



ISSN: 0067-2904

## Synthesis and Investigation of the Structure and Optical Properties of Nano-Ni-Cr Films

Jinan H. Awadh

Department of Physics, College of Science, Al Nahrain University, Baghdad, Iraq

Received: 23/4/2019

Accepted: 27/3/2020

### Abstract

The thermal evaporation technique was used to prepare the Ni-Cr films with a thickness of 200 nm and a rate of deposition ( $r_d$ ) of 0.22nm/Sec. The annealing was performed at 373 and 473 K. The structural and optical analyses of the grown layers were achieved and XRD patterns showed amorphous structure transferred to polycrystalline for film annealed at 373 and 473 K. AFM analysis showed that the surface of Ni-Cr films is homogenous and the average roughness, optical energy gap and absorption coefficient were increased with increasing annealing temperature ( $T_a$ ).

**Keywords:** NiCr thin film, annealing temperature, structural properties optical properties

### دراسة الخصائص التركيبية والبصرية لأغشية Ni-Cr النانوية

جنان حسين عوض

قسم الفيزياء، كلية العلوم، جامعة النهرين، بغداد، العراق

### الخلاصة

حضرت أغشية Ni-Cr بطريقة التبخير الحراري بسلك 200 nm معدل الترسيب (0.22nm/sec) كدالة لدرجات الحرارة التلدين عند (373 و 473 K) درست الخصائص البصرية والتركيبية للأغشية المحضرة. بينت فحوصات XRD وجود التركيب العشوائي للغشاء عند RT ولوحظ زيادة درجة التبلور مع زيادة درجة حرارة، اظهرت نتائج AFM زيادة في التجانس ومعدل الخشونة مع ازدياد درجة حرارة التلدين كما بينت النتائج البصرية زيادة في فجوة الطاقة ومعامل الامتصاص للأغشية المحضرة مع ازدياد درجات حرارة التلدين

### Introduction

In the recent years, many research groups studied the physical properties of Ni-Cr films using different deposition techniques, because of their usages in various microelectronic applications such as strain gauge, fusible links, type- $\pi$  attenuators, potentiometers, thin-film resistors, read-only memories, and humidity sensors [1-5]. NiCr alloy is one of the highly important materials because of its low temperature coefficient of resistance, high electrical resistivity, relatively large resistivity and outstanding thermal long-term stability [2, 6]. NiCr thin films can be produced on a wide variety of substrates for the deposition of Ni-Cr alloys, such as stainless steel, silicon wafer, glass ceramic, and polymers like polyimide [7]. Ni-Cr alloys on the above mentioned substrates have been widely used as a sensor or chip resistor for common integrated circuits [7]. Physical and chemical properties of NiCr thin films depend on the formation conditions used in the deposition environment [5]. Ni-C films have been deposited by using sputtering, PLD and chemical method [8, 9]

\*Email: Jinanph1987@gmail.com

In this paper, the dependence of structure, morphology and optical characteristics of NiCr films on annealing temperature is investigated.

### Experimental Part

NiCr films were deposited on the glass substrate by thermal evaporation technique in a unit vacuum (Edwards 306A). The evaporation was achieved under vacuum pressure of  $10^{-5}$  Torr at room temperature. The annealing was performed under vacuum at  $10^{-2}$  mbar with temperatures of 373K and 473K and annealing time of around 60 minutes. The structural properties were studied by X-ray diffraction (XRD) (PANalytical). Atomic Force Microscopy (AFM, AA2000 Nanoscope III Digital Instruments) was used to study the topography of the deposited films. The optical properties were studied by UV- spectrophotometer (UV-1601C).

