

Optical Monitoring of Aging Effect of $\text{YBa}_2\text{Cu}_3\text{O}_x$ Targets in RF Magnetron Sputtering

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Abstract

The aging effect of $\text{YBa}_2\text{Cu}_3\text{O}_x$ oxide targets in rf magnetron sputtering was studied by means of analyzing plasma emission spectra, film composition and target bias voltage as a function of sputtering time in pure Ar and 80 % Ar / 20 % O_2 atmosphere. The long presputtering time of 10 – 30 h needed to obtain the stable cation concentration of as-grown films was due to a slowly changing oxygen content at the target surface to reach the thermal equilibrium of the target. As the content of oxygen at the target surface increased, sputtering yields of Y changed little, those of Ba decreased, those of Cu increased and emission intensity of Y and Ba decreased extremely and emission intensity of Cu decreased a little. Peak heights of emission lines located at 613.21 and 614.84 nm were measured as a function of sputtering time and were assigned as due to YO. Most of yttrium atoms ejected from the target were soon oxidized as YO. Although emission intensity of Y decreased extremely with increasing the oxygen content at the target surface, the content of yttrium compounds deposited on the substrate did not decreased.

Key Words: high-temperature superconductor, sputter deposition, thin films, plasma diagnosis, aging effect

1. Introduction

Sputter deposition is a popular method of fabricating thin films. By bombarding a target with accelerated ions such as Ar^+ , target atoms are removed from the target and deposited on a substrate. It has been revealed as the one of the most valuable techniques to deposit thin films of high-temperature superconducting $\text{YBa}_2\text{Cu}_3\text{O}_x$ oxide. Although films can be routinely deposited by this method, there remains problems to obtain high-quality films. One of the major problems encountered in a single target sputter process is poor stoichiometry in as-deposited films. Two major contributors to poor stoichiometry are aging of the target^{1,2)} and sensitivity to process variables³⁻⁶⁾.

Selinder *et al.*¹⁾ had grown $\text{YBa}_2\text{Cu}_3\text{O}_x$ thin films from a newly fabricated stoichiometric oxide target using dc magnetron sputtering in a pure Ar atmosphere. Initially, the film composition was strongly off-stoichiometric and the deposition rate was very low. After extensive presputtering of 20 – 30 h, stoichiometric films, with respect to the metal content, were deposited and the deposition rate increased. On the other hand, for a target which was annealed in an Ar atmosphere for 6 h at 800°C prior to installation in the sputtering source, the time to obtain the steady state conditions was reduced to about 8 h. They assigned that the long presputtering time was due to a slowly changing oxygen content on the target surface. However, they had not examined the oxygen content of the target surface.

It is necessary to know the complete understanding of the microscopic details of the methods by

which high-quality superconducting films are deposited. To accomplish the understanding of the sputter deposition and eventually control this process, real time diagnostics for sputter deposition are needed. One method is optical emission spectroscopy. When positive ions strike a solid target, it may cause ejection of target atoms as ions or as ground-state or excited-state neutral atoms. The presence of excited atoms and molecules in the stream of particles leaving the target directed toward the substrate provides a convenient diagnostic tool. With a relatively simple optical measuring system, the identity of some of the particles leaving the target may be determined. Changes in sputtering parameters such as argon and oxygen partial pressures, *etc.*, are reflected in changes in the optical output from species near the target surface.

Klein and Yen²⁾ reported the plasma emission spectra of Ba and Cu resulting from rf sputtering of $\text{YBa}_{1.82}\text{Cu}_{2.62}\text{O}_x$ target as a function of sputtering time with 98 % Ar / 2 % O_2 atmosphere. They observed that for a newly fabricated target, emission intensity of Cu rose quickly to a nearly constant value and those of Ba rose gradually, but for a previously sputtered target, the transient response had a much shorter time constant. This suggests that direct optical monitoring of the rf plasma may provide a sensitive means of tracking rf plasma transients important in determining cation stoichiometry.

In this paper, we deposited thin films on MgO substrates by sputtering from $\text{YBa}_2\text{Cu}_3\text{O}_x$ targets in pure argon and argon-oxygen mixed atmosphere, measured plasma emission spectra of Ar, Ba, Cu, H, O and Y as a function of sputtering time, and compared these spectra with film composition and target bias voltage, in order to clarify the aging effect of the $\text{YBa}_2\text{Cu}_3\text{O}_x$ target.

