

Fabrication of Er silicate crystalline waveguide by directed self-assembly approach using radical assisted sputtering

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1. Introduction

$\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ layered crystalline thin films have been investigated as an optical gain medium for silicon photonics [1],[2]. Pulsed laser deposition (PLD) is frequently used for preparation of complex metal oxide crystalline thin films such as layered perovskite structures with remarkable success. It has been reported that directed self-assembly following layer-by-layer process by PLD enlarges grain size of $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ layered crystals [3]. The directed self-assembly is performed by using rapid thermal crystallization. In order to proceed with the further device applications, the deposition process with high uniformity, high accuracy, large area and high speed is required.

Recently we have attempted to utilize radical-assisted sputtering (RAS) method [4] to form the layered complex metal oxide crystalline thin films. Schematic of the RAS system is shown in Fig.1. RAS technique uses a high-speed rotatable drum as a substrate holder, and a radical source and metal targets set up independently around the drum. Due to control of the drum rotation and sputtering conditions, it is possible to repeat metal-sputtering and oxidation processes with layer-by-layer accuracy. Consequently, the deposited materials with large area and similar atomic arrangements to the goal crystal can be obtained.

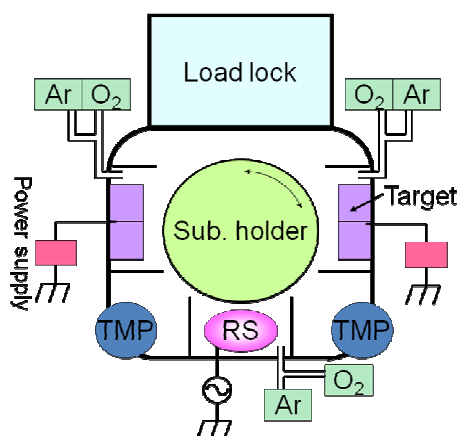


Fig. 1 Schematic diagram of Radical-Assisted Sputtering

Therefore RAS is suitable for fabrication of the layered crystalline films such as Er silicates and their device

applications. In this paper, directed self-assembly formation of Er silicate layered crystalline thin films by using RAS technique is demonstrated. Also its application to Si-guide layer buried $\text{Er}_{0.45}\text{Y}_{1.55}\text{SiO}_5$ crystalline waveguide[5] is reported.

2. Directed self-assembly

Formation of $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ crystalline thin film was performed by rapid thermal annealing of ErYSiO_5 layered amorphous preforms. Then we considered directed self-assembly for the $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ layered crystal, and prepared the layered amorphous similar to the crystalline phase. RAS system (Shincron, RAS-1100C) was used to prepare the layered amorphous thin films on Si (100) substrates at room temperature. Oxygen radical source and each metal target of Er, Y and Si were arranged around the drum-style substrate holder, respectively. The drum rotation was ~ 100 rpm and the deposition rate was 0.86nm per one rotation which corresponds to d-space of (100) direction of $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ layered crystal. The total layer is about 500nm thick, and Er ratio x is estimated to be 0.45. After the deposition, samples were annealed at 1200 and 1250°C for 10 minutes.

In comparison with sol-gel and PLD, smooth and uniform samples were obtained by RAS. Figure 2 shows XRD patterns of $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ crystalline thin film at each crystallization temperature. Closed circles indicate each diffraction peak of Er_2SiO_5 crystal. Both samples show highly orientation to the (100) direction. Accordingly the highly orientation suggests that the layered crystalline structure is formed by directed self-assembly using RAS.

Figure 3 shows PL spectra of $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ crystalline thin film under various crystallization temperatures. The particular PL fine structure is in good agreement with that of crystalline Er_2SiO_5 . The result indicates the coordinate environments around Er^{3+} ions do not change and there is only one type of luminescence center in $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ crystals.