### Results and discussion

#### X-Ray Diffraction

XRD was carried out to identify the Ni-Cr thin film phase present in the film. From fig.(1.a), we can observe that the Ni-Cr thin film before annealing was of an amorphous structure with no apparent crystalline phases. Similar results were reported by a previous work [6, 9]. After the annealing process, Ni-Cr was converted to a polycrystalline phase at (111) in  $2\theta$  (44.51 and 44.45) for films annealed at 373 and 473 K, respectively, as shown in Table-1. These results are in agreement with those of Bizhouet *et al.* [10]. The NiCr film growth was accompanied by an oxidation process. NiCr oxide was observed by comparing with ASTM data (PDF #210596) for NiCr-oxide. This behavior suggests that the annealing temperature has an influence on the improvement of Ni-Cr films

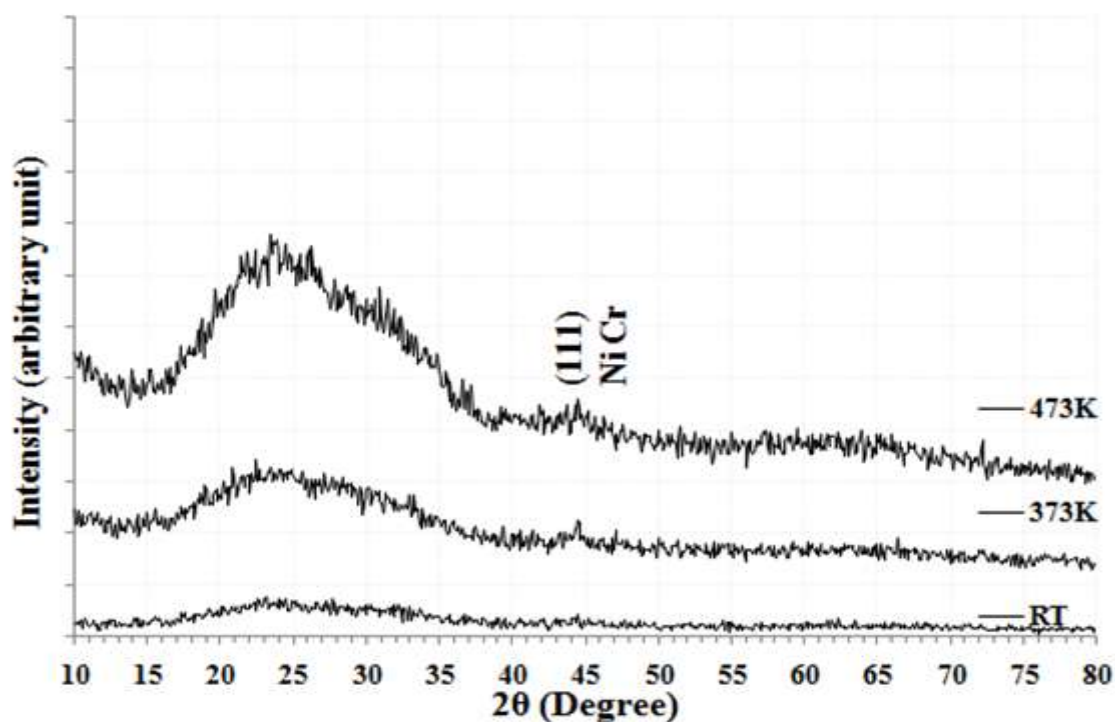


Figure 1-XRD spectrum for NiCr films with different annealing temperatures .