2. Experimental

Stoichiometric composite $\text{YBa}_2\text{Cu}_3\text{O}_x$ targets were used in these experiments. Commercial $\text{YBa}_2\text{Cu}_3\text{O}_x$ powder was calcined at 900°C, pressed to form a 2-inch-diameter target and sintered at 950°C. The newly fabricated $\text{YBa}_2\text{Cu}_3\text{O}_x$ target was pressed to a magnetron source (LESKER MODEL TRS-002C) using an indium sheet.

Sputtering was done without interruption for 60 h in pure Ar and 80 % Ar / 20 % O_2 atmosphere, respectively. A gas pressure in a deposition chamber was fixed to 5.0 Pa. Ar and O_2 gases were introduced in the sputter chamber through gas flow controllers (MKS TYPE 246). The sputtering pressure was monitored both by Schulz and Pirani gauges and held constant using the gas flow controllers.

An rf (13.56 MHz) power of 50 W was supplied to the target. Ten electrical resistances of 100 kW and an electrical resistance of 10 kW were connected in series to the target and a capacitor of 0.01 μF was connected in parallel to the electrical resistance of 10 kW. The voltage of the 10 kW resistance was measured by a digital voltmeter to obtain the target bias voltage.

For the compositional and thickness analysis, thin films were deposited on the (100) oriented surfaces of MgO single crystals $10 \times 10 \times 1 \text{ mm}^3$ in size. The deposition time was 3 h in each substrate. The substrate holder was held at the ground potential, and the substrates were not intentionally heated to obtain a sticking coefficient close to unity for all atoms. All films described in this report were analyzed in as-deposited condition without any post-annealing. This should give nearly identical composition of the films as compared with the flux of sputtered atoms from the target. Energy dispersive x-ray spectroscopy (EDX) was carried out to determine the metallic composition of the as-deposited films. Stoichiometric $\text{YBa}_2\text{Cu}_3\text{O}_x$ bulk samples were used as elemental standards when calibrating the EDX analyses.

When the plasma started, the bright region was ring shaped. The optical emission from this region was analyzed. Light emitted by the plasma passed through a quartz window and an optical filter to eliminate second-order diffracted lights, was chopped by a light chopper and focused on an

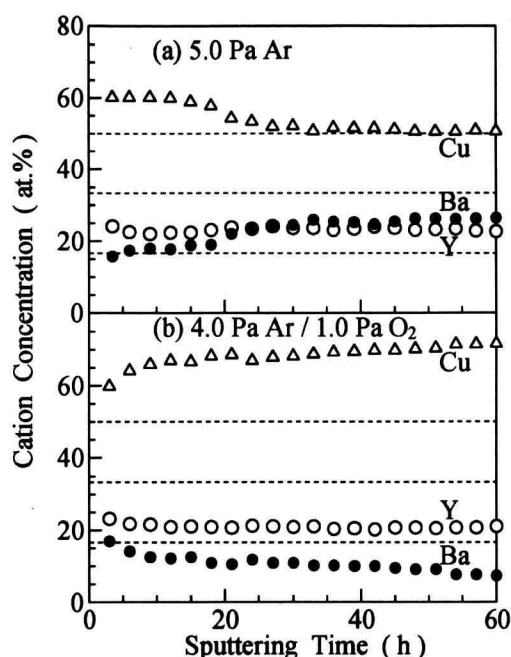


Fig. 1 Cation concentration of as-deposited films as a function of sputtering time, (a) in 5.0 Pa Ar atmosphere, (b) in 4.0 Pa Ar / 1.0 Pa O_2 atmosphere. Open circles represent Y, filled circles Ba, open triangles Cu, respectively. Stoichiometric compositions (Y: 16.7 %, Ba: 33.3 %, Cu: 50.0 %) are indicated by dashed lines.

entrance slit of a 50-cm monochromator (SPEX MODEL 1870) by a quartz lens. Spectral resolution of the monochromator was 0.05 nm. Signals detected by a photomultiplier (HAMAMATSU R928) were amplified using a lock-in amplifier. The lock-in amplifier and the monochromator were controlled by a computer.

