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Deposition of Cu-Ni films by Magnetron Co-Sputtering and Effects of Target Configurations on Film Properties

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Abstract - Structural properties of Cu-Ni alloy films, such as preferred orientation, crystallite size, inter-planar spacing, cross-sectional morphology, and electrical resistivity, are investigated in terms of target configurations that are used in the film deposition by means of magnetron co-sputtering. Two different target configurations are considered in this study: a dual-type configuration in which two separate targets (Cu and Ni) and different bias types (RF and DC) are used and a Ni-on-Cu type configuration in which Ni chips are attached to a Cu target. The dual-type configuration appears to have some advantages over the Ni-on-Cu type regarding the accurate control of atomic composition of the deposited Cu-Ni alloy. However, the dual-type-produced film exhibits a porous and columnar structure, the relatively large internal stress, and the high electrical resistivity, which are mainly due to the relatively low mobility of adatoms. The affects of thermal treatment and deposition conditions on the structural and electrical properties of dual-type Cu-Ni films are also discussed.

Keywords: Cu-Ni alloy, co-sputtering, target configuration, structural and electrical properties

1. Introduction

Cu-Ni alloy films are considered to have potential for piezo-resistive applications, such as thin film strain gauges, mainly due to the low temperature coefficient of resistivity (TCR) [1]. The Cu-Ni alloy forms a complete solid solution in the entire region of compositions since the Cu and Ni atoms constitute a face-centered cubic (FCC) structure. A co-sputtering method has widely been used to deposit the thin film of Cu-Ni alloy by adopting the various types of target configuration [2-4]. Among the target configurations, the following two types have often been introduced: one is the configuration that uses a single target with several Ni chips attached on the Cu-base target (hereafter, denoted by *an Ni-on-Cu target*) [4] and the other is the configuration that uses separate targets consisting of Cu and Ni (hereafter denoted by *a dual-target*) [2-3]. However few studies in literature address the influence of target configurations on the growth behaviors and properties of deposited Cu-Ni alloy films.

In this research, we systematically investigate the effects of target configurations, including both the Ni-on-Cu type and the dual-type configurations, on the structural and electrical properties of deposited Cu-Ni films. All the results obtained from this research are characterized in terms of the two target configurations.

2. Experimental

The Cu-Ni films were deposited using a magnetron co-sputtering system composed of tilted DC and RF multi-cathodes. P-type Si (100) and glass were used as substrates for the morphology study and crystal structure analysis, respectively. The atomic composition ratios of Cu to Ni in deposited Cu-Ni alloys were controlled in the following two ways. First, in the dual-type configuration, DC power varying from 27W to 61W was applied to the Cu target and RF power of 130 W and 140 W was applied to the Ni target. Secondly, in the Ni-on-Cu type, the relative ratio of the Ni-chip to the whole target area was altered and RF power of 100 W was applied to the target. The working pressure and substrate temperature varied in the range of 2-7 mTorr and 25-200° C, respectively.

The preferred orientation, crystallite size, and full-width at half maximum (FWHM) of deposited films were evaluated from the x-ray diffraction (XRD) patterns [5]. (The x-ray diffraction used Cu-Kα radiation, a 40-60° range, and a Bede D3 system.) The atomic composition was estimated using the electron dispersive x-ray spectrometer (EDXS) (model Oxford D-7168), which was at-

