Journal of the Korean Institute of Electrical and Electronic Material Engineers, Vol. 19, No. 8, p. 712, August 2006.

논 문 19-8-3

Thickness Dependence of the Electrical Properties in NiCr Thin Film Resistors Annealed in a Vacuum Ambient for π- type Attenuator Applications

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Abstract

NiCr thin films prepared on SiO_2/Si substrates at room temperature by magnetron co-sputtering technique and then annealed in a vacuum ambient (3 x 10^{-6} Torr) at 400 °C. The grain size and crystallinity of the films increased with film thickness. The resistivity of the films slightly decreases as the film thickness increases. Temperature coefficient resistance (TCR) exhibits positive values irrespective of film thickness and TCR in the range of 50 to 400 nm thickness shows suitable values for the application of 10 dB in π- type attenuators.

Key Words : NiCr films, TCR, Sputtering, Resistivity

1. INTRODUCTION

NiCr is the most frequently used as the thin film resistor material in hybrid-integrated circuits[1,2]. because of their advantage that include high resistivity and low TCR, and good long-term stability[3]. Recently, this alloy has been applied in thin film configurations for resistive components. The highresistivity and low TCR, which guarantee low constant electric resistance over wide range of temperatures, are required in microelectronics, especially in portable terminal or π-type attenuators, for saving the consumption of batteries. The effect of chromium concentration on the electrical properties including TCR was studied extensively in NiCr films[4]. For as-deposited films with chromium concentration of 50 atomic percentages, Toth et al. observed a quasia- morphous structure with a few crystallites embedded in the amorphous matrix[5]. The characteristics of structure in NiCr (22 atomic% Cr) films depending on thickness (20 - 200 nm) was investigated[6]. The TCR accuracy depends on the precision in both film composition and annealing treatment. Therefore, the degree of amorphism may depend on sputter conditions and thereby influences the final TCR value. The requirement of thin film resistors for π- type attenuator applications is the realization of appropriate resistance and a near zero TCR. For instant, the resistivity of couples of NiCr and TaN in 30 dB and 10 dB applications should be 209 and 190 μΩ-cm, respectively. In microelectronic applications, the film thickness should be scaled down and proportional to the device size. Thus, it is valuable to examine the effect of film thickness on the microstructure and the electrical properties.

In this study, NiCr (50 atomic% Cr) thin films with various thicknesses were deposited on SiO_2(600 nm)/Si substrates using a magnetron co-sputtering technique. The structural and

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접수일자 : 2006. 4. 6
1차 심사 : 2006. 6. 22
2차 심사 : 2006. 7. 19
심사완료 : 2006. 7. 21

electrical properties of NiCr films were investigated as a function of thickness and an optimum film thickness that have an appropriate resistivity and a near zero TCR were also studied.

2. EXPERIMENT

NiCr films with various thicknesses were deposited at room temperature on SiO_2 (600 nm)/Si substrates by dc magnetron sputtering technique and then annealed in vacuum (3 x 10^{-6} Torr) at 400 °C for 1h. From the previous studies[7], the heat treatment conditions for NiCr films were chosen to exhibit optimum properties including TCR and resistance. The targets were Ni and Cr metals of 2- inch diameter with purity of 99.99 %. The working pressure was maintained at 3.5 mTorr with 8 sccm (standard cc/min) of Ar flow rate. The power supplied to Ni and Cr targets is 40 W and 90 W, respectively. The crystalline structure and preferred orientation of the NiCr films were examined by x-ray diffraction (XRD). The surface morphologies were observed by atomic force microscopy (AFM, PSI) using a contact mode and scanning electron microscopy (SEM). The thickness of the films was measured by cross-sectional images by SEM. The composition and electrical resistance (R_S) of the NiCr films were measured by electron probe x-ray microanalysis (EPMA) and by four-point probe with an electrometer (CMT-SR 1000), respectively. TCR measurement in NiCr thin films were patterned using a shadow mask. Firstly, the NiCr films were deposited on the four-terminal structure pattern using a shadow mask at room temperature and then annealed in conditions mentioned above. Finally, 100-nm-thick Pt electrodes by dc magnetron sputtering were deposited on the four-terminal NiCr patterns formed by photolithography. TCR of the films was measured through a heating and cooling procedure (in an air atmosphere from 25 to 120 °C) in a thermostatically controlled oven by a digital multimeter (HP3458A). TCR values were calculated using the following equation[8]:

