Light Emission at 1530 nm from Mixture of Er_2O_3 and P_2O_5 Nanoparticles on Silicon

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Abstract — **We introduce a new manufacturing technique that lays a light emitting layer on silicon wafer. This layer is formed with the mixture of Er_2O_3 nanoparticles and spin-on glass. It emits 1530nm light because Er_2O_3 releases Er^{3+} at high temperature. The process is simple. We also add P_2O_5, Al and Ag nanoparticles to improve light emission.**

Index Terms —**Nanotechnology, optical communication, optical pumping, rare earth compounds.**

I. Introduction

The amount of data transmission continues to grow, so the advantage of high transmission capability of optical fiber is of great worth. The demand for optical components also rockets up. Erbium-doped optical fiber amplifier is the core technique of modern optical communication systems. However, erbium-doped optical fiber has several disadvantages. For example, it has expensive fabricating cost. In addition, it is difficult to monolithically integrate with electronics. Thus, we introduce a new manufacturing technique to create a light emitting layer on Si wafer. It emits light at 1530nm. The fabrication process is very simple and nearly costless, compared with ion implantation technique. In addition, it can be possibly integrated with mature IC manufacturing process widely used today and realizes monolithic integration. Moreover, we can extend the applications of Si such as taking the Si optoelectronic integrated circuits (OEIC) for the light source of optical communication systems.

II. Experiment

The manufacturing process is schematically shown in Fig.1. A piece of silicon wafer is cleaned with standard procedure. Er_2O_3, P_2O_5, Al and Ag nano-particles are mixed into spin-on glass (SOG), which is taken as the host material. The Er_2O_3 nanoparticles are uniformly distributed in the solution. Then, we deposit the solution on the silicon wafer and soft bake in 80°C for 1 minute. Repeat this step for a few times to obtain a thick emitting layer. In the final step, heat the sample in 880°C~1000°C for 30~150 minutes in order to make the Er_2O_3 release Er^{3+} and react with SOG. The heating temperature has to be 880°C or above so that Er_2O_3 would be reactive [1].

A large Er^{3+} doping concentration in silica glass results in concentration quenching caused by ion clusters. Phosphate and silicate glasses are superior to silica glass for the realization of high concentration erbium-doped optical amplifiers. Due to the high solubility of rare-earth ions without cluster formation, phosphate glasses are of great interest as a gain medium for compact erbium-doped optical amplifiers [2]. Therefore, we add P_2O_5 nanoparticles to the solution of light emitting layer to reduce cluster formation.

The different sets of Er_2O_3, P_2O_5, and Ag mixture with different volume ratio were experimented. The different compositions result in samples with variable properties, such as conductivity and formation of cluster. Table I lists these different compositions. Following measurements of photoluminescence are under optimized alignment.

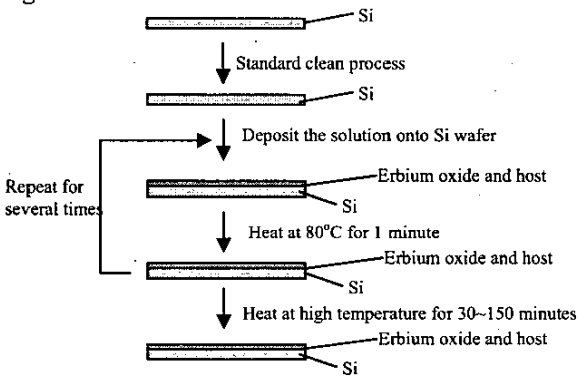

Fig.1 Sample manufacturing process.

