Fabrication of Tm-doped Ta$_2$O$_5$ thin films using a co-sputtering method

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ABSTRACT

Thulium-doped tantalum-oxide (Ta$_2$O$_5$:Tm) thin films were prepared using a simple co-sputtering method. A remarkable photoluminescence peak having a wavelength of around 800 nm due to Tm$^{3+}$ was observed from a film annealed at 900 °C for 20 min. The δ-Ta$_2$O$_5$ (hexagonal) phase of the Ta$_2$O$_5$:Tm sputtered film is very important for obtaining strong photoluminescence.

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1. Introduction

Tantalum (V) oxide (Ta$_2$O$_5$) is a high-refractive-index material (refractive index n > 2) used in passive optical elements such as Ta$_2$O$_5$:SiO$_2$ multilayered wavelength filters for dense wavelength-division multiplexing (DWDM). Recently, it has also been used as a high-index material of autocloned (multilayered) photonic-crystal elements for the visible to near-infrared range [1–3]. However, Ta$_2$O$_5$ has recently attracted much attention as an active optical material, since broad red photoluminescence (PL) spectra at wavelengths of 600–650 nm were observed from thermal-oxidized amorphous Ta$_2$O$_5$ thin films [1,2]. In our previous work, we demonstrated blue PL from Ta$_2$O$_5$ thin films deposited by radio-frequency (RF) magnetron sputtering [5].

Furthermore, many studies on rare-earth-doped Ta$_2$O$_5$ have been conducted because Ta$_2$O$_5$ is a potential host material for new phosphors due to its low phonon energy (100–450 cm$^{-1}$) compared with other oxide materials such as SiO$_2$ [6]. We reported on green PL from erbium-doped Ta$_2$O$_5$ (Ta$_2$O$_5$:Er) thin films produced by a very simple co-sputtering method using RF magnetron sputtering [7,8]. Their PL spectra had main peaks at a wavelength of 550 nm due to the transition of Er$^{3+}$ from the $^4$S$_{3/2}$ to the $^4$F$_{5/2}$ state ($^4$S$_{3/2}$ $\rightarrow$ $^4$F$_{5/2}$), and at a wavelength of 670 nm due to the transition from the $^4$F$_{9/2}$ to the $^4$I$_{15/2}$ state ($^4$F$_{9/2}$ $\rightarrow$ $^4$I$_{15/2}$). We also reported on red or orange PL from europium-doped Ta$_2$O$_5$ (Ta$_2$O$_5$:Eu) thin films deposited using the same co-sputtering method [9]. We observed four PL peaks at wavelengths of around 600, 620, 650, and 700 nm from our Ta$_2$O$_5$:Eu films after annealing at 600 to 900 °C. These four peaks seem to be the results of the $^5$D$_0$ $\rightarrow$ $^7$F$_{1}$, $^5$D$_0$ $\rightarrow$ $^7$F$_{2}$, $^5$D$_0$ $\rightarrow$ $^7$F$_{3}$, and $^5$D$_0$ $\rightarrow$ $^7$F$_{4}$ transitions of Eu$^{3+}$, respectively.

In this study, we fabricated thulium-doped Ta$_2$O$_5$ (Ta$_2$O$_5$:Tm) thin films using the simple co-sputtering method in order to expand the useful wavelength range of our Ta$_2$O$_5$-based light-emitting sputtered films. We obtained a remarkable PL peak around a wavelength of 800 nm from a Ta$_2$O$_5$:Tm co-sputtered film after annealing at 900 °C for 20 min.

2. Fabrication of Ta$_2$O$_5$:Tm thin films

Ta$_2$O$_5$:Tm thin films were deposited using an RF magnetron sputtering system (ULVAC, SH-350-SE). A Ta$_2$O$_5$ disc (Furuuchi Chemical Corporation, 99.99% purity, diameter 100 mm) was used as the sputtering target. We placed three Tm$_2$O$_3$ pellets (Furuuchi Chemical Corporation, 99.9% purity, diameter 20 mm) on the Ta$_2$O$_5$ disc as illustrated in Fig. 1. The Ta$_2$O$_5$ disc and the three Tm$_2$O$_3$ pellets were co-sputtered by supplying RF power to the target. The flow rate of argon gas introduced into the vacuum chamber was 15 sccm, and the RF power supplied to the target was 200 W. Commercial fused silica plates (1 mm thick) were used as substrates, and they were not heated during sputtering. We subsequently annealed the samples in ambient air at 600, 700, 800, or 900 °C for 20 min using an electric furnace (Denken, KDF S-70). We set the annealing time to 20 min because this was the proper condition for our Ta$_2$O$_5$:Er to obtain strong PL intensities [7,8].

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pellets and annealed at 600, 700, 800, or 900°C. The transition of \(\text{Tm}^{3+}\) (hexagonal) phase of fibres. Microelectron J


Fig. 2 presents PL spectra of \(\text{Ta}_{2}\text{O}_{5}:\text{Tm}\) films deposited using three \(\text{Tm}_{2}\text{O}_{3}\) pellets and annealed at 600, 700, 800, or 900°C for 20 min. A sharp PL peak having a wavelength of around 800 nm due to the \(\text{H}_{4} \rightarrow \text{H}_{6}\) transition of \(\text{Tm}^{3+}\). The \(\delta-\text{Ta}_{2}\text{O}_{5}\) (hexagonal) phase of the \(\text{Ta}_{2}\text{O}_{5}:\text{Tm}\) sputtered film is very important for obtaining a strong PL peak at the wavelength of 800 nm from our \(\text{Ta}_{2}\text{O}_{5}:\text{Tm}\) co-sputtered films.

4. Conclusions

\(\text{Ta}_{2}\text{O}_{5}:\text{Tm}\) thin films were prepared using a simple co-sputtering method. A sharp PL peak having a wavelength of around 800 nm due to the \(\text{H}_{4} \rightarrow \text{H}_{6}\) transition of \(\text{Tm}^{3+}\) was observed from a film annealed at 900°C for 20 min. The \(\delta-\text{Ta}_{2}\text{O}_{5}\) (hexagonal) phase of the \(\text{Ta}_{2}\text{O}_{5}:\text{Tm}\) sputtered film is very important for obtaining a strong PL peak. We are working to optimize the Tm concentration and annealing time of our \(\text{Ta}_{2}\text{O}_{5}:\text{Tm}\) sputtered films in order to obtain stronger PL-peak intensities. Such rare-earth-doped \(\text{Ta}_{2}\text{O}_{5}\) sputtered films can be used as high-refractive-index materials of autocloned photonic crystals [1–3] that can be applied to novel light-emitting devices.

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