Optical Gain at 1530 nm from Si-Based Light Emitting Layer Containing Mixture of Er_2O_3, P_2O_5, Yb_2O_3 Nanoparticles and Spin-on Glass

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***Abstract*- A new way for light emission at 1530 nm is explored using mixtures of Er_2O_3, P_2O_5, Yb_2O_3 nanoparticles and spin-on glass deposited on silicon wafers. This layer is very thin, but exhibits optical gain.**

I. Introduction

The Er-doped optical fiber amplifier is the core technique of modern optical communication systems [1]. However, erbium-doped optical fiber has several disadvantages. For example, it requires a quite long distance to acquire optical gain and has expensive fabricating cost. In addition, it is difficult to monolithically integrate with electronics. Thus, lots of efforts are now on developing Si-based planar optical components comprising passive and active ones [2].

A number of competing technologies for fabrication of active devices, which have been investigated in the past decade, include ion implantation, plasma enhanced chemical vapor deposition, molecular beam epitaxy, and solid phase epitaxy. These fabrication techniques have several disadvantages, however, e.g. high cost, low deposition speed, and difficult to control thickness [3]-[4].

A new manufacturing technique to create a light emitting layer on Si wafer is introduced here. It emits light at 1530 nm with optical gain. The fabrication process is very simple and with very low cost, compared with other techniques above. It can also be possibly integrated with mature IC manufacturing process widely used today and realizes monolithic integration. Moreover, the optical gain enables the fabrication of Si-based lasers at 1530 nm. Therefore, we can extend the applications of Si such as taking the Si optoelectronic integrated circuits (OEIC) for optical communication systems.

II. Experiment

A. Fabrication Process

The method of manufacturing the sample is described here. First is the preparation of the solution for light emitting layer. Er_2O_3, P_2O_5, and Yb_2O_3 nanoparticles are mixed into spin-on glass (SOG), which is taken as the host material. The nanoparticles are uniformly distributed in the solution by means of ultrasonic agitation. Then, we deposit the solution on the silicon wafer cleaned with acetone, methanol, and deionized water. P_2O_5 sublimes at 358°C. Therefore, heating the sample at 300°C for 30 minutes could prevent P_2O_5 from sublimation and help the formation of phosphate glass. In the final step, heating the sample at 1000°C for 90 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 [5]. The fabrication process is schematically shown in Fig. 1.

B. Measurement for Optical Gain

Optical gain coefficients can be measured by the variable stripe length (VSL) technique firstly introduced during the seventies [6]. The big advantage of such a widely used experimental method is that no special sample preparation is needed. Both transparent and opaque samples are equally suited for gain measurements [7].

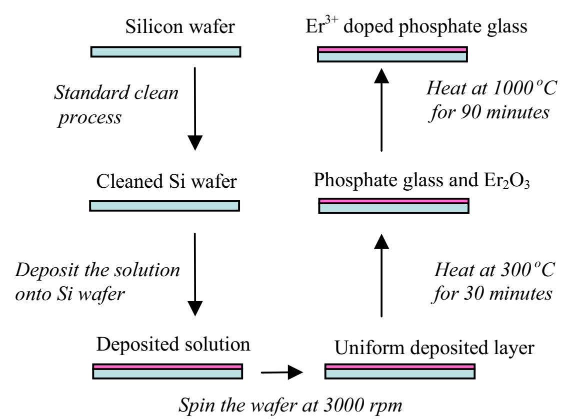

Fig. 1. Si-based emitting layer fabrication process.

III. Results

A. Non-linear Variation of 1530 nm Signal

The photoluminescence spectrum of the sample pumped by 12.5 W/cm^2 (pumping stripe width w ~ 0.4 mm) are shown in Fig. 2. The sample has a signal peak at 1530 nm. By VSL method, the signal at 1530 nm is observed to super-linearly proportional to the pumping length, while the pumping power is linearly proportional to the pumping length, as shown in Fig.

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2. With the decrement of pumping density, the super-linear growth falls away. For pumping length smaller than 1.25 mm, an exponential increase of 1530 nm amplified spontaneous emission (ASE) is observed. For pumping length above 1.25 mm, ASE intensity I_{ASE} saturates as expected. These evidence that the emitting layer exhibits optical gain.

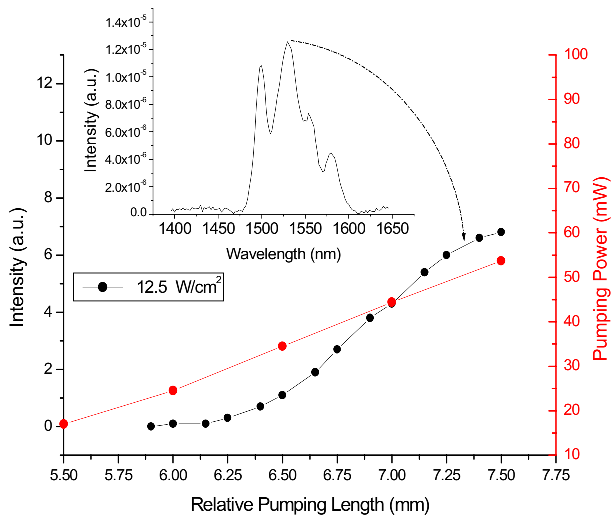

Fig. 2. Photoluminescence spectrum of the sample pumped by 980 nm for power density 12.5 W/cm^2. The pumping power at 980 nm and the I_{ASE} at 1530 nm vs. pumping length diagram are shown below.

B. *Gain Coefficient*

A locally enlarged VSL data are shown in Fig. 3. The pumping conditions including power densities P_d and pumping width w are listed too. By an exponential fitting, optical gain coefficients can be deduced. The deduced gain coefficient is about 12.4.

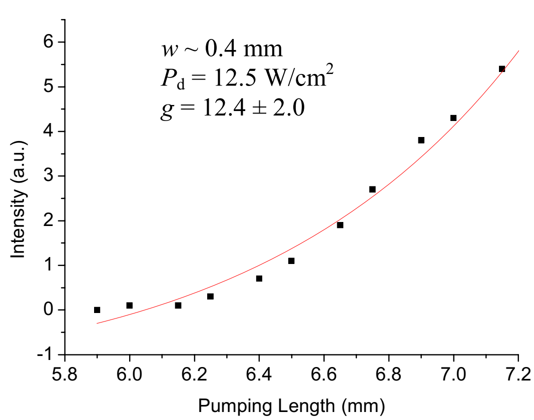

Fig. 3. Locally enlarged I_{ASE} vs. pumping length diagram. The curve is fitted exponentially to evaluate gain coefficient.

IV. CONCLUSION

This emitting layer can provide optical gain at 1530 nm. A very valuable part of this process is that it can be possibly integrated with IC fabricating process. In the future, building electrical and optical systems together on silicon is expected.

With VSL method, which frequently used to measure optical gain in semiconductor, the optical gain at 1530 nm of nanoparticle-formed light-emitting layer is measured for the first time. This is a novel fabrication process to provide erbium-doped planar optical gain devices. Furthermore the gain coefficient is deduced by exponential fitting. Benefit from Yb^{3+} sensitization, the gain coefficient measured is about 12.4 cm^{-1}. It is sufficient for microlaser operation if a resonant cavity is formed.

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