TABLE I

SUMMARY OF COMPOSITIONS AND HEATING TREATMENT

	Compositions (Volume Ratio)				Heating Temperature and Duration	
Set	Er_2O_3	SOG	P_2O_5	Ag	Temperature (°C)	Duration (min.)
A	1	1			880	90
B	1	1	1		1000	90
C1	2	2	2	1	1000	90
D1	1	2	2	1	1000	30
D2	1	2	2	1	1000	150

III. RESULTS

A. Er_2O_3, and SOG Only

In Set A, only Er_2O_3 and SOG were mixed. Although the compositions are quite simple, there is already an emitting peak at 1530nm (Fig. 2).

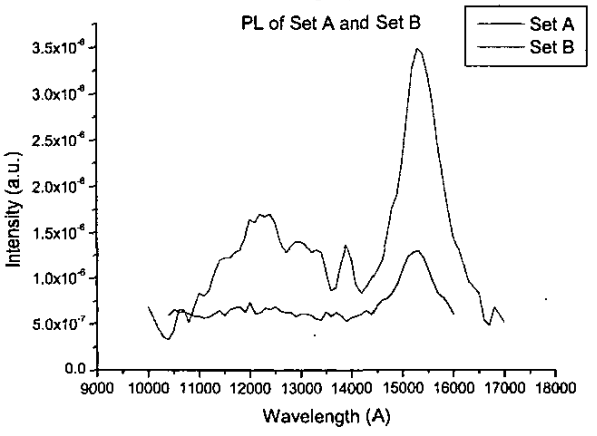

Fig. 2 Photoluminescence spectra of Set A and B.

B. Effect of P_2O_5 and Ag Nanoparticles

The effect of P_2O_5 and Ag nanoparticles was investigated with samples prepared using a similar procedure (Fig. 1). We added P_2O_5 nanoparticles to the solution of Set B, and Ag nanoparticles to the solution of Set C1. Fig. 3 illustrates the photoluminescence spectra of Set A and Set B. Fig. 3 illustrates the photoluminescence spectrum of Set C1. These samples have different physical properties and all of them emit light at 1530nm with different light emission characteristics of spectrum. Set C1 shows highest signal level among all the sets. Although it has quite high signal level, the layer of sample C1 is somehow badly uniform.

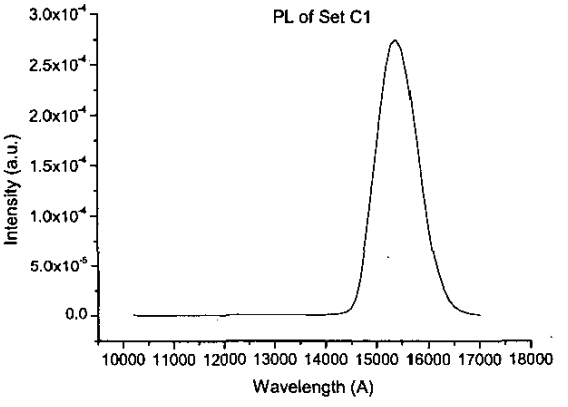

Fig. 3 Photoluminescence spectrum of Set C1 shows high intensity at 1530nm.

C. Effect of Heating Duration

To reveal the effect of heating duration, we compare the difference between set D1 and set D2, which was heated for 30 and 150 minutes respectively. Their manufacturing processes are the same as other samples (Fig. 1), and compositions are listed in TABLE I. Fig. 4 shows the photoluminescence for Set D1 and Set D2. The

TABLE II

SUMMARY OF SIGNAL TO BACKGROUND LEVEL RATIO

Set	Signal Peak Values (a.u.)	Background Level (a.u.)	Peak to Background Ratio (dB)
A	$1.30x10^{-6}$	$6.2x10^{-7}$	3.2
B	$3.49x10^{-6}$	$4.9x10^{-7}$	8.5
C1	$2.76x10^{-4}$	$9.2x10^{-7}$	24.9
D1	$4.97x10^{-6}$	$4.9x10^{-7}$	10.1
D2	$2.51x10^{-5}$	$4.9x10^{-7}$	17.2

comparison between D1 and D2 shows that samples with a longer heating duration (D2) have more emission than samples with a shorter heating duration (D1). Their signal to background level ratio is listed in TABLE II.

