Preparation of Cr_2O_3-Ta_2O_5 Composites Using RF Magnetron Sputtering

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Abstract

We prepared Cr_2O_3-Ta_2O_5 composite films using our RF magnetron co-sputtering method for the first time. X-ray diffraction (XRD) patterns and photoluminescence (PL) spectra of the films annealed at 700˚C, 800˚C, 900˚C, and 1000˚C were evaluated. From their XRD patterns, the Cr_2O_3-Ta_2O_5 film annealed at 700˚C seemed to be almost amorphous, and the one annealed at 800˚C seemed to be hexagonal Ta_2O_5 doped with Cr. In addition, the Cr_2O_3-Ta_2O_5 films annealed at 900˚C and 1000˚C seemed to include tetragonal $CrTaO_4$ phases. Furthermore, it seems that almost no defect exists in our Cr_2O_3-Ta_2O_5 composite films annealed at 700˚C - 1000˚C because their PL spectra have no defect-related peak. We thus find that good-quality Cr_2O_3-Ta_2O_5 composite films including $CrTaO_4$ can be obtained using our very simple co-sputtering method and subsequent annealing above 900˚C.

Keywords

Ta_2O_5, Cr_2O_3, Co-Sputtering, X-Ray Diffraction, Photoluminescence

Subject Areas: **Composite Material, Material Experiment**

1. Introduction

Tantalum (V) oxide (Ta_2O_5) is a higher refractive index ($n > 2$) and lower phonon energy (100 - 450 cm^{-1}) material than other popular oxides (e.g., SiO_2). It can be widely applicable to various passive/active optoelectronics elements such as anti-reflection coatings for silicon solar cells [1], photonic crystals fabricated using the autocloning method [2] [3], and novel phosphors doped with rare-earths [4]. We have so far prepared various rare-earth (Er, Eu, Yb, Tm, Y, and Ce) doped Ta_2O_5 thin films using radio-frequency (RF) magnetron co-sputtering of rare-earth oxide (Er_2O_3, Eu_2O_3, Yb_2O_3, Tm_2O_3, Y_2O_3, and CeO_2) pellets and a Ta_2O_5 disc [5]-[18], and we have obtained various photoluminescence (PL) properties from the films.

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Furthermore, we have also prepared copper (II) oxide (CuO) and Ta_2O_5 co-sputtered ($CuO-Ta_2O_5$) films using the same co-sputtering method, and we have evaluated X-ray diffraction (XRD) and PL properties of the films after annealing [19]. We find that our $CuO-Ta_2O_5$ composite films annealed above 700˚C can be tetragonal $CuTa_2O_6$ phases, and good-quality $CuTa_2O_6$ films with almost no defect can be obtained using our co-sputtering method and subsequent annealing above 900˚C. $CuTa_2O_6$ films are applicable to chemisorption-type conductometric gas sensors [20].

Chromium (Cr) is also one of transition metals, and Cr-doped garnets are well known as tunable solid-state laser materials in the red or near infrared regions [21] [22]. Novel Ta_2O_5-based functional materials are expected to be realized by doping with Cr into host Ta_2O_5. In this short report, we will demonstrate the first preparation of a Cr (III) oxide (Cr_2O_3) and Ta_2O_5 co-sputtered (Cr_2O_3-Ta_2O_5) composite film using simply co-sputtering of Cr_2O_3 and Ta_2O_5.

2. Experiments

A Cr_2O_3-Ta_2O_5 film was deposited using our RF magnetron sputtering system (ULVAC, SH-350-SE). A schematic figure of the system was presented in our previous report [6]. A Ta_2O_5 disc (Furuuchi Chemical Corporation, 99.99% purity, diameter 100 mm) was used as a sputtering target in the system. We placed three Cr_2O_3 pellets (Furuuchi Chemical Corporation, 99.9% purity, diameter 20 mm) on the erosion area of the Ta_2O_5 disc as presented in **Figure 1**. The Cr_2O_3 pellets and the Ta_2O_5 disc were co-sputtered by supplying RF power to them. The flow rate of argon gas introduced into the processing vacuum chamber was 15 sccm, and the pressure in the chamber during deposition was kept at ~5.4×10^{-4} Torr. The RF power supplied to the target was 200 W. A fused-silica plate was used as a substrate, and it was not heated during sputtering. We prepared four specimens from the as-deposited Cr_2O_3-Ta_2O_5 sample by cutting it using a diamond-wire saw, and we subsequently annealed the four specimens in ambient air at 700˚C, 800˚C, 900˚C, or 1000˚C for 20 min using an electric furnace (Denken, KDF S-70).

The XRD patterns of the specimens were recorded using an X-ray diffractometer (RIGAKU, RINT2200VF+/PC system). The PL spectra of the specimens were measured using a dual-grating monochromator (Roper Scientific, SpectraPro 2150i) and a CCD detector (Roper Scientific, Pixis: 100B, electrically cooled to −80˚C) under excitation using a He-Cd laser (Kimmon, IK3251R-F, wavelength λ = 325 nm).