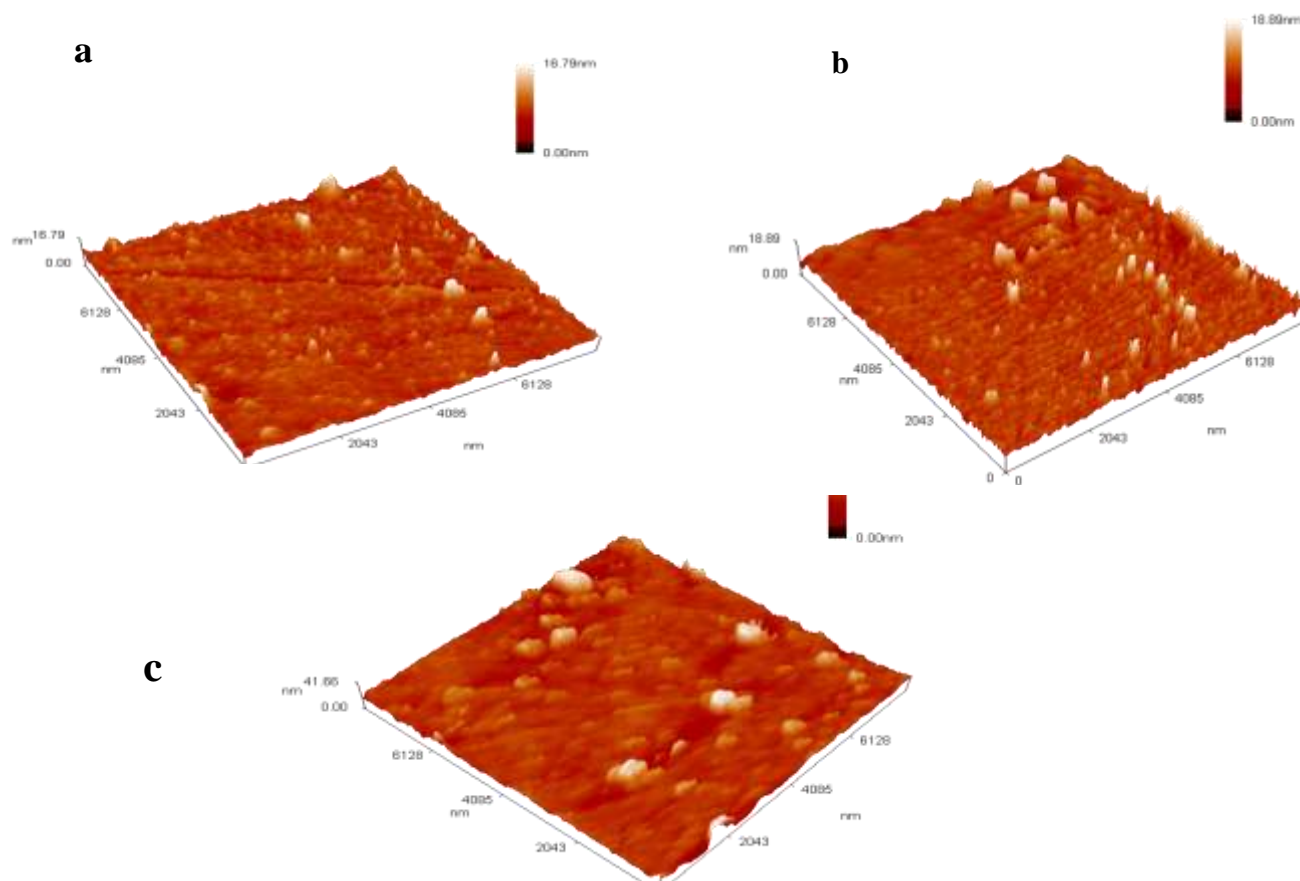
Table 1-XRD results for NiCr oxide thin films for difference  $T_a$ .

Sample	$2\theta$ Exp. (Deg.)	FWHM Exp. (Deg.)	$d_{hkl}$ Exp.(Å)	D (nm)	hkl	Card No.
RT	Amorphous					
373K	44.5151	1.8459	2.0337	4.7	(111)	96-901-1598
473K	44.4508	1.7624	2.0365	4.9	(111)	96-901-1598

### 3.2 Atomic Force Microscopy (AFM) Analysis

The morphological characteristics of NiCr -oxide thin films were studied. AFM was used to observe the nanostructure of NiCr thin films. Fig. (2) (a-b-c) shows the topography of NiCr thin films grown

by thermal evaporation technique on the glass substrate with different annealing temperatures of 373 K and 473 K. This figure shows that the NiCr films have a uniform surface. The average roughness was increased from 0.812 nm at RT to 2.28 nm at 473 K. The root mean square was increased from 1.16 nm at RT to 3.54 nm at 473K, as shown in Table-2. This indicates that the increase in annealing temperature leads to a reduction in the density of state and grain boundary [10]. This behavior leads to increasing the grain size, as shown in the x-ray diffraction where the grain size increased from 4.7 to 4.9 nm when the annealing temperature increased from 373 to 474 K. AFM analysis enhanced the results of x-ray diffraction measurement.