$$TCR\ (ppm/K) = (R_{120} - R_{25})/R_{25}/\ (120-25) \times 10^6$$

Irreversibility of resistance measured from room temperature to 120 °C was indicated by R/R_o, where Roand R are a resistance measured at room temperature before and after one cycle, respectively.

3. RESULTS AND DISCUSSION

Figure 1 shows XRD patterns of the NiCr films with different thicknesses from 50 to 400 nm. As shown in Fig. 1, the samples annealed at 400 °C showed a crystalline nature which exhibits a main peak of (110) plane at 2 θ = 44.3° and the position of this peak coincides with (111) reflection of the face centered cubic lattice of the nickel. It can be concluded that the main contribution to the peak is attributed to the nickel lattice, as already reported by Huang and Howard[6]. The peak intensity of NiCr (111) increases with increasing film thickness.

The surface morphologies of the films as a function of film thickness were illustrated by SEM

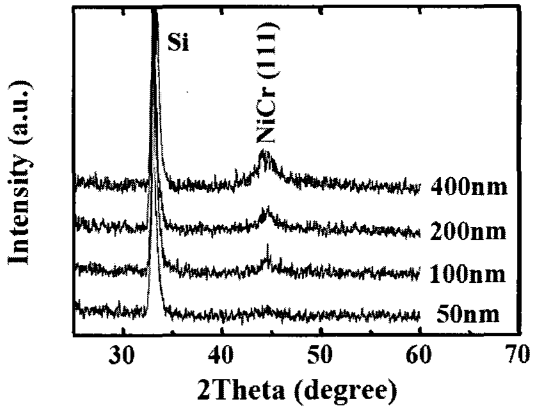

Fig. 1. X-ray diffraction patterns of the NiCr films with different thicknesses.

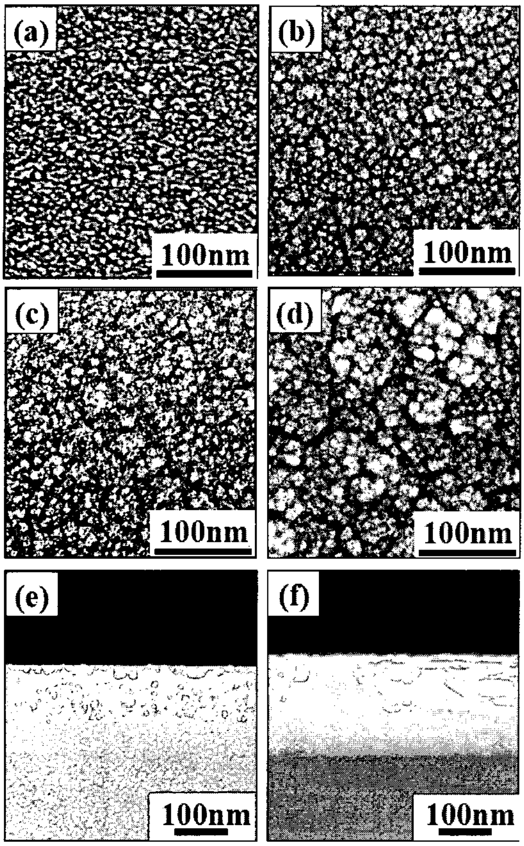

Fig. 2. The surface morphologies of the films as a function of film thickness (a) 50 nm, (b) 100 nm, (c) 200 nm, (d) 400 nm and the cross sectional images of the films as a function of film thickness (e) 100 nm and (f) 200 nm.

