Pergamon

Solid State Communications, Vol. 96, No. 5, pp. 317–320, 1995
Elsevier Science Ltd
Printed in Great Britain
0038-1098/95 $9.50+.00

0038-1098(95)00448-3

Luminescence of Er-implanted porous silicon

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(*Accepted* 10 *June* 1995 *by Z. Gan*)

After Er^+ ion implantation the bright visible emissions of porous silicon (PSi) still remain. After annealing 1.54μm characteristic emissions of Er^{3+} in PSi have been measured, and its intensity is much more intense than that of Si processed by same conditions. Further experiment shows that enhancement of the Er^{3+} emission relates to the surface layer of porous silicon. It is probable that the impurities introduced in surface layer by electrochemical process give rise to 1.54μm luminescence enhancement.

Keywords. A. nanostructures, A. semiconductors, E. luminescence

1. Introduction

Silicon is the important semiconductor, it has been extensively applied in microelectronic technology. At room temperature, the band gap of silicon is 1.11ev, corresponding to 1.14μm wavelength of light emission, lying on near infrared region of spectrum. Unfortunately, silicon has an indirect band gap, its efficiency of light emission is too small to use practically in optoelectronic devices. Recently silicon has been doped with rare earth element Er, and the Er^{3+} characteristic light emission has been observed at 1.54μm[1-3]. It just lies on a low-loss region in silica optical fiber transmission. It is of interest to note whether silicon doped Er can be made into light emission device with the power enough to practical use. Recently, the intense visible light emission of porous silicon (PSi) has been observed[4] at room temperature, which broke through one's traditional knowledge for silicon. PSi cannot only emit visible light from red to blue, but the emission is efficient. A wonderful future has been laid out before us for silicon-based optoelectronics devices.

Recently T. Kimura at al[5] have prepared Er-doped PSi with electrochemical method and obtained 1.54μm emission at room temperature. In this paper, we investigated the light emission of Er-implanted PSi in visible and near-infrared regions. 1.54μm Er^{3+} characteristic emission has been obtained in PSi. Its intensity is much more intense than that in Si processed by same condition. It is probalble that the impurities introduced in surface layer by electrochemical process give rise to 1.54μm luminescence enhancement.

2. Experiment

Single crystals used in the experiment were liquid encapsulated Czochralski grown n-type Si, (111) oriented, with a resistivity of 10-12Ωcm. PSi were prepared by electrochemical etching in a solution of HF: C_2H_5OH = 1 : 1 (volume). The current density of 20mA/cm^2 was kept for 25 minutes. During etching the samples were illuminated by a infrared lamp. The surface layer depth of the prepared PSi was about 2.5μm, the depth of porous layer was about 15μm and pore radius is microns.

Erbium ion implantations were perfomed at an energy of 350kev. Ion doses were in $1\times10^{12}-1\times10^{15}$/cm^2 range. The samples were then annealed in a dry nitrogen atmosphere at a temperature of 950℃ for 10 minutes.

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Photoluminescence (PL) spectra of visible region were measured with the spectrofluorophotometer at room temperature. The excitation source was 365nm line of Xe lamp. Infrared PL measurements were performed at 77K and the samples were excited by the 632.8nm line of He-Ne laser. PL signal was detected by a liquid nitrogen cooled Ge detector.

3. Result and Discussion

Before Er ion implantation, PSi presented bright hamogeneous yellow light emission under ultraviolet light excitation at room temperature. Its visible spectrum is showed in Fig. 1(a). The peak of spectrum is at 575nm. The PSi was cut in five. The one remained as the original sample, and the others were used for Er-implanted experiments. The ion energy was 350kev, and the ion doses were 1×10^{12}, 1×10^{13}, 1×10^{14} and $1\times10^{15}/cm^2$ respectively. After ion implantation the bright yellow emission still presented with the excitation of ultraviolet lamp. Fig. 1(b) is the spectrum of the sample implanted with $1\times10^{14}Er^+/cm^2$. The peak wavelength at 562nm is somewhat shorter than that of non-implanted PSi.