3. Experimental Results and Discussion

Figures 1 (a) and (b) show the cation concentration of as-grown films deposited on MgO single crystals as a function of sputtering time in pure Ar and 80 % Ar / 20 % O_2 atmosphere, respectively. In the Figures, open circles represent Y, filled circles Ba, open triangles Cu, respectively. Stoichiometric compositions (Y: 16.7 %, Ba: 33.3 %, Cu: 50.0 %) are indicated by dashed lines. The film composition is initially off-stoichiometric (Y: 23 – 24 %, Ba: 16 – 17 %, Cu: 60 %), with Ba being deficient, and Cu and Y in excess. The content of Y does not depend on the sputtering time in pure Ar and 80 % Ar / 20 % O_2 atmosphere. The content of Ba increases with the sputtering time in a pure Ar atmosphere, but decreases in 80 % Ar / 20 % O_2 atmosphere. On the other hand, the content of Cu decreases with the sputtering time in a pure Ar atmosphere, but increases in 80 % Ar / 20 % O_2 atmosphere. In a pure Ar atmosphere, after 30 h of sputtering, a stable condition (Y: 23 %, Ba: 26 %, Cu: 51 %) is finally achieved. In the stable condition, Ba is still deficient and Y is in excess. In 80 % Ar / 20 % O_2 atmosphere, the cation concentration changes rapidly for the first 10 h, afterward changes slowly and is extremely off-stoichiometric (Y: 21 %, Ba: 7 %, Cu: 72 %) at 60 h.

An initial off-stoichiometric composition is normal when sputtering is done from an alloy or a

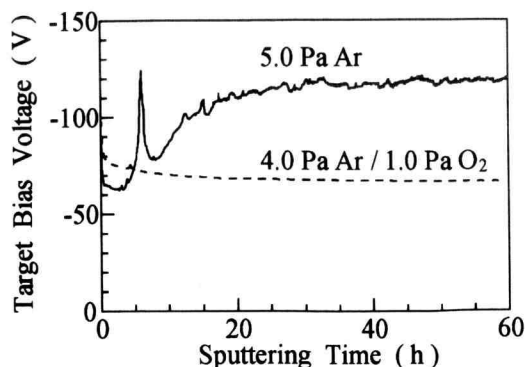


Fig. 2 Target bias voltage as a function of sputtering time. A solid line represents in 5.0 Pa Ar atmosphere, a dashed line in 4.0 Pa Ar / 1.0 Pa O₂ atmosphere, respectively.

compound target. A layer of altered composition is formed on the target surface if the sputtering yields of the constituent atoms are different. The time needed to stabilize the film composition is dependent on factors such as differences in sputtering yields, ion energy, and ion flux. For example, a high ion flux or increased sputtering yield leads to faster formation of the steady-state altered layer. But it is usually only in the range of a few minutes for an alloy or a compound target⁷⁾. The composition of the target surface will also influence the total deposition rate. This is particularly noticeable for variations in the oxygen content on the surface since oxides normally have a very low sputtering yield. Thus, if the surface composition of the oxide target is changed, a change in the total deposition rate can be expected.

To see the surface state of the target, the target bias voltage was measured. Figure 2 shows the target bias voltage as a function of sputtering time. In the Figure, the solid line represents in a pure Ar atmosphere, and the dashed line in 80 % Ar / 20 % O₂ atmosphere, respectively. In a pure Ar atmosphere, the target bias voltage decreases rapidly when the sputtering starts. At the sputtering time of about 6 h, the target voltage has a sharp peak. The target voltage still increases after 6 h and a steady-state condition is reached finally after 30 h of sputtering. In 80 % Ar / 20 % O₂ atmosphere, the target bias voltage decreases rapidly when the sputtering starts. At the sputtering time of about 5 h, the target voltage has a small peak. The target bias voltage decreases gradually afterward.

In order to investigate variations of the content of oxygen at the target surface and to monitor the sputtered atoms, we measured emission spectra of plasma generated by rf magnetron sputtering. A spectroscopic analysis of plasma in the wavelength region from 280 to 870 nm reveals many emission lines due to Ar, Ba, Cu, H, O, Y and YO. The observed emission lines are identified

Table I. Atomic and ionic emission lines which are examined.