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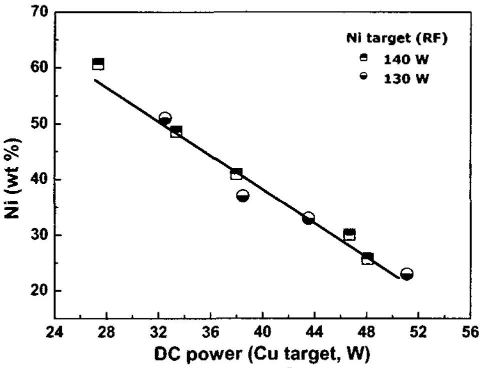
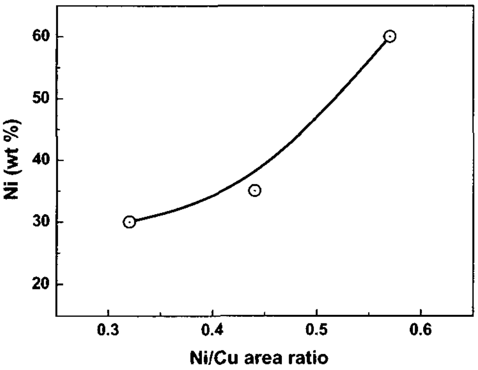
tached to the field-emission scanning electron microscopy (FE-SEM) equipment (model JSM-6330F). The cross-sectional morphology was monitored from the high-resolution FE-SEM images. The electrical resistivity was also measured using the four-point probe technique.

3. Results and Discussion

Figs. 1(a) and 1(b) show the Ni content variations incorporated in the deposited Cu-Ni films in terms of the two proposed target configurations. The various atomic composition ratios were found to be obtained either by varying the DC power (for dual-target) or by changing the Ni/Cu area ratio (for Ni-on-Cu target). In addition, the result indicated that the more precise and easier control for the atomic composition was possible by adopting the dual-target rather than the Ni-on-Cu target configurations.



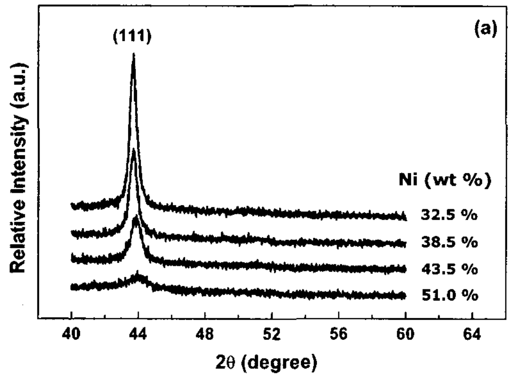
(a) dual-type (for Ni target, ◒ : RF 130 W and ⊟ : RF 140 W)



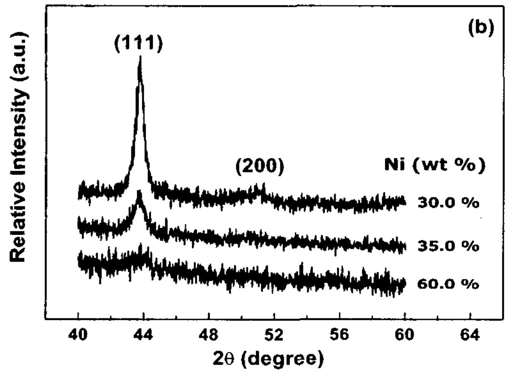
(b) Ni-on-Cu type (⊙ : RF 100 W) target configurations

Fig. 1 The variations of Ni content in Cu-Ni alloy films deposited using (a) dual-type and (b) Ni-on-Cu type target configurations

The XRD patterns were measured from all the Cu-Ni films deposited using the two proposed target configurations and the results were compared as shown in Fig. 2. All the peaks were assigned to the Cu-Ni solid solution of FCC crystal structure, while no diffraction peak due to atomic Ni was observed. The intensity of the (111)-plane was found to be greater than that of the (200)-plane, which indicates that the Cu-Ni film deposited on the glass substrate preferred to grow along the <111>-direction since the FCC structure's (111)-plane was closely packed with a relatively small lattice energy. As the Ni content increased, the (111)-peak shifted to a higher diffraction angle of 2θ, while the preferred orientation scarcely changed.



