한국전기전자재료학회
'00 영호남 학술대회논문집

Fabrication of High-sensitivity Thin-film Type Strain-guges

고감도 박막형 스트레인 게이지의 제작

Gwiy-Sang Chung*, Jeong-Hwan Seo**
정귀상*, 서정환**

Abstract

The physical, electrical and piezoresitive characteristics of CrN(chromiun nitride) thin-films on silicon substrates have been investigated for use as strain gauges. The thin-film depositions have been carried out by DC reactive magnetron sputtering in an argon-nitrogen atmosphere(Ar-(5~25 %)N_2). The deposited CrN thin-films with thickness of 3500Å and annealing conditions(300℃, 48 hr) in Ar-10 % N_2 deposition atmosphere have been selected as the ideal piezoresistive material for the strain gauges. Under optimum conditions, the CrN thin-films for the strain gauges is obtained a high electrical resistivity, ρ=1147.65 $\mu\Omega$cm, a low temperature coefficient of resistance, TCR=-186 ppm/℃ and a high temporal stability with a good longitudinal gauge factor, GF=11.17.

Key Wards : chromiun nitride, thin-film, strain gauge, temperature coefficient of resistance, gauge factor, hysterisis, aging effect, I/V/T curve

1. Introduction

As the silicon planar process and micromaching technologies advanced, solid-state pressure sensors using the exellent elastic properties of silicon have been rapidly developed. These sensors offer high performance, sensitivity and accuracy in combination with small dimensions, low power consumption, good linearity, no hystersis, good stability, and suitability for batch fabrication.[1] However, use of silicon is restricted to temperature below 120℃ and low dynamic pressure ranges.[2]

Recently, pressure sensors with wide dynamic pressure ranges which can be used at high temperature, pressure, humidity, and vibration environments, are particularly demanded in automotove, aircraft-engine, industrial and laboratory pressure sensing instruments.[3] Pressure sensors are basically electromechanical devices used for a variety of applications. A pressure sensor essentially consists of a diaphragm which undergoes deformation due to applied pressure. This mechanical deformation of the diaphragm converted into an electrical response by strain gauges bonded to or piezoresistors difussed it.

To overcome the shortages mentioned above, thick-film, some kinds of metal alloys are used as materials for a high temperature or corrosive applications.[4-9] However, they have a low sensitivity because of a low gauge factor and a low electrical resistivity. They are difficult to be miniaturization. Conventional diffused semiconductor strain gauges have a high gauge factor and a high electrical resistivity, but they are limited in

*동서대학교 정보통신공학부,
(부산시 사상구 주례동 산69-1, FAX: 051-320-1592
E-mail : gschung@kowon.dongseo.ac.kr)
** 대양전기공업(주) 기술연구소 센서소자팀

their use above 120℃. Other semiconductor materials like polysilicon,(10) diamond,(11) and SiC(12) have been developed as strain gauges which can use in a high temperature, but they are impossible to have repeatability.

In order to develope the strain gauges with wide dynamic pressure ranges which can be in harsh surroundings, thin-film stain gauges were investigated. Compared with conventional sensors, these devices have some advantages, such as a wide temperature range, excellent thermal compatibility with their substrates, and long-term stability, and are suitable for manufacturing miniaturized snesors with high internal resistance. Besides, they are characterized by the precisely-controlled technology and itss advantages in batch manufacture. The distinct advantages are absence of adhesive material, flexibility to tailor the properties of the sensing film. Several ceramics have comparatively higher electrical resistance, stress sensitivity and gauge factor than metals. They have the possibility to use in a high temperature, and they are also available as materials of the thin-film strain gauges.(13)

In this article, we describe the physical, electrical and piezoresitive characteristics of CrN thin-films on silicon substrates for use as strain gauges. The CrN thin-films are deposited using by DC reactive magnetron sputtering in an argon-nitrogen atmosphere(Ar-(5~25 %)N_2). In order to improve the piezoresistive properties of the sensing element, deposition parameters and post-deposition thermal treatments have been chosen. The thin-film depostion and masking methodes for the development of a sensing element based on piezoresistive CrN thin-films are also presented. Finally, under optimum conditions of deposition and annealing, this paper applies the I(current)/V(voltage)/T(time) curves of CrN thin-film strain gauges, hysterisis characteristics by changing in temperature and resistance, and aging effect to the ceramic thin-film stain gauges.