Species	Emission lines (in nm)		
Ar I	419.832	420.068	
Ar II	427.755		
Ba I	553.555		
Ba II	455.404		
Cu I	324.754		
H	486.133	656.285	
O I	777.193	777.414	777.543
Y I	410.238		
Y II	371.029		
YO	613.21	614.84	

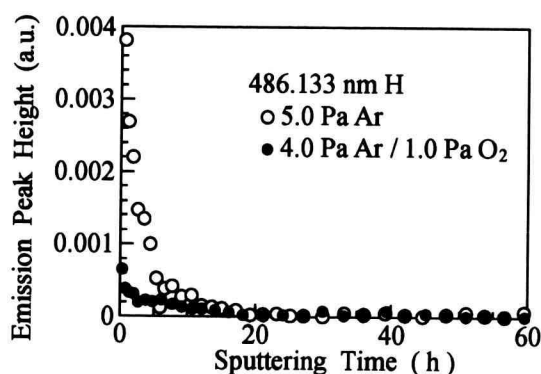


Fig. 3 Peak height of emission line of H at 486.133 nm as a function of sputtering time. Open circles represent in 5.0 Pa Ar, filled circles in 4.0 Pa Ar / 1.0 Pa O_2 atmosphere, respectively.

according to standard tables of spectral lines^{8,9}). The emission lines whose time dependence are examined are listed in Table I. In the Table, the numeral I or II after the elements indicates that the line has been assigned to a neutral atom (I) or to a singly ionized atom (II)^{8,9}). These lines are well isolated from the other lines. Emission lines due to Cu II are also observed, but are very weak.

Emission lines due to H come from water adsorbed to the vacuum chamber, according to the reaction: $\text{H}_2\text{O} + \text{e}^- \rightarrow \text{OH} + \text{H} + \text{e}^-$. Emission lines due to OH are observed in the wavelength region of 281 – 292 nm and 309 – 327 nm¹⁰). Figure 3 shows the peak height of emission line of H at 486.133 nm as a function of the sputtering time. In the Figure, open circles represent in a pure Ar atmosphere, filled circles in 80 % Ar / 20 % O_2 atmosphere, respectively. The time dependence of the peak height of H at 656.285 nm is similar to that at 486.133 nm as shown in Fig. 3. In a pure Ar atmosphere, the peak height of emission of H has a depression at 6 h and has disappeared completely at 20 h. In 80 % Ar / 20 % O_2 atmosphere, the peak height of emission of H decreases with the sputtering time, and has disappeared at 20 h.

Figure 4 shows the peak height of emission line of O I at 777.193 nm as a function of the sputtering time. Peak heights of open circles are multiplied by a factor of 10. The time dependence of peak heights of emission lines of O I at 777.414 and 777.543 nm is similar to that at 777.193 nm as shown in Fig. 4. In a pure Ar atmosphere, the peak height of emission of O I has a peak at 2 h, has a sharp depression at 6 h, decreases slowly after this, and the peak height becomes a steady

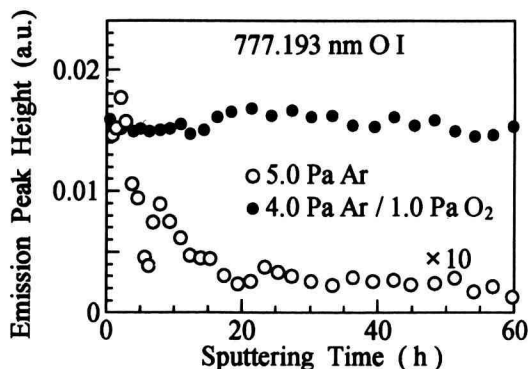


Fig. 4 Peak height of emission line of O I at 777.193 nm as a function of sputtering time. Open circles represent in 5.0 Pa Ar, filled circles represent in 4.0 Pa Ar / 1.0 Pa O_2 atmosphere, respectively. Peak heights of open circles have been multiplied by a factor of 10.

