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1.5μm LUMINESCENCE CHARACTERISTIC OF ERBIUM IN B, P DOPED a-SiO:H FILMS*

Liang Jian-jun(梁建军)[a)b)c)], Chen Wei-de(陈维德)[a)b)c)], Wang Yong-qian(王永谦)[a)b)c)], Chang Yong(常 勇)[c)], and Wang Zhan-guo (王占国)[a)]

[a)] *Institute of Semiconductors, Chinese Academy of Sciences, Beijing* 100083, *China*

[b)] *Center for Condensed Matter Physics and State Key Laboratory for Surface Physics, Chinese Academy of Sciences, Beijing* 100080, *China*

[c)] *State Key Laboratory for Infrared Physics, Shanghai Institute of Technical Physics, Chinese Academy of Sciences, Shanghai* 200083, *China*

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Hydrogenated amorphous silicon films co-doped with oxygen (O), boron (B) and phosphorus (P) were fabricated using PECVD technique. The erbium (Er) implanted samples were annealed in a N_2 ambient by rapid thermal annealing. Strong photoluminescence (PL) spectra of these samples were observed at room temperature. The incorporation of O, B and P could not only enhance the PL intensity but also the thermal annealing temperature of the strongest PL intensity. It seems that the incorporation of B or P can decrease the grain boundary potential barriers thus leading to an easier movement of carriers and a stronger PL intensity. Temperature dependence of PL indicated the thermal quenching of Er-doped hydrogenated amorphous silicon is very weak.

Keywords: erbium, photoluminescence, a-SiO:H, boron and phosphorus co-doping
PACC: 7855, 6170

I. INTRODUCTION

Enormous interest has been attracted to the fabrication of erbium-doped semiconductor films for silicon-based optoelectronics, because Er ions produce characteristic intra-4f luminescence emissions which have little dependence on the host material or temperature.[1,2] Of particular interest is Er ion emission of photons at 1.54μm, which falls inside a window of absorption minimum for silica-based fibers.[3,4] Therefore, the luminescence behavior of Er-doped silicon has been studied extensively during recent years.[5−8] The realization of integration of Si:Er light emitting devices indicated the great potential of Er-doped semiconductor materials in optoelectric application.[8] Hydrogenated amorphous silicon film allows to side-step the problem of limited solubility of Er in crystalline semiconductors, and to incorporate more impurities such as oxygen and carbon which can enhance the luminescence of Er. Also it has good electrical quality and is a mature semiconductor. We have studied the effect of the oxygen concentration on luminescence and shown, the range of an optimum oxygen content for the strongest PL.[9,10] In this paper we study the role of B and P on the photoluminescence (PL) of Er-doped a-SiO:H, the behaviors of thermal annealing and excitation mechanism of Er are also studied and discussed briefly.

II. EXPERIMENTAL

Hydrogenated amorphous silicon oxide films were fabricated on the c-Si substrates using plasma-enhanced chemical vapor deposition (PECVD) technique at 250°C. SiH_4(100%) and N_2O(100%) were guided into the chamber at the same flow rate. X-ray photoelectron spectroscopy (XPS) analysis showed that the O/Si ratio in the film (a-SiO:H) was approximately 1. The parameters of B or P codoped with oxygen to grow a-$SiOB_x$:H or a-$SiOP_x$:H films were the same as that of the a-SiO:H film except that B_2H_6(0.5%) or PH_3(5%) gas was added into the chamber, respectively. The Er^{3+} was implanted into the three samples at 400 keV with a dose of 2×10^{15}cm^{-2} at room temperature. And another sample, the hydrogenated amorphous silicon (a-Si:H) film was also made with the 5:20 flow ratio of SiH_4(100%) and H_2(100%). The Er^{3+} was implanted at 400 keV with a dose of 2×10^{15}cm^{-2} and O was implanted at 60keV with a dose of 5×10^{16}cm^{-2}. All four films(a-SiO:H, a-$SiOB_x$:H, a-$SiOP_x$:H and a-Si:H) were annealed in a N_2 ambient and PL spectra were measured by Fourier transform infrared spectroscopy.

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Ⅲ. RESULTS AND DISCUSSION

The room temperature PL spectra of three different films annealed at 550°C for 240s are depicted in Fig.1. Both the a-SiOP$_x$:H(Er) film and a-SiOB$_x$;H(Er) film have stronger luminescence than that of a-SiO:H(Er) film. Obviously, the incorporation of B or P could enhance more effectively the PL intensity. The role of B in our experiment is the same as that of Michel's result,[11] which showed that B will benefit to PL intensity of Er, but P has not the same role as reported. They argued that the heavier elements, such as, P has little effect on the PL intensity of Er. But in our case as shown in Fig.1, the P-codoped film has also a strong PL intensity of Er.