(a) dual-type



(b) Ni-on-Cu

Fig. 2 X-ray diffraction patterns of Cu-Ni alloy films deposited using (a) dual-type and (b) Ni-on-Cu type target configurations

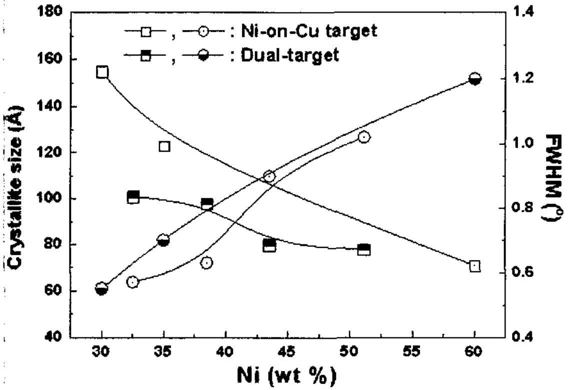


Fig. 3 Crystallite sizes (□, ⊟) and FWHM values (⊙, ◒) of deposited Cu-Ni films as a function of Ni content

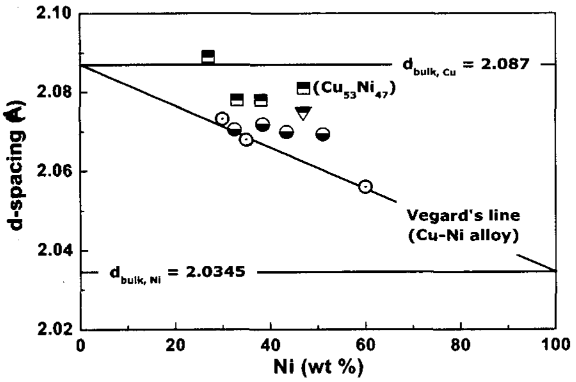
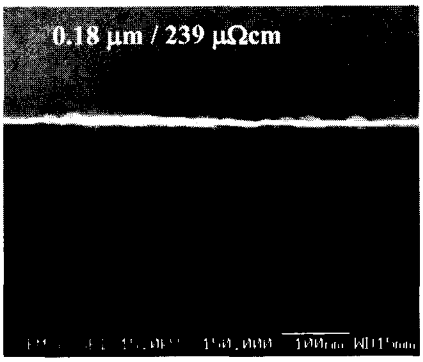


Fig. 4 The variation of inter-planar d-spacing as a function of Ni content. The lines illustrate the Vegard's law. (◒ : dual-type/130 W, ⬒ : dual-type/140 W, ⊙ : Ni-on-Cu type/100 W, ▽ : dual-type/140 W/annealed $Cu_{53}Ni_{47}$)

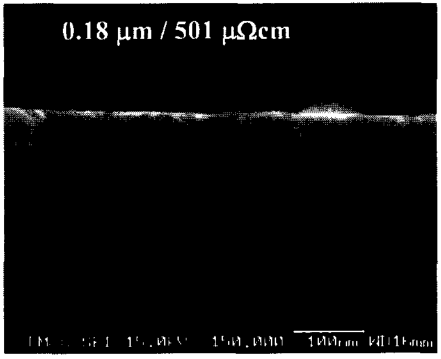
Fig. 3 shows the variations of FWHM value and crystallite size which was estimated from the XRD patterns shown in Fig. 2. As the Ni content increased, the FWHM value increased and correspondingly the crystallite size decreased. In addition, note that the crystallite size of the Ni-on-Cu type Cu-Ni films was larger than that of the dual-type film. In the dual-type configuration, the overlap of two plasmas generated from the two separate targets is unavoidable, which may lower the ion energy of sputtered particles and thus reduce the mobility of adatoms reaching the deposited film surface. The reduced adatomic mobility in the dual-type configuration is believed to have hindered the crystal growth of Cu-Ni films.

