Newly developed novel transparent conductor of Mg(OH)2-C compounds†

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1. Introduction

Kondoh's group has recently reported very interesting results on transparent Mg-C compounds [1]. The structure of compounds was identified to be amorphous. The elemental composition was controlled by magnesium content in films. Colored glassy films were obtained.

Our research group has studied on synthesizing Mg based alloys by Mechanical Alloying (MA) and their properties, i.e., hydrogen solubility in the non-equilibrium and/or meta-stable phases [2,3]. From our series of works, it has been demonstrated that even immiscible elemental couples could be alloyed by accumulating the excess mechanical energy created during the MA process. Mg-C couple is the case , according to equilibrium phase diagram [4,5].

In this study, we will propose a newly developed compound composed of elements of Mg-C-O-H with the potential high transparency and electro conductivity. In order to obtain the transparency without loosing electro conductivity, the material was synthesized by two steps including alloying of Mg-C by magnetron co-sputtering and post- reaction of the film with moisture in the air. It was found that the compound has a Brucite type hexagonal structure of $Mg(OH)_2$-C.

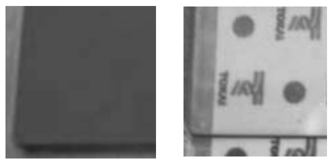
From our literature survey, it was concluded that transparent conductive materials are metal oxides without exception. In this paper, the transparent and electro conductive properties of non-oxide material, $Mg(OH)_2$-C will be demonstrated.

2. Experimental

The film samples were made on glass substrates using an RF-sputtering apparatus made in ANELVA, SPC-350. The depositions of Mg-C thin films were performed at temperature of from 297 to 320 K in a pressure of 0.5 Pa during the Ar process gas. The substrate used for experiment was made in Corning #7059 with size of 25 mm square. The substrates were set on the holder, and it was turned in front of the target at 60 rpm. The targets of magnesium and carbon disks were placed on each cathode with the magnetron. Both of the disk shaped targets were a diameter of 3 inch., and purity was 99 %.The electric power densities applied to each cathode where the film is >90% for the visible light (380-780 nm), which is excellent even compared with practical ITO(Indium Tin Oxide).Closely controlled from 23 to 26 kW/m^2 and from 73 to 100 kW/m^2, respectively.

3. Results and Discussions

Figure 1 shows an appearance of as-sputtered Mg80-C20 black film and the film after exposing in air for an appropriate period. We can see excellent and clear transparency after exposing in the air at 298K and 80% of humidity. We can see clearly our university logo placed behind the $Mg(OH)_2$-C film and glass substrate (Fig. 1(b)).



(a) (b)

Fig. 1 Appearance of (a) as-sputtered, (b) after post-reaction.

Diffraction pattern of as -sputtered Mg-C film includes peaks from some unidentified peaks. As-sputtered Mg-C film showed a diffraction pattern which was not identified with peaks from either C or Mg. Unfortunately the phase from these limited peaks could not be identified. However, It can be concluded that a Mg-C new phase was formed although the crystal symmetry was not be identified [11]. The XRD diffraction peaks from the transparent film were well fitted to those from $Mg(OH)_2$, but the lattice was slightly elongated along the hexagonal c-axis due to the existence of C atoms in the Mg(OH)2 lattice [6], There are

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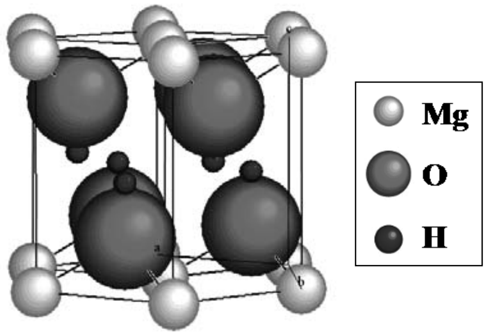

Fig. 2 Lattice image of $Mg(OH)_2$.

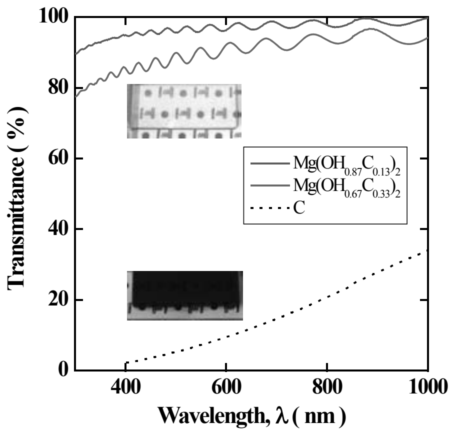

Fig. 3 Transmittance spectra of the films.

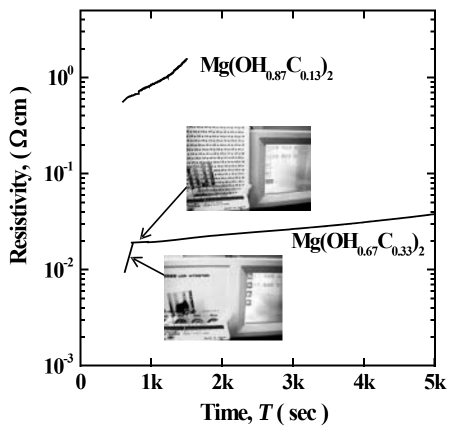

Fig. 4 Resistivity of the samples.

possible two types of C atoms in the in the $Mg(OH)_2$-C lattice, i.e., substitution or interstitial type. As mentioned above, there are many interstitial sites large enough for C atoms to stay in the lattice of $Mg(OH)_2$. However, if electrically neutral C atoms stay in interstitial sites. $Mg(OH)_2$-C should not be semi-conductor. We first hypothesized the case that neutral C atoms stay in (0,0,1/2). However, Rietveld's analysis of XRD pattern indicated that this is not the case, On the other hand, In the case that a half of H atoms are hypothetically replaced by C atoms, XRD peak pattern should be fitted well, implying that C was not segregated in the boundary of $Mg(OH)_2$ grains and formed $Mg(OH)_2$-C compound as shown in **Fig. 2**. This was confirmed from EPMA elemental mapping for Mg ,O and C. Any segregation of C in the film morphology during the process of black Mg-C film to transparent $Mg(OH)_2$-C did not occur.

Figure 3 shows the optical transmittance of the film with wavelength. It can be seen that the optical transmittance of the film is >80% for the visible light (380-780 nm), which is excellent even compared with practical ITO.

The electric resistance of the transparent films shown in **Fig.4**. The resistance of MgC black film increased with loosing the color gradually with time after exposing it in the air [6]. Then the variation in resistance somewhat fat with time when the film became almost transparent, although increasing still exists with time. The resistivity is strong dependent upon the C composition in the film as shown in Fig. 4. The Electric resistivity of the transparent film was order of the 10^{-2} Ωcm. For practical uses, we need one order lower value of resistivity of the film, which is 10^{-3} Ωcm which is important present work made effort in our group because of opening wide applications for our $Mg(OH)_2$-C film.

4. Conclusions

In this work, New Mg-C crystalline phase was successively prepared by co-sputtering of Mg and C. The Mg-C black film became transparent with time after air exposing for an appropriate time. This transparency behavior was yielded by the reaction of Mg-C with moisture in the air. Consequently, C atoms were distributed in the $Mg(OH)_2$ crystal grain. i.e., $Mg(OH)_2$-C. This film had excellent optical transmittance for the visible light and again excellent low electric resistance of the order of 10^{-2}Ωcm. In conclusion we have successively developed a new transparent conductor of $Mg(OH)_2$-C except metal oxides.

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