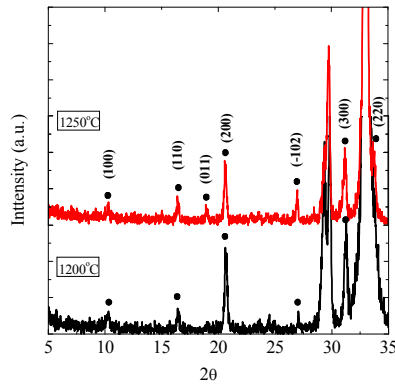


Fig.2 XRD patterns of $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ layered crystals

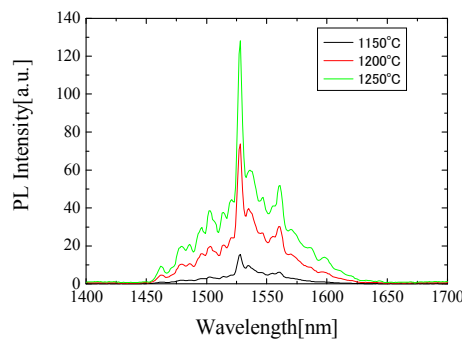


Fig.3 PL spectra of $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ layered crystals

3. Waveguide fabrication and characterization

Si-guide layer with $4\mu\text{m}$ width and 30nm thickness was deposited on SiO_2/Si substrates by electron beam evaporation. Amorphous ErYSiO thin films were formed on the processed substrates by using RAS. The $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ layer was obtained 500nm thickness and optical confinement factor of the waveguide Γ was estimated to be 0.71. After the deposition, the sample was annealed for crystallization at 1200°C for 10 minutes. $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ waveguides with buried Si-guide layer was coupled with a lensed fiber through facet. An optical pumping was performed through a lensed-fiber from the left facet of the waveguides by $1.48\mu\text{m}$ light with a power of 20mW. And top views of the waveguide were observed by a visible CCD for CUC emissions and an infrared camera for the pumping light scattering behaviors.

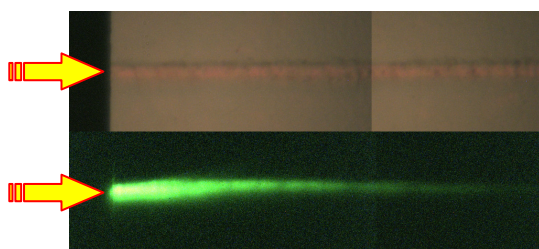


Fig. 4 Green emission decay behaviors and their intensity profile of $\text{Er}_x\text{Y}_{2-x}\text{SiO}_5$ crystalline waveguide.

The CCD top view of waveguide is shown in Fig.4. The emission lines exhibited red ($^4F_{9/2} \rightarrow ^4I_{15/2}$), green ($^2H_{11/2}, ^4S_{3/2} \rightarrow ^4I_{15/2}$) and blue ($^2H_{9/2} \rightarrow ^4I_{15/2}$) emissions related to CUC in Er ion. The sample shows intense emission and the green light tail is $140\mu\text{m}$. These results suggest that the waveguide fabricated by RAS is efficient for light emission and low light propagation loss. The propagation loss consists of absorption by Er ions and scattering loss. The decay profile of green light reveals strong suppression of scattering loss by 82 cm^{-1} , in comparison with the previous devices fabricated by sol-gel method [5]. However the scattering loss is still high. An optimization of waveguide structure and the Er content of $\text{Er}_{0.45}\text{Y}_{1.55}\text{SiO}_5$ crystal is necessary. These improvements now go on.

4. Conclusions

Directed self-assemble formation of Er silicate layered crystalline thin films has been demonstrated. RAS is suitable for formation of the layered crystals because of the precise deposition with layer-by-layer accuracy. We also have demonstrated buried Si-guide strip layer into $\text{Er}_{0.45}\text{Y}_{1.55}\text{SiO}_5$ crystalline waveguide fabricated by using RAS. This waveguide shows much smaller scattering loss than the waveguide prepared by the sol-gel method. In comparison with the previous report, the loss coefficient was drastically decreased. However, this structure is to make an improvement in terms of lateral optical confinement.

Acknowledgement

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References

- [1] H. Isshiki, M.J.A. de Dood, A. Polman, T. Kimura, Appl. Phys. Lett. 85, p 4343 (2004)
- [2] K.Masaki, H.Isshiki, T.Kawaguchi and T.Kimura. Opt. Mat. 28 (2006) 831-835
- [3] T. Kimura, Y. Tanaka, H. Ueda, and H. Isshiki, Physica E 41, pp.1063-1066 (2009)
- [4] S. Matsumoto and K. Kikuchi, US Patent 6103320
- [5] K.Homma, T.Nakajima, T.Kimura and H.Isshiki, 2010 International Conference on Solid State Devices and Materials, D-9-2, 2010