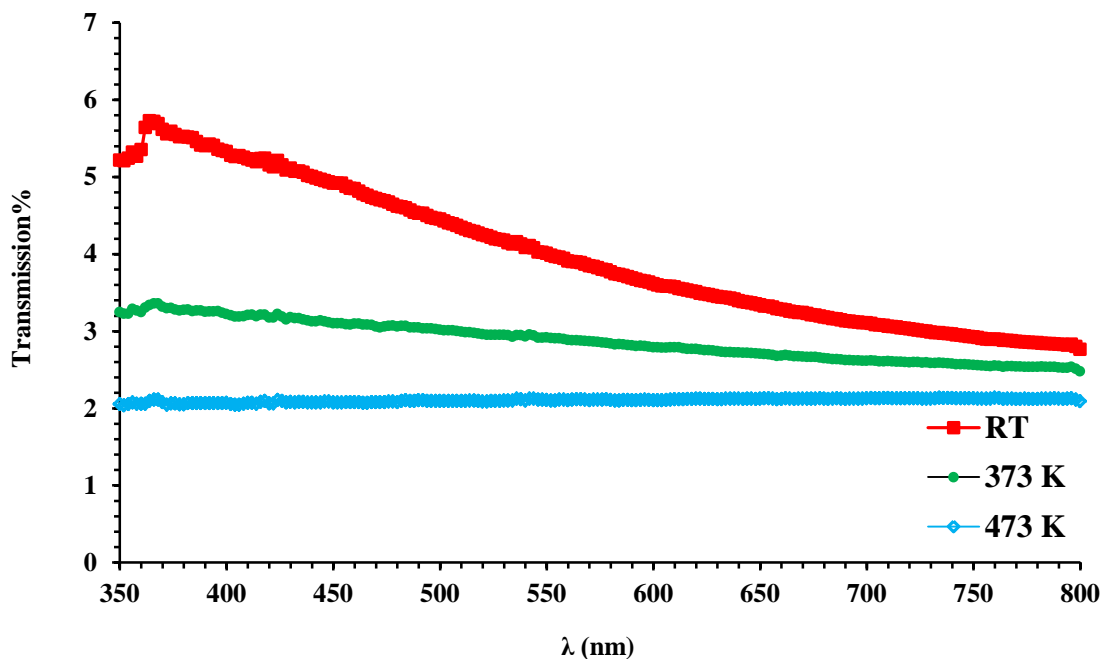
**Figure 2**-AFM analysis of NiCr-oxid thin films (a) 300K, (b) 373K and (c) 473 K.