2. Experimental

CrN thin-films were deposited onto thermally oxidized 500 μm thick silicon substates by DC reactive magnetron sputtering in an argon-nitrogen atmosphere(Ar-(5~25 %)N_2). Prior to the depostion, the silicon substrates were cleaned in an ultrasonic degreasing bath in clean-room environment. The purity of metallic Cr target with diameter of 2-inch was 99.9%. The residual gas pressure was less than 5×10^{-6} Torr and the total gas pressure of the Ar-N_2 mixture during CrN depostion was held at 0.9 Torr. The Ar gas flow was 60~76 sccm, the N_2 gas flow 4~20 sccm. The deposition rates of 350~400Å/mim were achieved. A 7 W/㎠ r.f bias was applied to the substrate during the deposition. Thin-film thickness between 1500Å and 5000Å were measured with a profilometer. A post-deposition thermal treatment(heat tempera- ture ; 100~300℃ and heat time; 24~72 hr) in an N_2 atmosphere was also carried out to investigate the annealing effect of the CrN thin-films. The structural and compositional properties of the CrN thin-films were evaluated by SEM(scanning electron microscope), XRD(x-ray diffraction) and EDS(electronic diffraction spectroscope). All the electrical measurements were made by four-point prove methods.

The CrN thin-film resistors, 35 μm wide and with a 32 mm long meandering path, were patterned using photolithographic techniques. An automatic data-acquisition system controlled by a personal computer was used for the TCR(temperature coefficient of resistance) measurement in the range 25~150℃. Accelerated life tests at 150℃ were made to study the long-term stability of CrN thin-film resistors. I/V/T characteristics were used to analyze the electrical conduction mechanism of the CrN thin-films. The longitudinal gauge factor of the CrN thin-films was determined using the cantilever beam method. The hysteresis effect due to strain cycling was also examined.

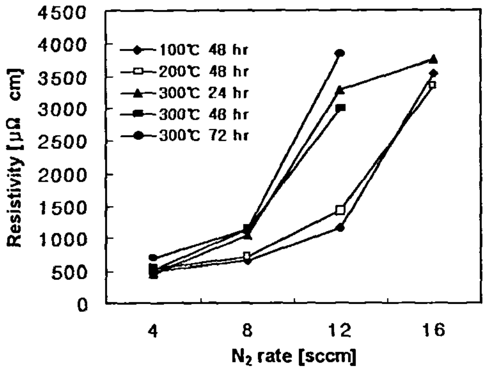


Fig. 1. Variations of electrical resistivity according to annealing conditions of CrN thin-film(heat temperature : 100~ 300℃, heat times : 24~ 72 hr).

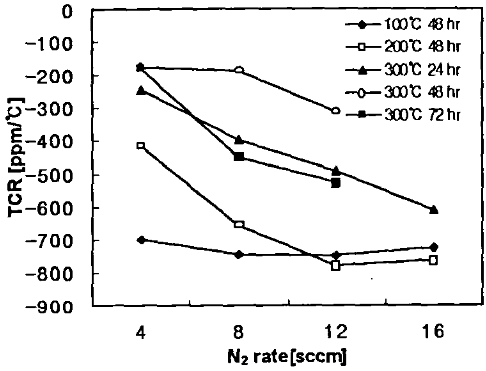


Fig. 2. TCR values according to annealing condition of CrN thin-film strain gauges (heat temperature : 100~ 300℃, heat times : 24~72 hr).

3. Results and Discussion

3-1. Electrical properties

Electrical measurements have been performed after annealing treatments. Fig. 1 and Fig. 2, respectively, shows the variations of electrical resistivity(ρ) and TCR as a function of the Ar : N_2 flow ratio during the DC reactive magnetron sputtering and annealing conditions.

