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1.5 µm Photoluminescence from Conductive Er-doped SnO_X

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1. Introduction

Highest operation frequency of microprocessors has saturated around 4GHz because of many serious electro-magnetic problems in electrical wiring such as cross talk, clock skew, and so on. Parallel processing scheme has become a mainstream with multi-core microprocessors utilized, where enormous amount of data should be transmitted within a chip. For thus busy intra-chip communications, a silicon-based optical interconnection technology (silicon photonics) is highly attractive and, hence, required. Additionally, the optical interconnection scheme with the silicon photonics basis is also promising for inter-chip, board to board, and box to box communications. To realize the essential framework of silicon photonics, the development of light sources compatible to complemental-metal-oxide-semiconductor (CMOS) processes has been one of the most critical issues: namely, one of the indispensable goals is to develop silicon-based infrared emitters with current injection operation modes. Up to now, such light sources realistically applicable to systems have not been achieved yet because of the indirect bandgap of Si, which has prevented efficient light emissions at room temperature.

Recently, much attention has been attracted to erbium (Er)-doped silicon suboxide (SiO_X: $x \leq 2$) as a promising material for silicon-based light source in the 1.5µm band [1-3]. Their studies are mainly photo-excited photoluminescence experiments. On the other hand, Castagna et al reported electroluminescence using Er-doped SiO_X layers ($x \sim 2$) [4], but they have two critical problems when carriers are injected into the layers: electrical breakdown of the SiO_X layers and very high operation voltage of several tens of volts. This is because the SiO_X is an insulator and its bandgap is as wide as 8 eV when its oxygen composition x is equal to 2. In order to overcome this obstacle, we have tried two kinds of approaches; one is the usage of Si-rich SiO_X with low oxygen composition ($x \sim 1.3$) having a narrower optical bandgap of ~2eV [5], and the other is formation of Er-doped tin-oxide (SnO_X) which is reported in this work. The latter is possibly expected to provide a high conductivity since transparent conductive films of SnO_2 have been used to amorphous Si solar cell. At the best of our knowledge, however, the reported trials with Er-doped SnO_X are mostly based on the sol-gel process [6]. Recently, we have tried to apply the vacuum evaporation method to formation of Er-doped SnO_X layers and have obtained some thin films. In this paper, we report preliminary investigation results for the Er-doped SnO_X films.

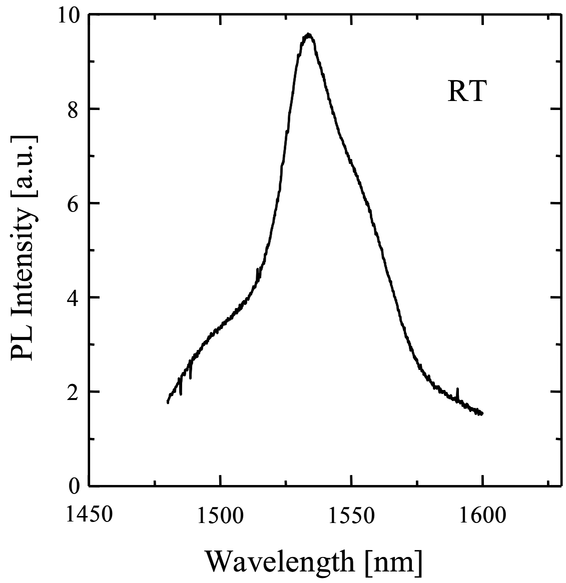

Fig. 1. Room-temperature photoluminescence spectrum of Er-doped SnO_X annealed at 700°C.

We found out that a photoluminescence (PL) signal was observed at 1.5µm from highly conductive films.

2. Experimental Procedure

For the formation of Er-doped SnO_X films, we have tried the vacuum evaporation method as described in the followings. Er and tin-monoxide (SnO) were thermally evaporated in a vacuum chamber and deposited onto synthetic quartz glass substrates. The temperature of the substrate was kept at 550 °C and the vacuum pressure was 1×10^{-4} Torr. Thicknesses of Er-doped SnO_X films were set to be 200nm, and Er concentration in the film was arranged about 3%. The samples were thereafter annealed for an hour in a furnace at various temperatures ranging from 600 °C to 900 °C with flowing pure oxygen at atmospheric pressure.

Photoluminescence spectra for the annealed samples were obtained with a grating monochromator equipped with InGaAs p-i-n photo-diodes. The samples were excited by an ultraviolet He-Cd laser (325nm, 8mW). Optical transmission characteristics were also measured with a spectrophotometer. Subsequently, energy dependence of absorption coefficients was obtained from the transmission spectra, and bandgap energies of the samples were estimated from the absorption edges. On the other hand, resistivity of the samples was characterized by four-terminal measurements and their carrier types were judged by the Seebeck effect.

3. Results and Discussion

Figure 1 shows room-temperature PL spectrum for an Er-doped SnO_X sample annealed at 700°C. The wavelength of the PL peak is 1.53μm and the shape of the emission spectrum is similar to that of Er-doped SiO_X [5]. The PL intensity shown in Fig. 1 is as high as that of Er-doped SiO_X samples, which are formed in our group [5], if the PL intensity is assumed to be proportional to the layer thickness.

In addition, PL spectra similar to that in Fig. 1 were observed for other samples with different anneal temperatures of 800 °C and 900 °C. On the contrary, any PL signal was not observed for the sample annealed at 600 °C. This is probably because the crystal formation process was not completed at the low temperature.

The optically estimated bandgap energies of the samples were around 4 eV with no anneal temperature dependence as long as it ranges from 700 °C to 900 °C. However, the optical bandgap for the sample annealed at 600 °C was found to be 3eV. This is probably because of the same reason as for the disappearance of PL signal.

Resistivity was found to be as low as 10^{-2} Ωcm showing high conductivity for the samples annealed at 700 °C to 800 °C. Their carrier type was judged to be n-type. These results suggest that electron density in the Er-doped SnO_X samples is high enough to provide electroluminescence if a p-n junction is formed.

From the above results, one can conclude that both optical and electrical characteristics are satisfactory in the present Er-doped SnO_X samples as long as the post-annealing temperature is appropriately chosen. The light emission property at 1.5 μm with the high conductivity is fairly attractive for the realization of CMOS-based infrared emitters with electrical injections.

4. Conclusion

Er-doped SnO_X samples with attractive optical and electrical features were successfully formed by a vacuum deposition of Er and SnO and a subsequent annealing process. Room-temperature photoluminescence at 1.53μm has been observed together with low resisitivity of ~10^{-2} Ωcm. The optical bandgap of the Er-doped SnO_X was evaluated to be ~4eV from the energy dependence of the absorption coefficients.

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