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Effect of Ion-beam Assisted Deposition on Resistivity and Crystallographic Structure of Cr/Cu

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Ion-beam assisted deposition (IBAD) for Cr/Cu coatings was investigated. For high density and electric resistivity, IBAD was found to be an appropriate method. The density was increased from 8.60 g/cm^3 to 8.85 g/cm^3, depending on IBAD conditions, and the resistivity was increased from 6.4 μΩ·cm to 7.2 μΩ·cm. It is also suggested that the crystallographic orientations of polycrystalline Cu surfaces were able to be aligned to (111) planes by the IBAD process.

Keywords: resistivity, copper, ibad, equilibrium shape

1. INTRODUCTION

Cu is the second highest electric conducting material, and thus is used in many electronic devices. In addition, due to its good ductility, high diffusivity, and thermal conductivity, Cu is being adopted in diffusion bonding materials, cooling passages, and heat sinks. Recently, Park *et al.* applied a Cu interlayer to create diffusion bonding of Be and CuCrZr joints which will be used for an ITER first wall.[1] A Cu layer has also been considered to act as a compliant layer to absorb the stresses between Be and CuCrZr under thermal heat loads.[1,2] In this work, as a continuation of prior works for ITER applications, the properties of Cu interlayers were investigated by introducing ion-beam assisted deposition (IBAD).

Because of the heteroepitaxy of Cu on a body centered cubic (bcc) substrate, the growth behavior, structural characteristics, and thermal stabilities of Cu have been studied widely.[3-5] The preferred orientation of Cu grains can be induced by the lattice and thermal mismatch or the surface stiffness. Woo *et al.* found the (111) growth habit of Cu on a Pt substrate, and (220) growth habit on a Cr substrate during electro-deposition.[4] Venugopal and Thijsse reported on the (111) preferred texture of Cu on (110) Ta.[5] The above behaviors were dependent on the film thickness and the type of substrates. The epitaxial growth as well as the preferred orientation is a matter of interest because of its enhanced mechanical and thermal stability, and because of its electrical properties.[4-6] In this study, the effect of IBAD on the orientation of Cu will be also discussed.

2. EXPERIMENTAL

For Cr/Cu film, Cr and Cu source materials of more than 99.99% purity were prepared. The Cr and Cu were coated on a glass substrate using a conventional electron-beam evaporation and deposition method and/or the IBAD method. The beam voltage and beam current were varied to investigate the effect of IBAD on coating properties. Vacuum condition was initially on the order of 10^{-5} torr, and increased to 10^{-4} torr with the introduction of Ar gas. The thicknesses for Cr and Cu were controlled at 1 μm and 10 μm, respectively, and their deposition rates were about 1 nm/s.

The thickness of the coated film was measured by using alpha step, and the resistivity was obtained by using CMT-SR1000. For the density of the coated film, sample dimensions as well as mass was measured and then calculated by dividing the weight by volume of the sample. The crystal phase of the film was analyzed by x-ray diffractometry using Cu K_α radiation. For the microstructure observation, the surface of the film was etched using a $65H_2O$– $25HNO_3$–$10H_2O_2$ (vol.%) solution, and then observed using scanning electron microscopy (SEM) equipped with a field-emission gun.

3. RESULTS AND DISCUSSION

Figure 1 shows the surface morphology of the Cr/Cu films

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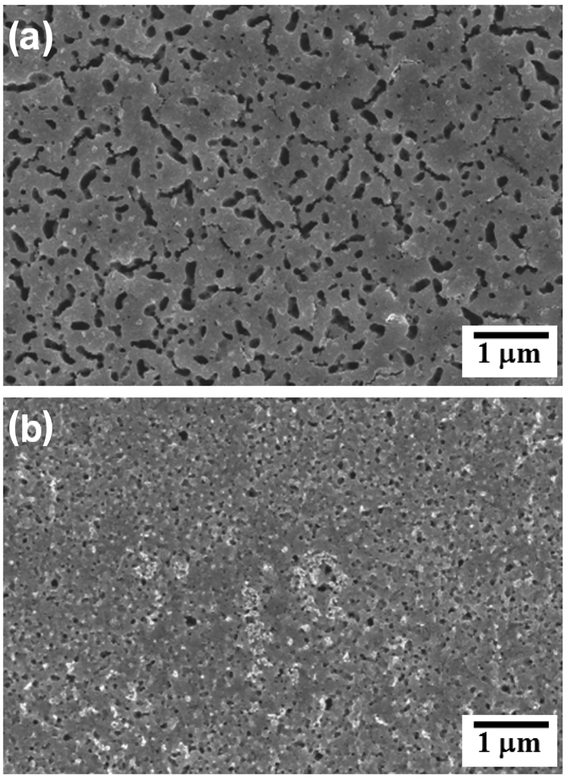