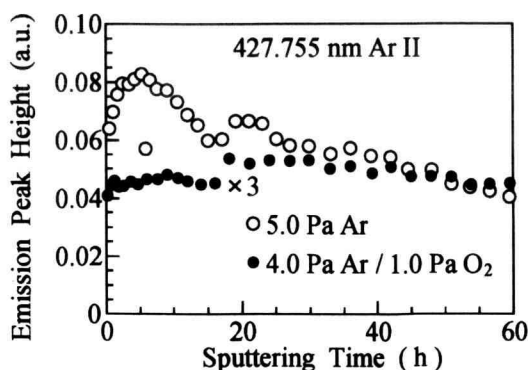


Fig. 5 Peak height of emission line of Ar II at 427.755 nm as a function of sputtering time. Open circles represent in 5.0 Pa Ar, filled circles in 4.0 Pa Ar / 1.0 Pa O₂ atmosphere, respectively. Peak heights of filled circles have been multiplied by a factor of 3.

state after 20 h of sputtering. The sputtering time of about 6 h when the peak height of emission line of O I has a sharp depression is just the time that the target bias voltage has a sharp peak. At this time, as the content of oxygen at the target surface decreases rapidly by the bombardment of Ar⁺ ions, electrons in the plasma move to the target and bias the target voltage to a more negative value. The temperature of the target soon increases by the bombardment of Ar⁺ ions accelerated by the increased target voltage. At this relatively high temperature, oxygen bulk diffusion is rapid¹¹⁾. The diffusion of oxygen to the target surface reduces the target bias voltage.

In a pure Ar atmosphere, oxygen has been released from the target. The emission of O I does not vanish even at the sputtering time of 60 h. The target is pressed to a water-cooled copper block of the sputter source. As the temperature of this side of the target is low, diffusion of oxygen from this side to the surface is slow. Thus, when sputtering from an oxide target in a pure Ar discharges, the release of oxygen from the target surface continues for a long time until a whole region of the target had depleted completely its oxygen.

In 80 % Ar / 20 % O₂ atmosphere, the emission intensity due to O I is much stronger than that in a pure Ar atmosphere. The emission of O I is mainly due to oxygen supplied to the vacuum chamber as the sputtering gas. The time dependence of the emission peak height of O I is small. The target bias voltage is closely related to the content of oxygen and the temperature at the target surface. The long presputtering time of 10 – 30 h needed to obtain the stable cation concentration of as-grown films in pure Ar and argon-oxygen mixed atmosphere, is due to the slowly changing oxygen content of the target to reach the thermal equilibrium of the target.

Figure 5 shows the peak height of emission line of Ar II at 427.755 nm as a function of the sputtering time. In a pure Ar atmosphere, intensity of Ar II has a peak at 5 h, has a sharp depression at 6 h, and decreases slowly after this. As the number of Ar⁺ atoms bombarding a target is proportional to a current going through the target, emission intensity of Ar II is expected to be proportional to a current going through the target. A constant rf power of 50 W was supplied to the target. The emission peak height of Ar II is expected to be inversely proportional to the target bias voltage. As the target bias voltage increases as shown in Fig. 2, emission peak height of Ar II decreases with the sputtering time as shown in Fig. 5.

In 80 % Ar / 20 % O₂ atmosphere, the time dependence of the peak height of emission line of Ar II is small. Although the target bias voltage decreases as compared with that in a pure Ar atmosphere, emission peak height of Ar II has not increased. As the probability of Ar atoms being excited by the discharge electrons decreases by adding oxygen, emission intensity of Ar II has not increased. Secondary electrons ejected from the target by the bombardment of Ar ions, lose their