**Table 2**-The average roughness and its r.m.s of NiCr-oxid thin films at RT and different  $T_a$ .

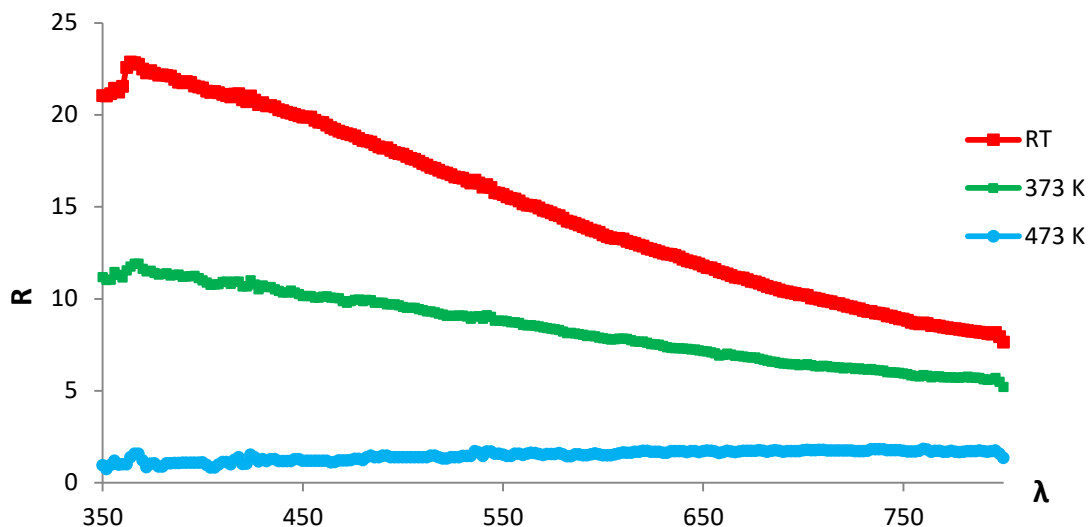
$T_a$ K	Average roughness (nm)	Root mean square (nm)
RT	0.812	1.16
373	0.998	1.47
473	2.28	3.54

### 3.2 Optical properties

NiCr-oxide thin films deposited at room temperature has a metallic color change to gray through the annealing process. Figure-3 shows the transmission as a function of wavelength for different annealing temperatures. We observe from this figure that the transmission was decreasing with increasing the annealing temperature and wavelength. NiCr films prepared at room temperature had a high reflection compared with the one annealed at 473, as shown in Figure-4. The interpretation of this behavior may be associated with improvement of the surface of NiCr-oxid films which becomes smooth with increasing annealing temperature