Fig. 1. Microstructures of Cr/Cu film coated (a) without and (b) with IBAD.

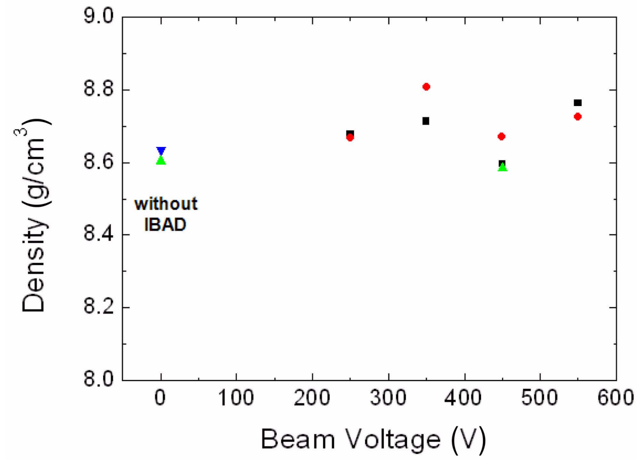

Fig. 2. Variation in density of the Cr/Cu film depending on the IBAD conditions. The different symbols indicate the scattering of data.

with and without IBAD coating. After severe etching, a lot of pores are observed in the microstructures. In the case of conventional coating, the pores are inter-connected through grain boundaries. However, the IBAD coated Cr/Cu revealed smaller isolated pores. Since the Cu is etched selectively at the grain boundaries or weak interfaces, it is suggested that the IBAD resulted in finer grain sizes and higher resistivity to etching. Although the finer grains have advantages for attaining higher density, the IBAD didn't significantly increase the density of the film in our experiment. Figure 2 shows the obtained density for different IBAD conditions. Density ranged from 8.60 g/cm^3 to 8.85 g/cm^3. There were a few IBAD conditions that gave rise to an increase in film density; however, a concrete dependency on IBAD was not found.

Figure 3 shows the resistivity with respect to various IBAD conditions. As compared to the non-IBAD coated sample (nil voltage and current in Fig. 3), the IBAD induced high resistivity. Since the grain size decreased and the density was almost the same, the resistivity would increase when IBAD is carried out. The resistivity was 6.4 μΩ·cm in the case of the conventional coating, and increased to 7.2 μΩ·cm with ion-beam assisted coating. The resistivity of pure Cu is 1.7 μΩ·cm and that for pure Cr is 12.5 μΩ·cm. The obtained values are between the resistivity of pure Cu and pure Cr. Beam voltages higher than 250 V were not effective at increasing the resistivity, as shown in Fig. 3(a).