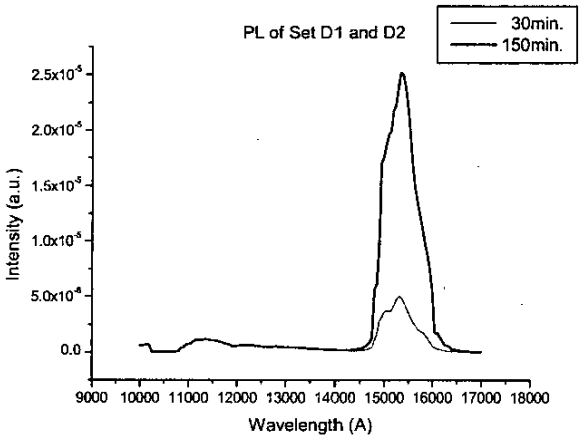

Fig. 4 Photoluminescence spectra of Set D1 and D2 show the effect of heating duration.

D. Effect of Al Nanoparticles

The samples with Al nanoparticles are also prepared. Fig. 5 is PL spectrum with the sample pumped by different pumping power. It shows relatively high signal level (13.7dB) and smooth spectrum curves. Al nanoparticles are possibly oxidized to form Al_2O_3 in the heating process and it has been known that Al_2O_3 can improve the solubility of rare earth ions [3].

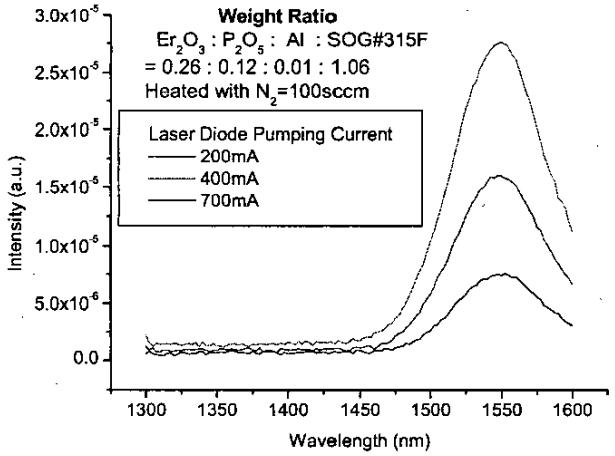

Fig. 5 Photoluminescence spectra of sample with Al nanoparticles under differernt pumping power.

IV. Discussion

Ordinary erbium-doped optical fiber requires a quite long distance to acquire significant light emission from Er_3^+ ions. Relatively, our emitting layer is able to show the signals only within 0.5μm due to the higher concentration of Er^{3+} and surface effect of nano-particles.

The original motivation of adding Ag nanoparticles to the solution of the emitting layer is to improve conductivity. However, we discovered an extra benefit of increasing light emission efficiency. Fig. 3 illustrates the high peak intensity of photoluminescence for the sample with the Ag nanoparticles (Set C1). To explain this phenomenon, we presume that Ag atoms play the role that transfers energy to Er^{3+} by free carrier absorption. Therefore, Er^{3+} ions are more easily to be excited for efficiency increase.

The heat treatment is also an important parameter of the experiment. In our experiment, samples without heat treatment of high temperature cannot emit light around 1530nm because Er_2O_3 is inertial below 880°C. Experiments show that light emission increases with the heating duration (Fig. 4). The peak intensity of Set D2 is about five times than peak intensity of Set D1.

V. Conclusion

Emitting 1530nm light on Si wafer is very useful because 1530nm is an important band in optical fiber communication. We demonstrated a simple process to form light-emitting layer on Si. The properties of samples can be varied through controlling the composition. A very valuable part of the process is that it can be possibly integrated with IC manufacturing process. In the future, building electrical and optical systems together on Si will be an expected achievement.

References

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