The cross-sectional SEM (scanning electron microscopy) micrograph of PSi have showed[6] that PSi can be separated into three layers: surface layer, porous layer and crystalline silicon substrate. The efficient visible light emission of PSi comes from the surface layer. Ion implantation usually induces serious radiation damage on the sample surface due to the high energy ion collision to the lattice, which forms the nonradiation recombination center in the band gap and result in the emission intensity reduction even disappearence. Our previous report has indicated[7] that after the implantation with ion energy of 350kev and Er ion dose of $-1\times10^{15}/cm^2$ an amorphous surface layer formed on the single crystal Si and the thickness of which was about 250nm. After Er-implantation in $1\times10^{12}-1\times10^{15}/cm^2$ dose range, our PSi keep bright visible emission yet. We can say that the radiation-resistance of the surface light emitting layer of PSi is well. It will be seen from those that the surface light emitting layer was not the order crystal, whereas may be some substance formed in electrochemical process.

In order to eliminate the damage induced by implantation and to activate Er ion, the samples were annealed in dry nitrogen atmosphere at 950℃ for 10 minutes. After annealing the visible light emission of PSi disappeared entirely.

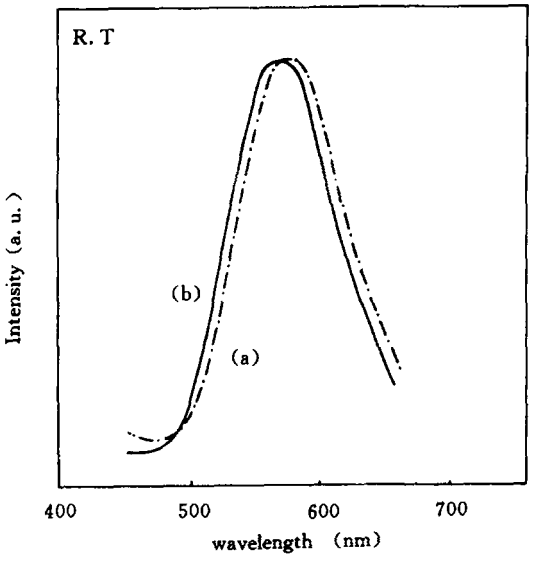

Fig. 1. Visible spectra of PSi
a) before implantation
b) after implantation
(350kev, $1\times10^{14}Er^+/cm^2$)

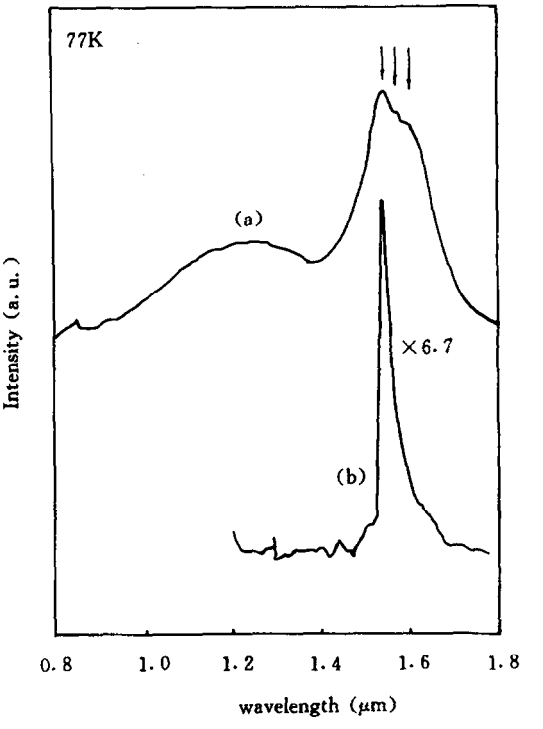

Fig. 2. Near-infrared spactra of Er-implanted samples
a) porous silicon
b) crystal silicon
(350kev, $1\times10^{13}Er^+/cm^2$, N_2, 950℃)