In general, the Cu and Ni atoms form a single solid solution that follows Vegard's law in the whole composition range since both atoms have similar electro-negativities and atomic radii [6]. Fig. 4 depicts the inter-planar d-spacing of deposited Cu-Ni films, which was calculated by applying the Bragg equation to the (111) peak [5]. For the Cu-Ni films deposited using the Ni-on-Cu target, the d-spacing value almost linearly decreased with Ni content, which was in good agreement with Vegard's line. For the films deposited using the dual-target configuration, however, the d-spacing value was relatively large and the variation of d-spacing with Ni content deviated from the Vegard's line. In addition, for the dual-target produced $Cu_{53}Ni_{47}$ film (marked by '⬒ ($Cu_{53}Ni_{47}$)' in Fig. 4), the thermal annealing was performed at 200° C for 3 h. The d-spacing value of the $Cu_{53}Ni_{47}$ film was estimated to be of 2.081 Å for the as-deposited state and 2.074 Å for the annealed state (marked by '▽' in Fig. 4), respectively.

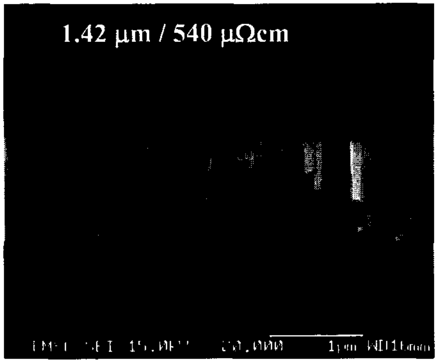
The large d-spacing value as well as the disobedience to Vegard's law, as observed in the dual-target produced Cu-Ni films, was attributed to strong internal compressive stress. The Cu-Ni film was previously reported [7] to contained compressive stress along the <111>-direction perpendicular to the growth surface, while the horizontal direction to the growth surface produced the tensile stress. The reduction of the d-spacing value, which was observed in the thermally-annealed $Cu_{53}Ni_{47}$ film, was believed to be due to the release of internal stress.



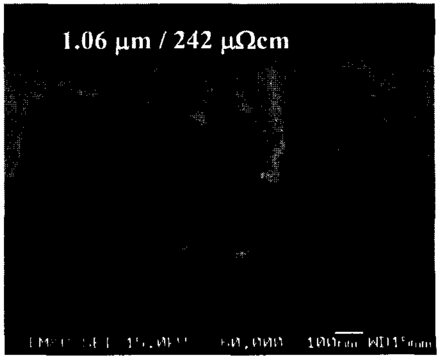
(a) Ni-on-Cu (5mTorr at room temperature)



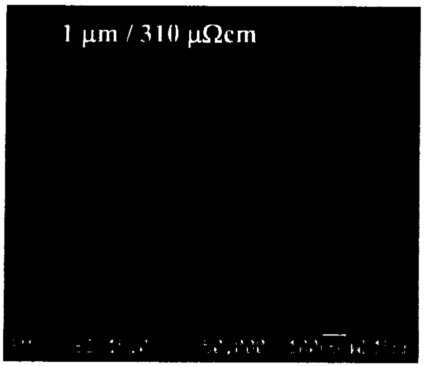
(b) Dual (5mTorr at room temperature)



(c) Dual (5mTorr at room temperature)



(d) Dual (2mTorr at room temperature)
(**Fig. 5** continued)



(e) Dual (5mTorr at 200^{O} C)

Fig. 5 Cross-sectional FE-SEM morphologies of Cu-Ni films as a function of working pressure and deposition temperature for (a) Ni-on-Cu type film and (b)-(e) dual-type films
(The measured values of film thickness/electrical resistivity are also designated.)

The tensile stress that has been reported [8] to be formed by low-mobility adatoms may lead the deposited Cu-Ni film to reveal a columnar structure. In addition, the formation of a grain boundary causes the tensile stress when the grain growth occurs from some initial islands. In this stage, when the high-mobility adatoms arrive at the grown film surface, the tensile stress is relaxed by the incorporation of those adatoms into the grain boundaries. On the other hand, when the low-mobility adatoms arrive at the surface, the tensile stress is maintained upon coalescence since the low-mobility adatoms are hardly diffused into the grain boundaries, which accordingly hinders the grain growth and results in a narrow columnar structure.

