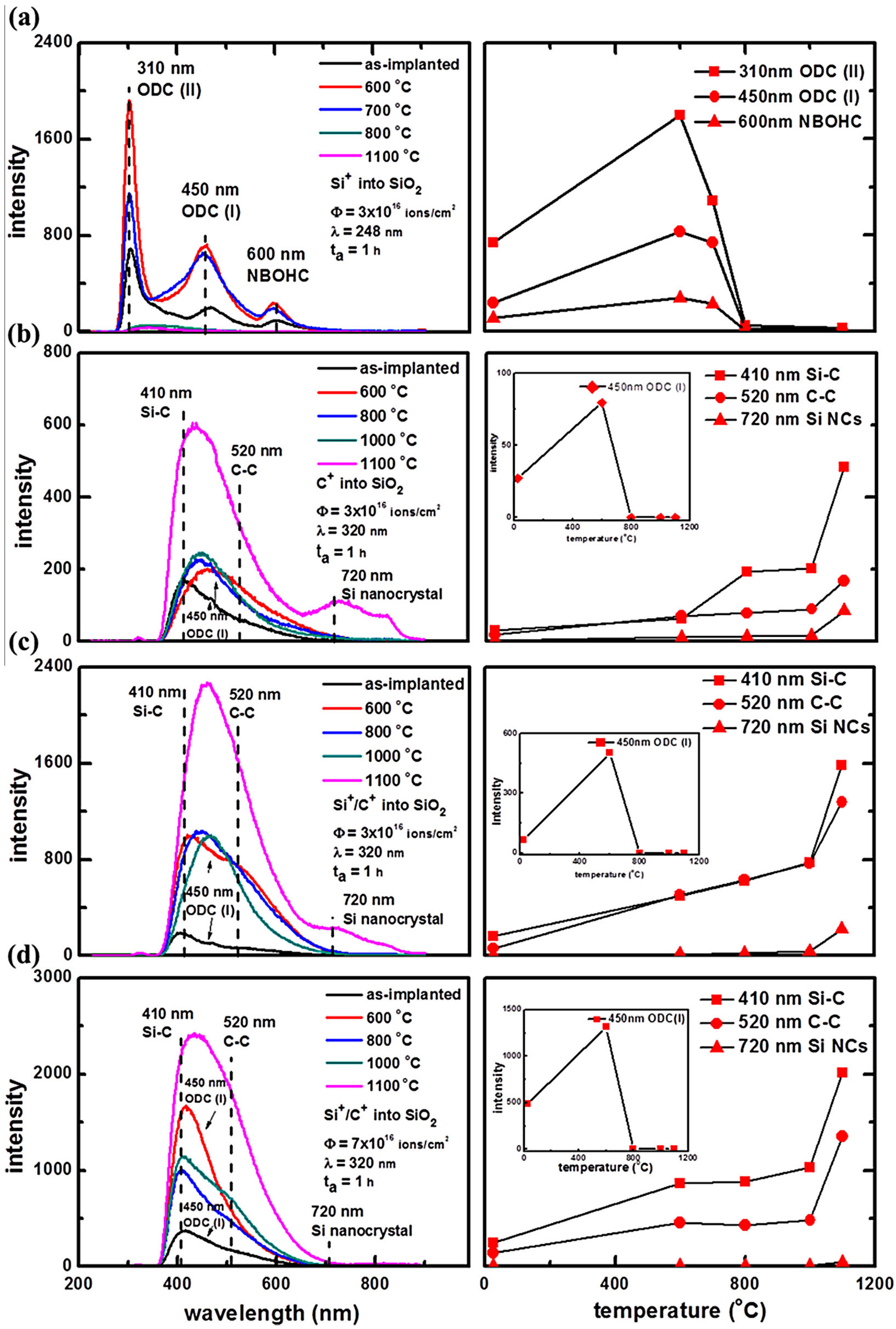

Fig. 1. PL spectra (left) and trend charts (right) of the specimens implanted with (a) Si^+ (3×10^{16} ions/cm^2), (b) C^+ (3×10^{16} ions/cm^2), (c) Si^+/C^+ (each 3×10^{16} ions/cm^2) and (d) Si^+/C^+ (each 7×10^{16} ions/cm^2) and annealed at different temperatures for 1 h.

thus producing a variety of luminescence sources. Among them, Si^+/C^+ co-implantation is the most common combination to incorporate multiple group-IV species into SiO_2 for multi-band luminescence. With addition of carbon, the original peaks of PL spectrum induced by Si nanoparticles embedded in SiO_2 would change and even develop additional peaks in the range of visible light, which could be the important constituent bands for efficient white-light emission. However, luminescence mechanism of nanostructure synthetized by ion implantation is still under discussion, including quantum confinement effect of nanoparticles [19] and internal defects at the interfaces between nanoparticles and SiO_2 matrix (e.g. oxygen deficiency centers (ODCs) and non-bridging oxygen