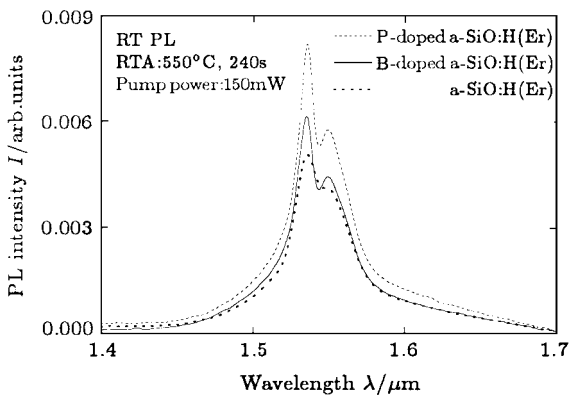


Fig.1. PL spectra at room temperature of three films: a-SiOP$_x$:H(Er), a-SiOB$_x$:H(Er) and a-SiO:H(Er).

When the Er ions are excited from the ground state to the first excited state by the recombination of bound excitons at the impurity related level, there are two paths to transfer the recombination energy: one is the bound excitons recombined and the energy transferred to the Er ions and excited the Er ions to excited state (T1); and the other is the recombination energy dissipated as a phonon or other ways (D1). On the other hand, the excited Er ions then come down to the ground state and emitted 1.54μm photon or they back-transfer the energy to host material and returned to ground state. The luminescence intensity will depend on which way is dominating in the energy transportation. Therefore, it is important to understand the microstructure of the film because it determines the paths of energy transferred to Er.

In our case, Raman spectrum showed that the Er-doped a-SiO:H, a-SiOB$_x$:H and a-SiOP$_x$:H films consisted of amorphous-Si/c-Si grains and amorphous SiO$_x$. Lombardo *et al.*[12] proved that the B or P incorporation will strongly influence the band bending and the height of potential barriers existing among the grains will be weaken or decreased due to the incorporation of B or P. We think that the Er ions existing in the grain boundary attribute to the PL intensity and the photocarriers have to surmount the potential barrier if they intend to move. Only the carriers that surmount the barriers can transfer the energy to Er. So the decrease of the grain boundary potential barrier due to the incorporation of B or P means that the photocarriers can move and transfer energy more easily. In turn, the possibility of the energy transferred to Er increases, resulting in a stronger PL intensity, that is, the incorporation of B or P will raise the possibility of T1.

On the other hand, the incorporation of B probably can passivate part of the defects which are non-radiative recombination centers in the film. Due to a small radius, a B atom is easy to fill in a defect caused by ion implantation, resulting in a decrease of the number of defects. Thus the incorporation of B decreases the possibility of D1. While P incorporation would promote the crystallization of the film.[13] Although the as-grown films are amorphous, the microcrystalline silicon will form after RTA and then strengthen the PL intensity of Er.[10]

Figure 2 is the annealing temperature dependence of PL intensity for four different samples. The optimum annealing temperature corresponding to the strongest PL intensity is at 450°C, 550°C and 650°C for S1, S2, both S3 and S4 samples, respectively. S1 is the Er and O co-implanted sample that shows the lowest PL intensity. It seems that there are a lot of non-radiative centers (defects) remaining in the sam-

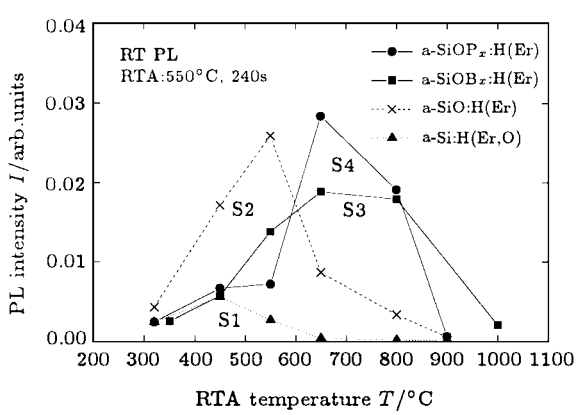


Fig.2. Annealing temperature dependence of PL intensity for four samples: a-SiOP$_x$:H(Er), a-SiOB$_x$:H(Er), a-SiO:H(Er) and a-Si:H(Er,O).