3. Results and Discussion

Figure 2 presents XRD patterns of the four specimens annealed at 700˚C, 800˚C, 900˚C, and 1000˚C. The Cr_2O_3-Ta_2O_5 film annealed at 700˚C seemed to be almost amorphous because no significant diffraction peak was observed from the film. The Cr_2O_3-Ta_2O_5 film annealed at 800˚C seemed to be hexagonal Ta_2O_5 doped with Cr because a major peak corresponding to the (2 0 0); δ-Ta_2O_5 phase (JCPDS No.00-018-1304) was observed from the film. Furthermore, four significant peaks were additionally observed from the specimens annealed at 900˚C and 1000˚C in addition to the peaks corresponding to the above-mentioned (2 0 0) (hexagonal Ta_2O_5) phase. These peaks correspond to tetragonal $CrTaO_4$ ((0 0 3), (1 1 0), (1 0 1), and (2 0 3)) phases (JCPDS No. 00-039-1428). We found that our Cr_2O_3-Ta_2O_5 composite films annealed above 900˚C include both hexagonal Ta_2O_5 and tetragonal $CrTaO_4$ phases.

Figure 3 presents PL spectra of the specimens annealed at 700˚C, 800˚C, 900˚C, and 1000˚C. No significant

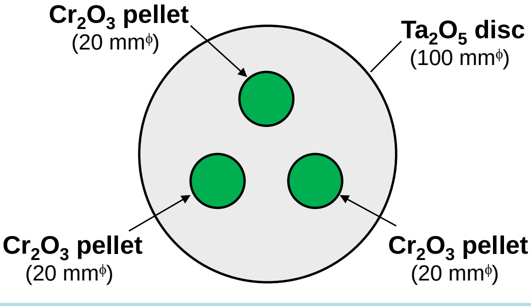

Figure 1. Schematic top view of the sputtering target for co-sputtering of three Cr_2O_3 pellets and a Ta_2O_5 disc.

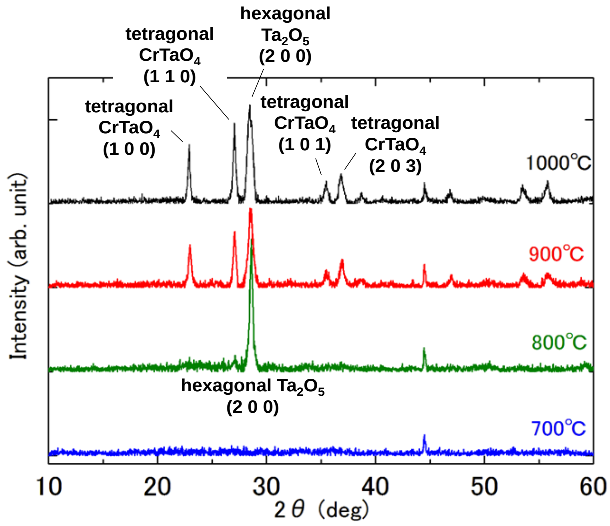

Figure 2. XRD patterns of Cr_2O_3-Ta_2O_5 films annealed at 700˚C, 800˚C, 900˚C, and 1000˚C.

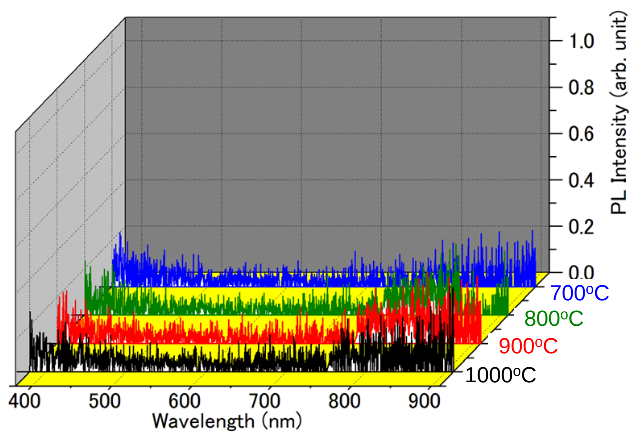

Figure 3. PL spectra of Cr_2O_3-Ta_2O_5 films annealed at 700˚C, 800˚C, 900˚C, and 1000˚C.

PL peak was observed from all the specimens. In our previous report, we found that the CuO-Ta_2O_5 composite films annealed at 700˚C - 900˚C were tetragonal $CuTa_2O_6$ phases, and we considered that our $CuTa_2O_6$ film annealed at 900˚C had almost no defect because broad PL peaks due to oxygen-vacancy trap levels were not observed [19]. Therefore, it seems that our Cr_2O_3-Ta_2O_5 composite films also have almost no defect because no significant PL peak was observed from the films as presented in **Figure 3**. As mentioned above, we can obtain tetragonal $CrTaO_4$ from our Cr_2O_3-Ta_2O_5 films after annealing above 900˚C. $CrTaO_4$ has also been prepared using other methods such as anodic spark deposition [23]. However, good-quality $CrTaO_4$ films without defects are expected to be obtained using our very simple co-sputtering method and subsequent annealing. We will try to calculate lattice parameters of the Cr_2O_3-Ta_2O_5 films annealed at the different temperatures, and characterize morphologies of the films using a scanning electron microscope.

4. Summary

We prepared Cr_2O_3-Ta_2O_5 composite films using our RF magnetron co-sputtering method for the first time. From the XRD patterns, the Cr_2O_3-Ta_2O_5 film annealed at 700˚C seemed to be almost amorphous, and the one annealed at 800˚C seemed to be hexagonal Ta_2O_5 doped with Cr. In addition, the Cr_2O_3-Ta_2O_5 films annealed at 900˚C and 1000˚C seemed to include tetragonal $CrTaO_4$ phases. Furthermore, it seems that almost no defect exists in our Cr_2O_3-Ta_2O_5 composite films annealed at 700˚C - 1000˚C because their PL spectra have no defect-related peak. It is expected that good-quality Cr_2O_3-Ta_2O_5 composite films including $CrTaO_4$ can be obtained using our very simple co-sputtering method and subsequent annealing above 900˚C.

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