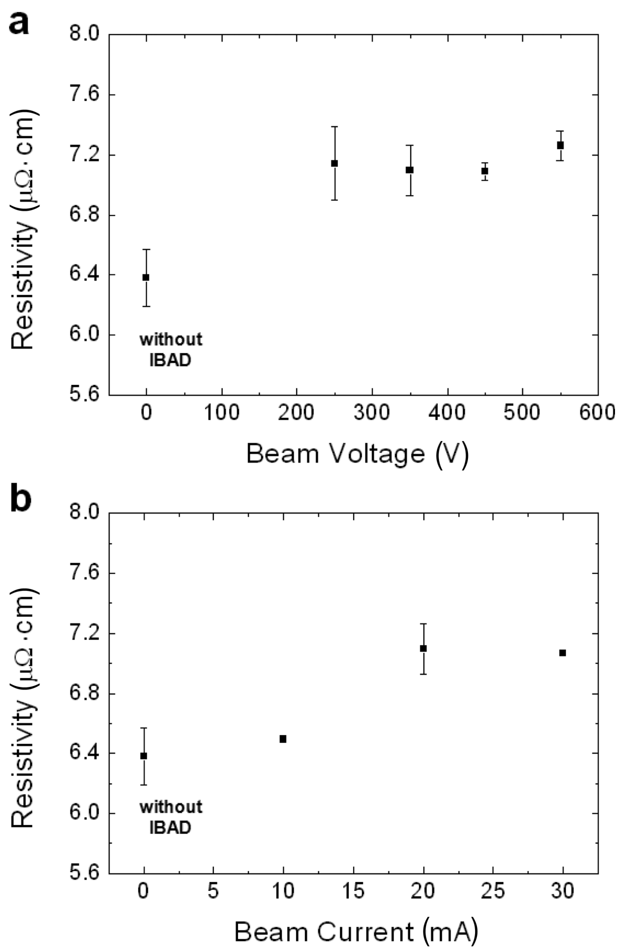

Fig. 3. Variation in resistivity of Cr/Cu film with respect to the IBAD conditions: (a) discharge voltage, and (b) beam current.

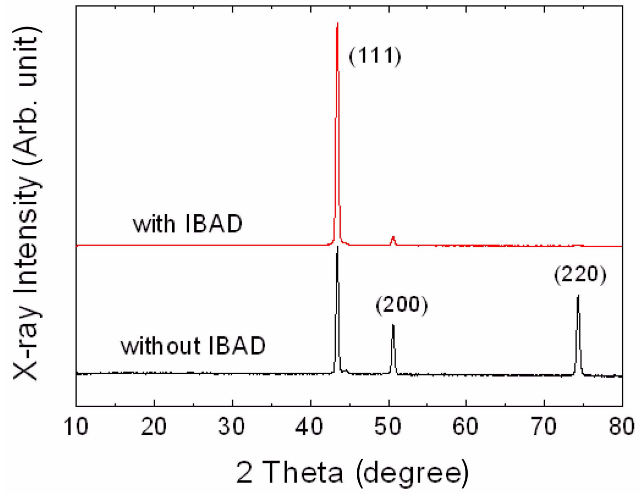

Fig. 4. X-ray diffraction pattern of copper film deposited on glass substrate.

According to Fig. 3(b), the threshold beam current of 20 mA was found when the beam voltage for IBAD was 350 V.

Figure 4 demonstrates the crystal orientation of the Cu film. Conventional coated Cr/Cu film showed crystalline peaks at (111), (200), and (220). The similar intensity at (111) and (220) indicates the random distribution of grains in the deposited film. On the other hand, the IBAD induced the alignment of (111) orientations of grains parallel to the substrate. The (200) and (220) peaks almost disappeared. The most stable surface in Cu is the (111) plane, as is true for most face centered cubic (fcc) materials.[7] During IBAD, the Cu surface seemed to be formed as a stable configuration on the bcc Cr substrate.

Lee suggested that a preferential orientation occurs as high surface energy (220) planes when the solute atoms are abundant, and is changed to (111) growth as the solute atoms decrease.[8] If the nucleation rate is faster than the atom flux into the substrate, the atom can settle into a stable lattice position by forming an energetically stable surface. During IBAD, it is suggested that Ag ions bombard the as-deposited add-atoms and eliminate the atoms in unstable lattice positions; finally, the stable (111) surface orientation remains. The growth of a grain proceeds to form its equilibrium crystal shape (ECS).[7] Generally, the rate of growth is slowest on a surface that consists of ECS. If the orientation of seed grains were random, the final grown film would not have a crystallographic texture. However, once the epitaxial growth was initiated on an aligned substrate, the grown microstructures will show the preferential orientation.

4. CONCLUSIONS

Cr/Cu film was formed by using the conventional physical vapor deposition, esp. electron-beam evaporation and deposition, and ion-beam assisted deposition. With the aid of Ar ion-beams, high density and electric resistivity of the Cr/Cu film was obtained. Moreover, the crystallographic orientation of the Cu film was changed by the introduction of the ion-beam assisted deposition.

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