images in Fig. 2. As film thickness increases, the grain size increases. The grain growth with increasing film thickness has also been observed in CuNi thin films deposited by magnetron sputtering[9]. Figures 2(e) and 2(f) show cross-sectional images of the films with thicknesses of 100 nm and 200 nm, respectively. As shown in Fig. 2(e), 100 nm-thick films showed a columnar structure. On the other hand, 200 nm-thick films were grown with an equiaxised structure.

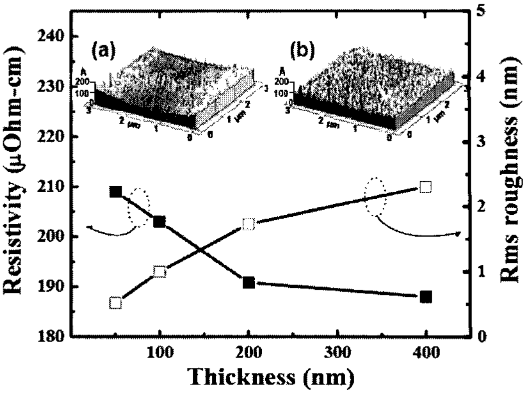

Fig. 3. The relationship between the resistivity and rms (root mean square) roughness of the films as a function of film thickness (a) 50 nm, (b) 200 nm.

Figure 3 shows the relationship between the resistivity and rms (root mean square) roughness of the films as a function of film thickness. The resistivities of the films linearly decrease with increasing film thickness. 50 and 200 nm-thick NiCr films exhibit the resistivity of 209 and 190 $\mu\Omega$-cm, respectively, and they are sufficient for π-type attenuator applications. It is well known that the resistivity depends on the film thickness. As film thickness decreases, the size of the regrown grains during sintering is smaller, and then increases the resistivity[10]. As expected, the minimum of resistivity correlates with the maximum of film thickness. Rms roughness of the films as shown in Fig. 3 increases gradually from 3 Å in 50 nm-thick films to 22 Å of 400 nm-thick films. The films become rougher due to strain relaxation because a strain accumulation is proportional to the film thickness[11]. The variation in surface roughness with increasing film thickness is additionally clarified in the three-dimensional AFM images (Figs. 3(a) and 3(b)). 50 nm-thick films exhibited smooth surface images of 3 Å. On the other hand, rough surface morphologies with rms roughness of about 17 Å were observed at 200 nm-thick NiCr films.

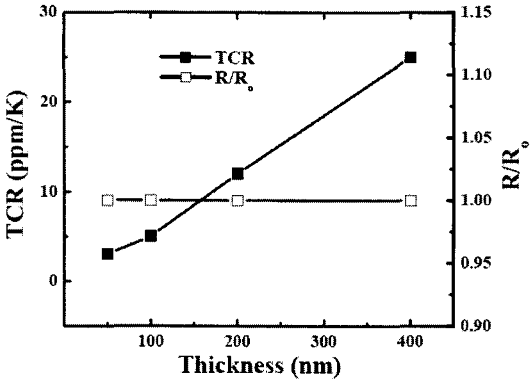

Fig. 4. Variations in TCR and irreversibility of the resistance as a function of film thickness.

Variations in TCR and irreversibility of the resistance as a function of film thickness are shown in Fig. 4. TCR values increase positively as film thickness increases from 50 to 400 nm. As shown in XRD patterns of Fig. 1, peak intensity of NiCr (111) increases with film thickness. Effect of the substrates on the crystallinity of the films increases with decreasing film thickness. Therefore, crystallinity of the films increases with film thickness. Most pure metals have a positive TCR of several thousand ppm/K.