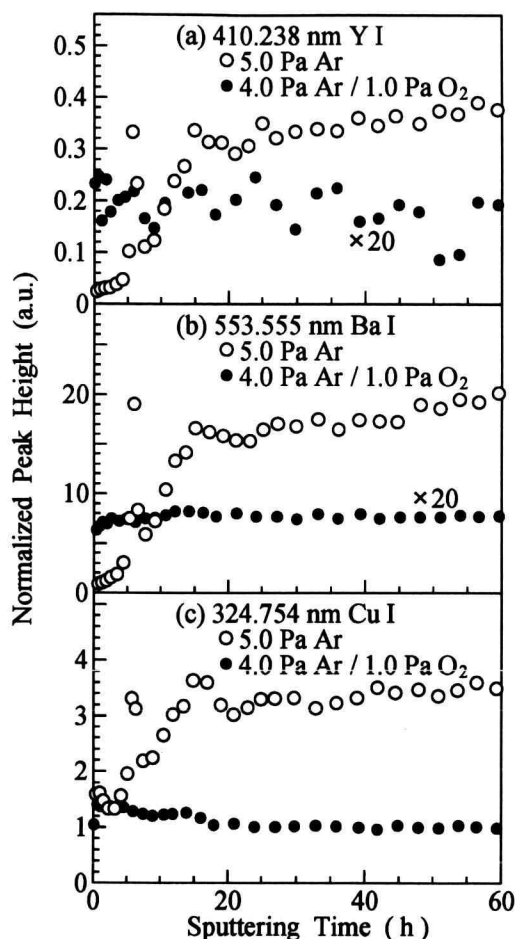


Fig. 6 Peak heights of emission lines of (a) Y I at 410.238 nm, (b) Ba I at 553.555 nm and (c) Cu I at 324.754 nm normalized to the emission peak height of Ar II at 427.755 nm as a function of sputtering time, respectively. Open circles represent in 5.0 Pa Ar, filled circles in 4.0 Pa Ar / 1.0 Pa O_2 atmosphere, respectively. Peak heights of filled circles in (a) and (b) have been multiplied by a factor of 20.

energy much faster through collisions in an Ar / O_2 mixture than in a pure Ar. The electrons travel shorter distances in an Ar / O_2 mixture. Actually, the bright region of the plasma is more confined to the target when there is oxygen in the sputtering gas.

In order to study the time dependence of emission peak heights of Y, Ba and Cu, peak heights are normalized to that of Ar II at 427.755 nm. Figures 6 (a), (b) and (c) show the normalized peak heights of Y I at 410.238 nm, Ba I at 553.555 nm and Cu I at 324.754 nm as a function of sputtering time, respectively. In the Figures, open circles represent peak heights normalized to that of Ar II at 427.755 nm in a pure Ar atmosphere, and filled circles represent peak heights normalized to that of Ar II at 427.755 nm in 80 % Ar / 20 % O_2 atmosphere, respectively. In a pure Ar atmosphere, all the normalized peak heights have sharp peaks at 6 h, when the target bias voltage has a sharp peak. The normalized peak heights of Y I and Ba I increase by a factor of 10, and that of Cu I increases by a factor of 2 in the sputtering time of 0 - 15 h. After the sputtering time of 15 h, normalized peak heights of Cu I, Y I and Ba I increase slowly with the sputtering time.

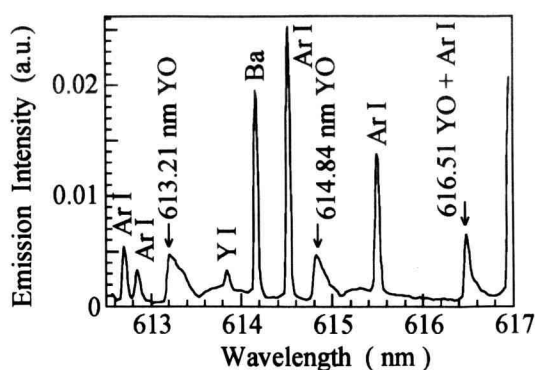


Fig. 7 Emission spectrum of plasma induced by rf magnetron sputtering of $\text{YBa}_2\text{Cu}_3\text{O}_x$ in the wavelength region of 612.5 - 617 nm in 5.0 Pa Ar atmosphere.

In 80 % Ar / 20 % O_2 atmosphere, the normalized peak heights of Y I and Ba I have been reduced by a factor of 1/40, and that of Cu I have been reduced by a factor of 1/3, as compared with those in a pure Ar atmosphere. The time dependence of the normalized peak heights of Y I, Ba I and Cu I is small.

The emission peak heights of Cu I, Y I and Ba I is closely connected to the content of oxygen at the surface of the target. The emission peak heights of Cu I, Y I and Ba I decrease with increasing the content of oxygen at the target surface. The dependence of emission peak heights of Ba I on the oxygen content at the target surface is more larger than that of Cu I. These results agree quite well with the time dependence of the cation concentration of as-grown films shown in Figs. 1 (a) and (b). In the cation concentration experiment of thin films, the content of Y does not depend on the sputtering time. In the plasma emission spectra, however, emission peak heights of Y I strongly depend on the sputtering time.