Fig. 2(a) shows the near-infrared spectrum of PSi Er^{3+}-implanted with dose $1\times10^{13}/cm^2$. For comparison, fig. 2(b) shows the spectrum of crystal Si processed by same conditions. The dominant peaks of two spectra all lie at 1.546μm. In PSi the spectrum is broader and the lines are richer. Besides the dominant peak there are two minor peaks, lying at 1.578μm and 1.597μm respectively. These emissions are characteristic emission due to 4f-transitions between the weakly crystal field split spin-orbit level $^4I_{13/2}$ — $^4I_{15/2}$ of Er^{3+} ($4f^{11}$). By comparing the dominant peak intensity of two spectra in Fig. 2, it is clear that the emitting intensity of PSi is much more intense than that of Si, and so are the samples throughout the applied doses.

Project range Rp of Er ion with 350kev energy is 110nm[7] in single crystal Si. The depth of surface layer of PSi used is about 2.5μm. After taking off the surface layer of PSi used in Fig. 2(a), we can not obtained the characteristic emission of Er^{3+} in our measurement conditions. To understand the effect of surface layer on Er^{3+} emission we prepared the sample in the following method: take off the surface layer of the local region of PSi, the porous layer was exposed. We labeled it with B. The other region was labelde with A. Then implantation and annealing were performed. Fig. 3(a) and 3(b) show the spectra of region A and region B respectively. By comparison, two spectra have the same peak wavelength. The emission intensity of spectrum A is much more intense than that of spectrum B, that is, emission intensity of Er^{3+} in surface layer is more intense than that in porous layer. Recently some researchers have investigated the effect of impurities on Er^{3+} emission in crystal Si. J. Michel at al[8] have confirmed that the impurities, as O、C、F etc, result in Er^{3+} emission enhancement in crystal Si. We also have obtained the Er^{3+} emission enhancement with O、Er coimplantation in Si (to be published). Erbium have extrmely high chemical activety, can form a variety of complex with impurities, which restrain Er migrating toward the surface, decrease Er segragating during annealing and are favourable to increase Er concentration. Zhou Yong-Dong[6] et al have showed that the surfce layer of PSi contains a lot of impurities, as O、C、F etc. Thus, it is probable that the impurities introduced be electrochemical process give rise to 1.54μm emission enhancement.

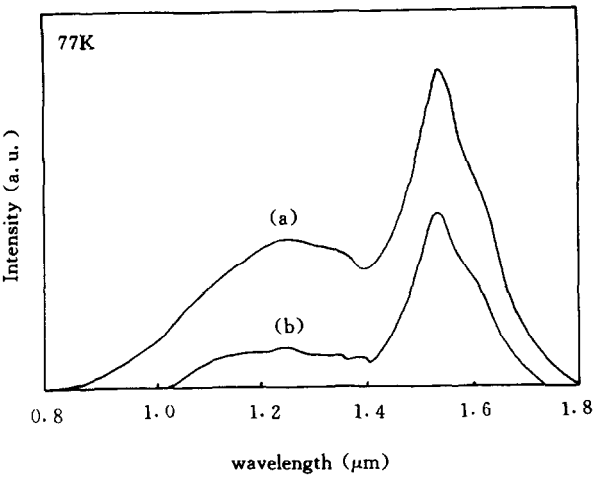

Fig. 3. Near-infrared spectra of Er-implanted PSi
a) region A (non-taking off the surface layer)
b) region B (taking off surface layer)

4. Summary

Radiation-resistance of surface light emiting layer of PSi is well, after Er ion implantation the bright visible emission still remain. After implantation and annealing 1.54μm characteristic emissions of Er^{3+} in PSi have been measured. and its intensity is much more intense than that of Si processed by same conditions. The experment shows that enhancement of the emission relates to the surface layer of PSi. It is proboble that the impurities introduced in the surface layer by electrochemical process give rise to 1.54μm luminescence enhancement.

Acknowledgements — The authors acknowledge with thank the financial support provided by the national natural science foundation of China.

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