ples, although implantation damage can be recovered partly by RTA. When RTA temperature is above 400°C the escape of H causes a number of defects which would dissipate the energy transferred to Er ions. S2 is the sample grown with a very high oxygen concentration. More optically active [Er-O] complexes formed after implantation of Er and O also have stronger bond with H, Er and Si. The presence of O improves the stability of the bonding and raise the optimum RTA temperature about 100°C. S3 and S4 are samples co-doped by B and P with O, respectively. The optimum RTA temperature of the two samples is raised by another 100°C. It seems that the affiliation of O, [B,O] or [P,O] may strengthen the bonds of the films, so RTA temperatures raise step by step. But how to further explain the fact that the incorporation of B or P raises the RTA temperature still needs to study.

Figure 3 shows the temperature dependence of PL intensity of a-SiO:H(Er) sample measured from 15 to 250K. The PL intensity decreases with increasing temperature. PL intensity at 250K is one half of that at 15K, so the thermal quenching is very weak in comparison with that of Er-doped crystalline silicon materials.[14] In Fig.3 the measured temperature dependence of PL intensity can be divided into three regions. The first region is from 15 to 35K; the second is from 45 to 90K and the third region is from 101 to 250K. The excitation of Er most likely takes place through an Er-related level in the Si bandgap. An electron-hole pair may be bound to this level, then recombine and transfer the recombination energy to Er ion. At low temperatures the possibility of excitons bounded at the in Er-related level is high, and the possibility of the recombination energy transferred to Er is also high, thus resulting in a stronger PL intensity. The number of excitons bounded at the level decreases when the temperature increases, leading to the decrease of PL intensity of Er. Possibly, an excitation mechanism with three activation energies[15] exists which correspond to the three regions in Fig.3. Also we notice that from 15 to 250K, no shift of the 1.54μm peak was observed, showing the independence of the host material and the temperature on the luminescence of Er ions.

Figure 4 is the square root of pump power dependence of PL intensity of a a-SiO:H(Er) sample. The linear relation between them indicates that non-radiative recombination energy transfer mechanism[16,17] is the main cause for the temperature quenching.

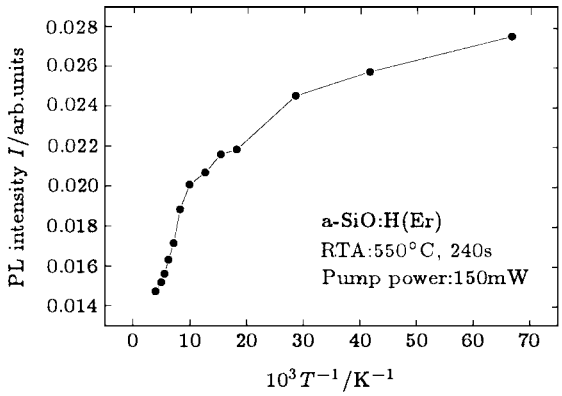


Fig.3. Temperature dependence of PL intensity from 15 to 250K.

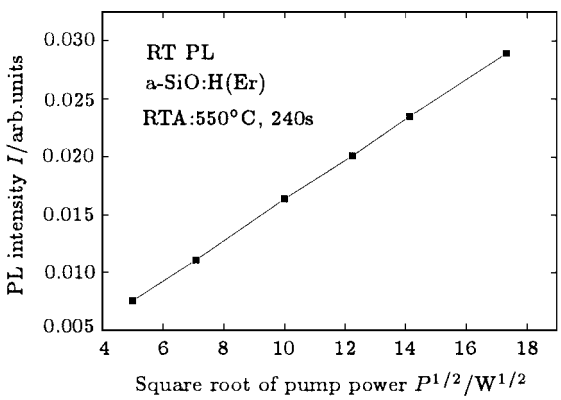


Fig.4. PL intensity at room temperature versus square root of pump power.

IV. CONCLUSION

In summary, PL intensity of Er was enhanced due to the incorporation of O, B and P in the hydrogenated amorphous silicon films. The presence of oxygen lead to the formation of optically active [Er-O] complexes with Er ions that enhance the luminescence, and the temperature quenching is improved in comparison with that of Er-doped crystalline silicon. The incorporation of B or P may decrease the grain boundary potential barrier, thus make the carriers move easier. And adulteration of these three elements elevates the RTA temperature corresponding to the strongest PL intensity.

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