In plasma spectra induced by rf magnetron sputtering, emission lines assigned to YO have been observed. Emission lines assigned to YO are reported at 597.22, 598.77, 600.36, 613.21, 614.84 and 616.51 nm by Xi *et al.*¹²⁾, at 597.20 nm by Lucia *et al.*^{13,14)}, and at 614.8, 615.0, 616.5, 618.2, 620.0, 621.8, 623.7, 627.5, 629.5 and 631.6 nm by Lecaer *et al.*¹⁰⁾. Figure 7 shows emission spectrum of plasma induced by rf magnetron sputtering of $\text{YBa}_2\text{Cu}_3\text{O}_x$ in the wavelength region of 612.5 - 617 nm in a pure Ar atmosphere. We examined two lines located at 613.21 and 614.84 nm

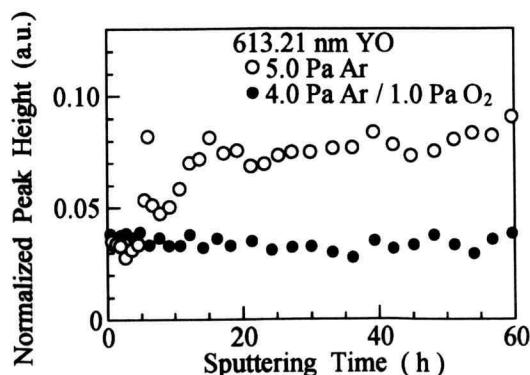


Fig. 8 Peak height of emission line of YO at 613.21 nm normalized to the emission peak height of Ar II at 427.755 nm as a function of sputtering time. Open circles represent in 5.0 Pa Ar, filled circles in 4.0 Pa Ar / 1.0 Pa O_2 atmosphere, respectively.

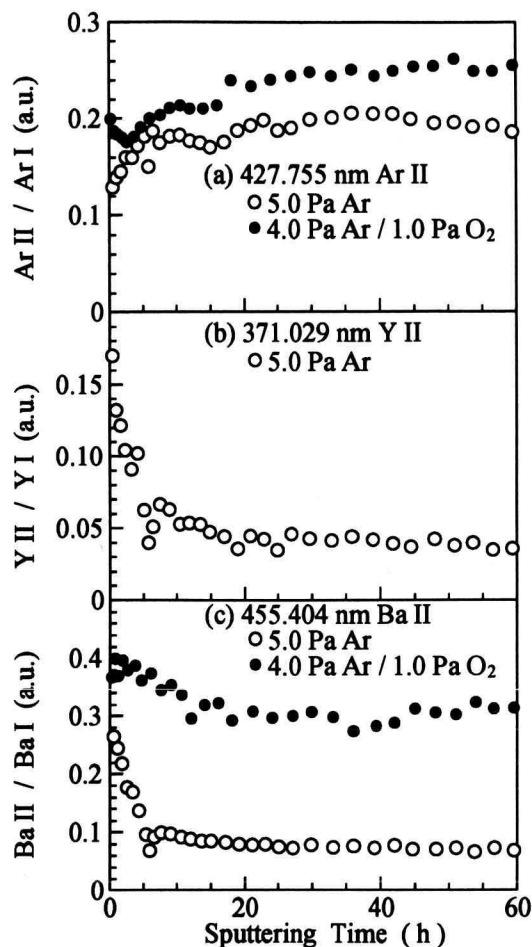


Fig. 9 Ratios of peak heights of emission lines of (a) Ar II at 427.755 nm to Ar I at 420.068 nm, (b) Y II at 371.029 nm to Y I at 410.238 nm and (c) Ba II at 455.404 nm to Ba I at 553.555 nm as a function of sputtering time, respectively. Open circles represent in 5.0 Pa Ar, filled circles in 4.0 Pa Ar / 1.0 Pa O_2 atmosphere, respectively.

as indicated by arrows in Fig. 7. These lines are well isolated from the other lines. An emission line due to YO is also observed at 616.51 nm in Fig. 7, but this line overlaps with an Ar I line at 616.511 nm.