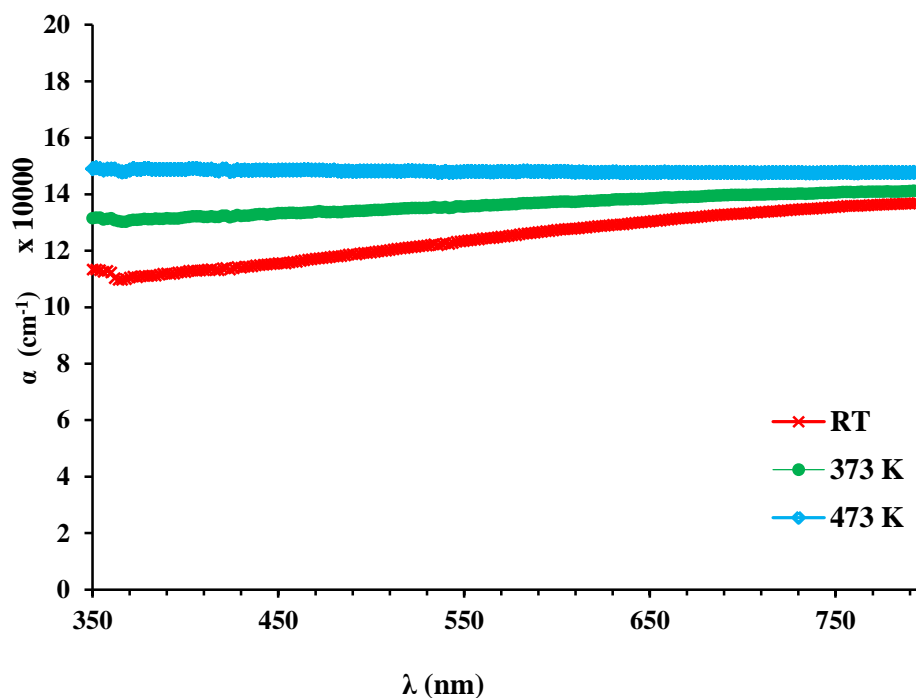


**Figure 3-**Optical Transmission of NiCr thin films at RT and difference Ta.



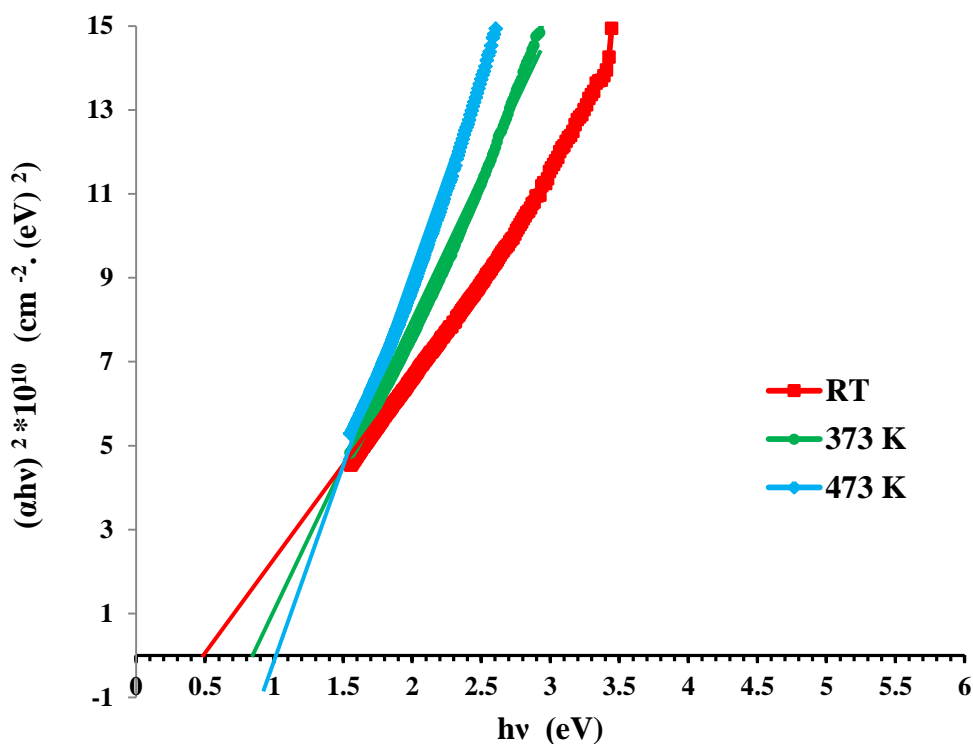
**Figure 4-**Optical reflection of NiCr-oxid thin films at RT and different Ta.

The absorption coefficient ( $\alpha$ ) properties as a function of wavelength are shown in Figure-5. It is clear from this figure that the absorption coefficient of NiCr-oxide films at RT and 373 was increased with increasing wave length, but decreased for films annealed at 473. This behavior is due to the fact that the annealing process leads to the oxidation of the films and the formation of clusters as NiO and Cr<sub>2</sub>O<sub>3</sub> at high Ta. A similar behavior of thin films was also reported earlier [11].



**Figure 5-** Absorption coefficient ( $\alpha$ ) of NiCr-oxid thin films at RT and different Ta.

The optical energy gap of the as-deposited NiCr-oxide films was determined from the extrapolated energy intercept and calculated to be 0.47 eV, which is much higher than that of bulk NiCr. The band gap energy remained at 0.81 and 1 eV for the films annealed at 373 and 473 K, respectively, as shown in Figure-6 and Table-3). This result supports the XRD, AFM and absorption coefficient results and proves that we obtained NiCr-oxide films at 473K.