Fig. 1 shows the variations of electrical resistivity according to annealing conditions of CrN thin-films (heat temperature; 100~300℃ and heat times; 24~72 hr) when a flow rate of N_2 gas is 4~16 sccm. Before annealing, the more N_2 rate increased, the more electrical resistivity of CrN thin-films increased. In 20 sccm N_2 rate, Chromium becomes nitrification and then was insulated. When N_2 rate was low, the Chromium became almost never nitrification. As N_2 rate increased, Chromium which had been prepared a metal phase by the sputtering method proceeded with nitration. Consequently, the CrN thin-films, which had a high electrical resistivity, seemed to control characteristics of the thin-films.[14] When annealing temperature increased, there were almost no variations of electrical resistivity values in N_2 rate of under 8 sccm, but electrical resistivity values increased in above 12 sccm. In particular, in 16 sccm N_2 rate and annealing conditions, heat temperature of 300℃ and heat time of 48 hr, high variations of electrical resistivity were appeared. It seems oxidation appearance by annealing of nitrified CrN thin-films.

Fig. 2 shows TCR values according to annealing condition of CrN thin-film strain gauges for N_2 rate. The more annealing temperature increased, TCR values decreased. When N_2 rate was 4~8 sccm, the variation width was the widest, that is, it seemed to reach the lowest TCR values in N_2 rate of 4~8 sccm, annealing temperature of 300℃ and annealing times of 48 hr. And when N_2 rate was more than 16 sccm, by annealing temperature more than 30 0℃ it could not be measure because resistance rate increased. Therefore, comparatively a high electrical resistivity value and a low TCR value of -186 ppm/℃ were given in N_2 rate of 8 sccm and annealing conditions which were heat temperature of 300℃ and heat times of 48 hr. The electrical resistivity in this situation is ρ = 1147.65 $\mu\Omega$cm.

Fig. 3 shows hysterisis characteristics of the variation rate of resistance according to temperature of CrN thin-film strain gauges in the

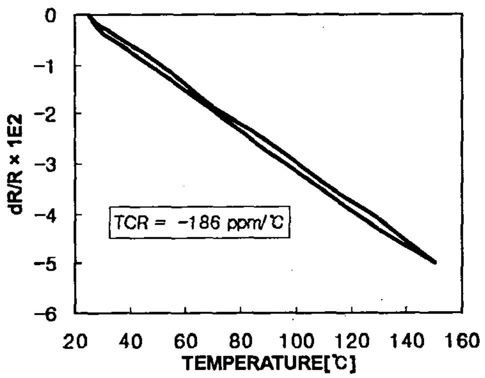


Fig. 3. Variation rate of resistance according to temperature of CrN thin-film strain gauges(N_2 rate : 8 sccm, annealing condition : 300℃, 48 hr).

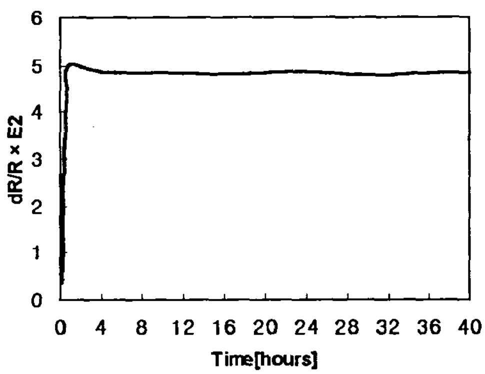


Fig. 4. Aging effect of CrN thin-film strain gauges(N_2 rate : 8 sccm, annealing condition : 300℃, 48 hr).

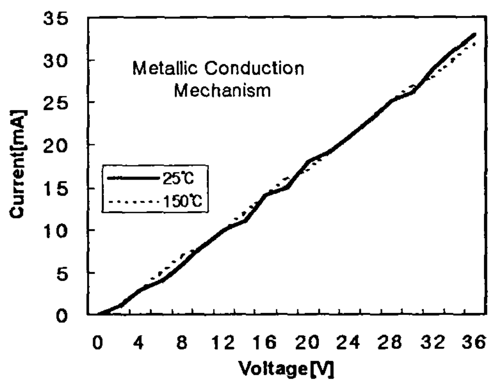


Fig. 5. I/V/T Characteristics of CrN thin-films(N_2 rate : 8sccm, annealing condition : 300℃, 48hr).