Figure 8 shows the emission peak height of YO at 613.21 nm normalized to that of Ar II at 427.755 nm as a function of the sputtering time. The time dependence of the normalized peak height of YO at 614.84 nm is similar to that at 613.21 nm shown in Fig. 8. In a pure Ar atmosphere, the normalized peak height has a sharp peak at 6 h, when the target bias voltage has a sharp peak. The normalized peak height of YO increases by a factor of 2 in the sputtering time of 0 – 15 h. After the sputtering time of 15 h, normalized peak height of YO increase slowly with the sputtering time.

In 80 % Ar / 20 % O_2 atmosphere, the normalized peak height of YO has been reduced by a factor of 1/2, as compared with that in an pure Ar atmosphere. The oxygen dependence of the normalized peak height of YO is quite smaller than that of Y I at 410.238 nm as shown in Fig. 6. Thus the lines located at 613.21 and 614.84 nm are confirmed to be due to YO. We could not observe emission lines due to BaO and CuO. As yttrium atoms are very reactive with oxygen, most

of these atoms ejected from a target are soon oxidized as YO and arrive at a substrate in the form of YO. Although emission intensities of Y I and Y II decreased extremely with increasing the oxygen content at the target surface, the content of yttrium compounds deposited on the substrate did not decrease.

It has been pointed out that the kinetic energy of ions, acquired from the slightly negative potential of the substrate relative to the plasma, along with their charges enhances the surface mobility of adatoms, the nucleation and coalescence rates, and chemical reaction in case of reactive sputtering, and ions contribute to the growth of high quality single crystalline $\text{YBa}_2\text{Cu}_3\text{O}_x$ films, than neutral atoms do¹²⁾. To monitor the ratios of ionized atoms sputtered from the target, ratios of peak heights of emission lines of ionized atoms to those of neutral atoms are measured. Figure 9 shows ratios of peak heights of emission lines of (a) Ar II at 427.755 nm to Ar I at 420.068 nm, (b) Y II at 371.029 nm to Y I at 410.238 nm and (c) Ba II at 455.404 nm to Ba I at 553.555 nm as a function of sputtering time, respectively. The emission line due to Y II at 371.029 nm is too weak to be observed in 80 % Ar / 20 % O_2 atmosphere. In a pure Ar atmosphere, the ratio of Ar II to Ar I rises and those of Y II to Y I and Ba II to Ba I decrease for the sputtering time of 0 - 6 h. Afterward, the change of ratios of Ar, Y and Ba is small. In 80 % Ar / 20 % O_2 atmosphere, the ratio of Ar II to Ar I rises gradually and that of Ba II to Ba I decrease slowly with the sputtering time. This result shows that the ratio of ionized atoms to neutral atoms decreases with decreasing the oxygen content at the target surface.

Conclusions

We have studied the aging effect of $\text{YBa}_2\text{Cu}_3\text{O}_x$ target in the rf magnetron sputtering. The film composition, the target bias voltage and the emission spectra resulting from sputtering of a newly fabricated target were measured as a function of sputtering time in pure Ar and 80 % Ar / 20 % O_2 atmosphere.

In a pure Ar atmosphere, the presputtering time needed to obtain the stable cation concentration of as-grown films on MgO (100) single crystal surfaces was 30 h, and in 80 % Ar / 20 % O_2 atmosphere, the presputtering time was reduced to 10 h. The long presputtering time needed was due to a slowly changing oxygen content on the target surface to reach the thermal equilibrium of the target. This was caused by bulk diffusion of oxygen in the target. The concentration of Y in the film was not sensitive to the content of the oxygen at the surface of the target, on the other hand, the concentration of Ba and Cu were very sensitive to the content of oxygen. The concentration of Ba decreased and that of Cu increased as the content of the oxygen at the target surface increased.

With increasing the content of oxygen at the target surface, peak height of emission line of Ba I decreased extremely, while peak height of emission line of Cu I decreased slowly. These results agreed well with the time dependence of the cation concentration of as-grown films. Although peak heights of emission lines of Y I and Ba I had the similar behavior, the time dependence of the concentration of Y in as-grown films was small in contrast to that of Ba. The time dependence of peak heights of emission bands located at 613.21 nm and 614.84 nm was measured and these lines were assigned as due to YO. As yttrium atoms were very reactive with oxygen, most of these atoms ejected from the target were soon oxidized as YO. Although emission intensity of Y decreased extremely with increasing the oxygen content at the target surface, the content of yttrium compounds deposited on the substrate did not decrease.

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