**Figure 6-**Optical energy gap ( $E_{go}$ ) of NiCr-oxid thin films at RT and different Ta.

**Table 3-**( $E_g$ ) and ( $\alpha$ )for  $\lambda$ , 350 and 750 nm for NiCr-oxid thin films.

Film	T <sub>a</sub> K	E <sub>g</sub> (eV)	$\alpha$ 350nm	$\alpha$ 750nm
NiCr	RT	0.47	11.32 x 10 <sup>4</sup>	13.52 x 10 <sup>4</sup>
	373	0.83	13.14 x 10 <sup>4</sup>	14.05 x 10 <sup>4</sup>
	473	1	14.89 x 10 <sup>4</sup>	14.76 10 <sup>4</sup>

#### 4. Conclusions

This study investigated the structure, morphology and optical properties of NiCr-oxid (50-50%) thin films on glass substrate at different annealing temperatures. X-ray diffraction of the deposited films showed an amorphous structure and polycrystalline nanostructure for films annealed at 373 and 473 K. This growth was accompanied by an oxidation process of NiCr-oxid. AFM measurements showed that the NiCr-oxid films have a uniform surface. The average roughness and root mean square were increased with increasing the annealing temperature, because of the grain size which affects the grain boundary. Heat treatments resulted in increasing the optical band gap, the absorption coefficient and reflection, whereas the transmission was decreased with increasing annealing temperature.

#### Acknowledgments

Special thanks to the Faculty of Science, Department of Physics, thin films laboratory university of Baghdad for preparing the samples, as well as to physic department College of Science, Al-Nahrain university for their support

#### ORCID

Jinan H. Awadh <https://orcid.org/0000-0002-3592-1489>

#### References

- Epling, W., Mount, C. and Hoflund, G. **1997**. Study of a polycrystalline Ni/Cr alloy V. Hydrogen-atom exposure, *Thin Solid Films*, **304**: 273-277.
- Kazi, I., Wild, P., Moore, T., Sayer, M. **2006**. Characterization of sputtered nichrome(Ni-Cr 80/20 wt.%) films for strain gauge application, *Thin Solid Films*, **515**: 2602-2606.
- Pitschke, W., Brückner, W. **1998**. Phase formation process of sputtered NiCr(37:63) thin films, *Fresenius J Anal Chem*, **361**: 608-609.
- Belic, L., Pozun, K. and Remskar, M. **1998**. AES, AFM and TEM studies of NiCr thin films for capacitive humidity sensors, *Thin Solid Films*, **317**: 173-177.
- Petrovic, S., Bundaleski, N., Radovic, M., Ristic, Z., Gligoric, G., Perusko, D. and Zec, S. **2006**. Structure and surface composition of NiCr sputtered thin films *Science of Sintering*, **38**: 155-160.
- Danismanand, M. and Cansever N. **2010**. Effect of Cr content on mechanical and electrical properties of Ni-Cr thin films *Journal of Alloys and Compounds*, **493**: 649-653
- Lai, L., Zeng, W., Fua, X., Sun, R. and Du., R. **2012** Annealing effect on the electrical properties and microstructure of embedded Ni-Cr thin film resistor, *Journal of Alloys and Compounds*, **538**: 125-130
- Brossard, S., Munroe, P. R., Tran, A. T. T. and Hyland, M. M. **2010**. Study of the microstructure of NiCr splats plasma sprayed on to stainless steel substrates by TEM. *Surface and Coatings Technology*, **204**(9-10): 1608-1615.
- Zhou, X., Gu, D., Ding, Z. and Jiang, Y. **2019**. A multilayer structure with high Vis-absorption based on ultrathin NiCr film. In *9th International Symposium on Advanced Optical Manufacturing and Testing Technologies: Micro-and Nano-Optics, Catenary Optics, and Subwavelength Electromagnetics* (Vol. 10840, p. 108401E). *International Society for Optics and Photonics*.
- Bizhou, S., Liping, P., Xuemin, W., Jianjun, W. and Weidong, W. **2015**. Morphology Structure and Electrical Properties of NiCr Thin Film Grown on the Substrate of Silicon Prepared by Magnetron Sputtering, *Journal of Wuhan University of Technology-Mater. Sci. Ed.* 30380-385
- Hong, K., Han Kim, J., Chang, K. and Kwon, J. **2018**. The role of Cr on oxide formation in Ni-Cr alloys: A theoretical study, *Computational Materials Science*, **142**: 185-191.