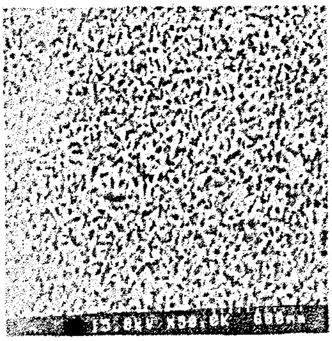
temperature range of 25~150℃ when N_2 rate is 8 sccm and annealing conditions are heat temperature of 300℃ and heat time of 48 hr. It showed a nonlinearity and a hysteresis less than 1.65 % FS and 2.27 % FS, respectively. The TCR shows a high linearity and a low hysteresis under this conditions. Variation rate of resistance according to temperature was very linear, and it seemed to get more stable characteristics according to annealing.

Fig. 4 shows the long-term stability according to times in temperature from an accelerated life test at 150℃ of CrN thin-film strain gauges, when N_2 rate is 8 sccm, annealing conditions are heat temperature of 300℃ and heat time of 48 hr. The resistance variation rate is very small for CrN thin-film strain gauges, $\Delta R/\Delta t = \pm$ 6ppm/h. this implies that the temporal stability is good.

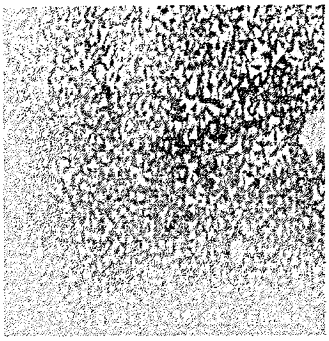
Fig. 5 shows I/V/T characteristics of CrN thin-films deposited in N_2 rate of 8 sccm and annealed at heat temperature of 300℃ and heattime of 48 hr. The resistance is held constant during the test. This phenomenon is in agreement with a metallic conduction mechanism. The high resistivity and the negative TCR values of CrN thin-films indicate that the conduction electron mean free path is very small.[15] It is believed that the high scatter in this type of material is caused by a large amount of disorder due to the amorphous structure of these CrN thin-films. The metallic conduction mechanism indicates the existence of a continuous metallic phase.

3-2. Physical properties

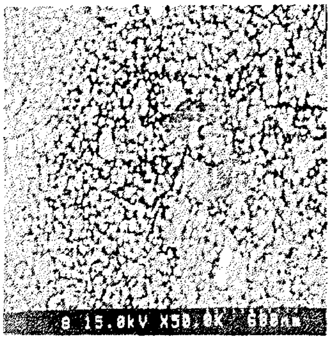
Fig. 6 shows SEM micrographs of CrN thin-films in annealing temperature range of 100~300℃, when N_2 rate is 8 sccm. In the temperature rang of 100~200℃, there were no variations, and at 300℃ crystal grain was made by increasing annealing temperature. And the border of particles was remarkable. The station was unstable electronically, but the gaps seemed to be adhered closely structurally. Consequently,



(a)



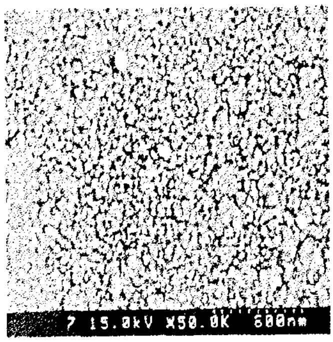
(b)



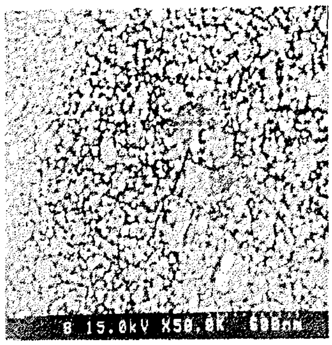
(c)

Fig. 6. SEM micrographs of CrN thin-films in annealing temperature (a) 100℃ (b) 200℃ (c) 300℃(N_2 rate : 8 sccm, annealing time : 48 hr).