TCR can be reduced by alloying, but it generally remains in a positive range. A negative TCR has been reported for several amorphous metals and in other metastable states such as the so-called quasicrystalline materials. TCR values are 3 and 12 ppm/K in 50 and 200 nm-thick films, respectively, resulting in suitable values for π-type attenuatorapplications. The irreversibility of resistance is an important parameter, which will be considered during the switching from room temperature to 120 °C in thin film resistors. The irreversible changes in all the films are not observed.

4. CONCLUSION

The structural and electrical properties of the NiCr films deposited at room temperature and then annealed at 400 °C on SiO_2/Si substrates were studied as a function of film thickness. The grain size and crystallinity of the films increased with film thickness. In addition, as film thickness increases, the resistivity of the films decreases. The positive TCR values increase with film thickness and are suitable for π-type attenuator applications.

ACKNOWLEDGMENTS

This research was supported by the Program for the Training of Graduate Students in Regional Innovation which was conducted by the Ministry of Commerce, Industry and Energy of the Korean Government and was partially supported by Korea Research Foundation Grant (KRF-2004-042-D00095).

REFERENCES

[1] A. Peled, Y. Zloof, J. Ferhadyan, and A. M. Peled, "A study of the temperature dependence of NiCr thin film resistors", Solid-State Electron., Vol. 34, p. 667, 1991.

[2] G. Nocerino and K. E. Singer, "The electrical and compositional structure of thin Ni-Cr films", Thin Solid Films, Vol. 57, p. 343, 1979.

[3] R. Tavzes, E. Kansky, A. Banovek, A. Zalar, M. Gregorec, A. Barna, P. B. Barna, and I. Pozsgai, "The evaluation of the technology for depositing NiCr resistive films", Thin Solid Films, Vol. 36, p. 379, 1976.

[4] M. P. Nguyen, D. J. Kim, B. D. Kang, C. S. Kim, and S. G. Yoon, "Effect of chromium concentration on the electrical properties of NiCr thin films resistor deposited at room temperature by magnetron co-sputtering technique", J. Electrochem. Soc., Vol. 153, No. 1, p. G27, 2006.

[5] L. Toth, A. Barna, and G. Safran, "In situ transmission electron microscopy annealing

of NiCR thin films with simultaneous Hall-voltage measurement", J. Vac. Sci. Technology, Vol. A5, p. 1856, 1987.

[6] T. C. Huang and J. K. Howard, "Characterization of Ni-Cr thin films by X-ray analysis", Thin Solid Films, Vol. 148, p. 209, 1987.

[7] M. P. Nguyen, D. J. Kim, B. D. Kang, and S. G. Yoon, "Structural and electrical properties of NiCr thin film resistors anneaed at various temperature in a vacuum and at nitrogen ambient", J. Electrochem. Soc., Vol. 153, No. 7, p. G660, 2006.

[8] M. Ishikawa, H. Enomoto, N. Mikamoto, T. Nakamura, M. Matsuoka, and C. Iwakura, "Preparation of thin film resistors with low resistivity and low TCR by heat treatment of multilayered Cu/Ni deposits", Surf. Coat. Technol., Vol. 110, p. 121, 1998.

[9] B. D. Kang, S. G. Hur, D. J. Kim, and S. G. Yoon, "Thickness dependence of the electrical properties of CuNi thin film resistors grown on AlN substrates for Π-type attenuator application", Electrochem. Solid. State. Lett., Vol. 8, No. 4, p. G92, 2005.

[10] B. W. Liou, Y. H. Wu, C. L. Lee, and T. F. Lei, "Thickness effect on hydrogen plasma treatment on polycrystalline silicon thin films", Appl. Phys. Lett., Vol. 66, p. 3013, 1995.

[11] C. P. Liu and H. G. Yang, "Deposition temperature and thickness effects on the characteristics of DC-sputtered ZrNx films", Mater. Chem. Phys., Vol. 86, p. 370, 2004.