In Fig. 5, the cross-sectional FE-SEM morphology of the dual-target produced Cu-Ni film is compared with the morphologies obtained from the Ni-on-Cu target films, along with the corresponding resistivies of both types of films. Even when the Cu-Ni films were prepared under the same working pressure (5 mTorr) and deposition temperature (room temperature), the dual-target films (see Figs. 5(b) and 5(c)) showed porous columnar structures and revealed relatively high resistivities (501 μΩcm and 540 μΩcm, respectively), while the Ni-on-Cu target film (see Fig. 5(a)) exhibited a granular structure and a relatively low resistivity. As already discussed, the columnar structures and higher resistivities observed in the dual-target Cu-Ni films were ascribed to the relatively low mobility of adatoms reaching the film surface. In addition, the resistivity of CuNi film was founded to be reduced either by decreasing the working pressure to 2 mTorr (see Fig. 5(d)) or by increasing the deposition temperature to 200° C (see Fig. 5(e)). These results indicated that the adatomic mobility was enhanced and the highly-consolidated Cu-Ni alloy films were obtained.

4. Conclusion

Experimental results regarding the preferred orientation, crystallite size, d-spacing, cross-sectional morphology, and electrical resistivity of Cu-Ni alloy films are presented in terms of two different target configurations. Although the dual-target configuration appeared to have some advantages for the precise and easy control of the atomic composition in the Cu-Ni alloy films, the dual-target films exhibited smaller grain sizes, higher resistivities, and porous columnar structures. In addition, the dual-target films' d-spacing variation with Ni content showed some deviations from Vegard's law. These results were ascribed mainly due to the relatively strong internal stress in the Cu-Ni films deposited using the dual-target configuration since the overlap of two plasmas reduced the mobility of the adatoms reaching the film surface and accordingly maintained the internal stress upon coalescence. In the dual-target Cu-Ni films, decreasing the working pressure, increasing the deposition temperature, or using thermal treatment reduced the d-spacing values and electrical resistivities and the highly-consolidated film structure of Cu-Ni alloy could be obtained due to the release of internal stresses through the enhancement of adatomic mobility.

Acknowledgements

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References

[1] H. Konishi, T. Suzuki, and M. Utsunomiya, "Constantan thin film strain gauge load cell," *Tech. Digest of the 9th Sensor Symposium*, pp. 149-152, 1990.

[2] F. O. Adurodija, J. S. Song, S. D. Kim, S. K. Kim, and K. H. Yoon, "Characterization of CuInS$_2$ thin films grown by close-spaced vapor sulfurization of co-sputtered Cu-In alloy precursors," *Japan J. Applied Physics*, vol. 37, pp.4248-4253, 1998.

[3] R. H. Horng, D. S. Wun, L. H. Wu, M. K. Lee, S. H. Chan, C. C. Leu, T. Y. Huang, and S. M. Sze, "Thermal stability of co-sputtered Ru-Ti alloy electrodes for dynamic random access memory applications," *Japan J. Applied Physics*, vol.37, pp. L1247-L1250, 1998.

[4] L. Sanques, S. Fagnent, M. C. S. Catherine, and C.

Sella, "Aluminium-aluminium nitride cermet films: preparation by co-sputtering and microstructure," *Surface Coating Technology*, vol. 102, pp. 25-34, 1998.

[5] B. D. Cullity, *Elements of X-ray Diffraction*, 2nd ed., Addison-Wesley Pub., 1978, pp. 81-106.

[6] I. mizushima, M. Chikazawa, and T. Watanabe, "Microstructure of electrodeposited Cu-Ni binary alloy films," *J. Electrochemical Society*, vol. 143, no. 6, pp. 1978-1983, 1996.

[7] H. Hiramatsu, W. S. Seo, and K. Koumoto, "Electrical and optical properties of radio-frequency-sputtered thin films of $(ZnO)_5In_2O_3$," *Chemical Materials*, vol. 10, pp. 3033-3039, 1998.

[8] F. Spaepen, "Interfaces and stresses in thin films," *Actuator Material.*, vol. 48, pp. 31-42, 2000.

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