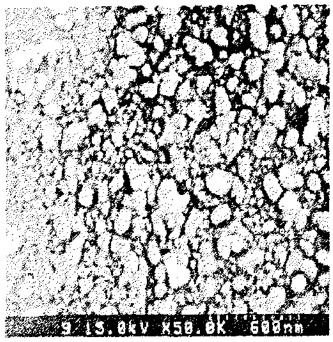
electrical resistivity of CrN thin-films and TCR values got stable values, and the physical and electrical characteristics of CrN thin-film was improved by annealing process.



(a)



(b)



(c)

Fig. 7. SEM micrographs of CrN thin-films in annealing time (a) 100℃ (b) 200℃ (c) 300℃(N_2 rate : 8 sccm, annealing temperature : 300℃).

Fig. 7 shows SEM micrographs of CrN thin-films according to annealing time in N_2 rate of 8 sccm and at annealing temperature of 300℃. The more annealing time increased, the border of particles was clearer. It was unstable electrically, but structurally, the gaps were adhered closely. And crystal grain got grower, it was conglomerated. Any islands were not made even in 300℃ and at 72 hr.

Fig. 8 shows XRD patterns of CrN thin-film according to annealing conditions, in which N_2 rate is 8 sccm. The peak values presented crystal of Chromium, it could not get high peak values by nitrification. As annealing temperature and times increased, the peak value had no high variations. The metal phase got smaller, and the material of nitride was made. It seems to show keeping metal phase and mixtured phase of amorphous a amorphous structure.

3-3. Piezoresitive properties

Fig. 9 shows variations of longitudinal gauge factor of CrN thin-film strain gauges according to annealing conditions. As annealing temperature and times increased, gauge factor kept regularly without high variations. The more N_2 rate increased, the more gauge factor of CrN thin-film strain gauges increased. It seems to not give many effects in sensitivity of strain gauges by annealing.

Fig. 10 shows response characteristics of longitudinal gauge factor according to stress of CrN thin-film strain gauges, in which have N_2 rate of 8 sccm and annealing conditions of 300℃ and 48 hr. A longitudinal gauge factor of 11.17 is obtained for this conditions. This value is slightly higher than the theoretical predictions for a piezoresistive metallic thin-film.(16) A high linearity in the piezoresistive behaviour is observed. This characteristics are suitable in a pressure sensing element. Under optimum deposition and annealing conditions, CrN thin-film strain gauges were changed variation rates of resistance almost linearly according to the supply stress of external

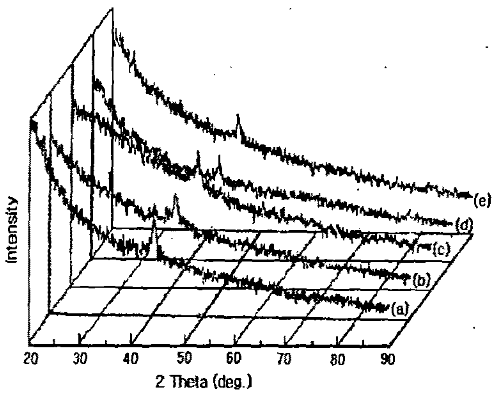


Fig. 8. XRD patterns of CrN thin-films in annealing condition (a) 100℃, 48 hr (b) 200℃, 48 hr (c) 300℃, 24 hr (d) 300℃, 48 hr (e) 300℃, 72 hr

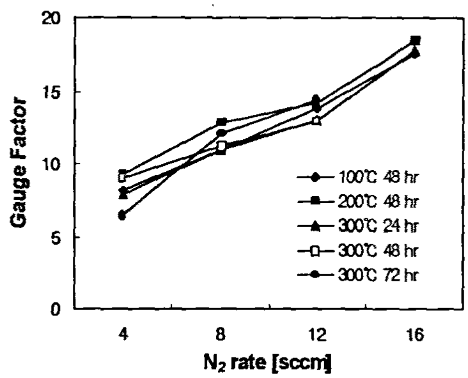


Fig. 9. Variations of gauge factor according to annealing condition of CrN thin-film strain gauges(heat temperature : 100~ 300℃, heat times : 24~72 hr).

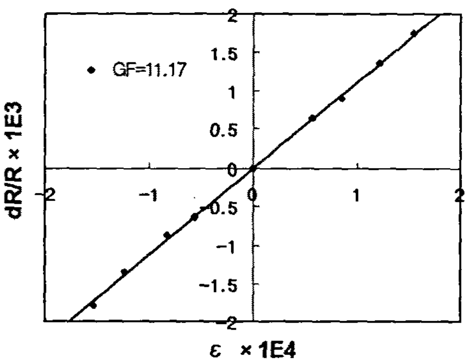


Fig. 10. Response characteristics of longitudinal according to stress of CrN thin-film strain gauges(N_2 rate : 8 sccm, annealing condition : 300℃, 48 hr).

4. Conclusions

The physical, electrical and piezoresitive characteristics of CrN thin-films on silicon substrates for use as strain gauges were studied. The CrN thin-films were deposited using by DC reactive magnetron sputtering in an argon-nitrogen atmosphere(Ar-(5~25%)N_2). The sputterimg and annealing conditions have been defined in order to optimize the piezoresitive properties of the sensing element. Optimum conditions of CrN thin-film strain gauges were thickness of 3500Å and annealing conditions of 300℃ and 48 hr, and N_2 rate of 8 sccm. CrN thin-films for strain gauges were obtained electrical resistivity of 1147.65 $\mu\Omega$cm, TCR = -186 ppm/℃ and longitudinal gauge factor of 11.17 at optiumum conditions. A metallic conduction mechanism has been identified in the deposited CrN thin-films. These properties of CrN thin-film strain gauges are very useful application as mechnical sensors.

5. Reference

[1] S. K. Clark and K. D. Wise: IEEE Trans. Electron Devices ED-26 (1979) 1887.

[2] S. C. Kim and K. D. Wise: IEEE Trans. Electron Devices ED-30 (1983) 802.

[3] P. Kayser, J. C. Godefroy and L. Leca: Sensors and Actuators A 37 (1993) 328.

[4] I. Obieta and F. J. Gracia: Sensor and Actuators 41 (1994) 521.

[5] I. Ayerdi, E. Castano, A. Gracia, F. J. Gracia: Sensor and Actuator A 46 (1995) 218.

[6] K. Rajanna, S. Mohan, M. M. Nayak, N. Gunasekaran and A. E. Muthunayagam: Trans. Electron Devices 40 (1993) 521.

[7] K. Rajanna and S. Mohan: Sensor and Actuators A 24 (1990) 35.

[8] W. Hongye, L. Kun, A. Zhichou, W. Xu and H. Xun: Sensor and Actuators 35 (1993) 265.

[9] S. Sampath and K.V. Ramanaiah: Thin Solid Films 137 (1986) 199.

[10] H. Konishi, T. Suzuki and M. Utsunomiya: Tech. Digest of the 9th sensor symposium (1990) 149.

[11] Y. Onuma, K. Kamimura and Y. Homma: Sensors and Actuators 13 (1988) 71.

[12] Y. Onuma, K. Kamimura, Y. Nagura, C. H. Yi and M. Kiuchi: Sensors and Materials 2 (1991) 207.

[13] R. Okojie, A. Ned and A. Kurtz: Sensors and Actuators A 66 (1998) 200.

[14] I. Ayerdi, E. Castano, A. Gracia and F. J. Gracia: Sensor and Actuator A 41 (1994) 435.

[15] Y. Tanaka, T. Ikeda, M. Kelly: Thin Solid Film 240 (1991) 238.

[16] A. Garicia-Alonso, J. Garcia, E. Castano, I. Obieta and F. J. Garcia: Sensor and Actuator A 37 (1993) 784.