Electrical properties of pure NiO and NiO:Au thin films prepared by using pulsed laser deposition

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Abstract

The electrical properties of pure NiO and NiO:Au Films which are deposited on glass substrate with various dopant concentrations (1wt.%, 2wt%, 3wt.% and 4wt.%) at room temperature 450 C^{o} annealing temperature will be presented. The results of the hall effect showed that all the films were p-type. The Hall mobility decreases while both carrier concentration and conductivity increases with the increasing of annealing temperatures and doping percentage, Thus, indicating the behavior of semiconductor, and also the D.C conductivity from which the activation energy decrease with the doping concentration increase and transport mechanism of the charge carriers can be estimated.

Key words

NiO:Au, thin films, Pulsed laser deposition.

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الخواص الكهربائية للاغشية الرقيقة لاوكسيد النيكل النقي والمشوب بالذهب المحضرة باستخدام ترسيب الليزر النبضي

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الخلاصة

الخواص الكهربائية للاغشية الرقيقة لاوكسيد النيكل النقي والمشوب بالذهب المرسبة على الزجاج بتراكيز تشويب مختلفه (1wt.%, 2wt%, 3wt.% and 4wt.%) بدرجة حرارة الغرفة ودرجة حرارة التلدين 450 ℃. نتائج تاثير هول بينت ان كل الافلام P- type. تحركية هول تقل بينما كل من تركيز الحاملات والتوصيلية تزداد مع زيادة درجة حرارة التلدين ونسبة التشويب، مما يدل على سلوك اشباة الموصلات. من خلال توصيلية ال D.C فان طاقة التنشيط تقل مع زيادة تركيز التشويب ويمكن حساب الية النقل لحاملات الشحنة.

Introduction

Nickel oxide (NiO) is the most exhaustively investigated transition metal oxide. It is a NaCl type antiferromagnetic oxide semiconductor. It offers promising candidature for many applications such as solar thermal absorber [1], catalyst for O_2 evolution [2], photoelectrolysis [3] and electrochromic device [4]. NiO is also a well-studied material as the positive electrode in batteries [5]. Pure stoichiometric NiO crystals are perfect insulators. Several efforts have been made to explain the insulating behavior of NiO. Appreciable conductivity can be achieved in NiO by creating Ni vacancies or substituting Li for Ni at Ni sites [6]. Gold is a soft, yellow metal with the highest ductility and malleability of all the elements. Pulsed laser deposition (PLD) is a very important and powerful technique for the growth of thin films of complex materials. It consists of three major parts, laser, vacuum system and chamber [7].

Experimental procedure

The pulsed laser deposition experiment is carried out inside a vacuum chamber generally at (10^{-3} Torr) vacuum conditions, at low pressure of a background gas for specific cases of oxides and nitrides. Photograph of the set-up of laser deposition chamber, as shown in Fig. 1, which shows the arrangement of the system includes the target and substrate holders inside the chamber with respect to the laser beam. The focused Nd:YAG SHG Q-switching laser beam coming through a window is incident on the target surface making an angle of 45° with it. The substrate is placed in front of the target with its surface parallel to that of the target. Sufficient gap is kept between the target and the substrate so that the substrate holder does not obstruct the incident laser beam. Modification of the deposition technique is done by many investigators from time to time with the aim of obtaining better quality films by this process. These include rotation of the target, heating the substrate, positioning of the substrate with respect to target.

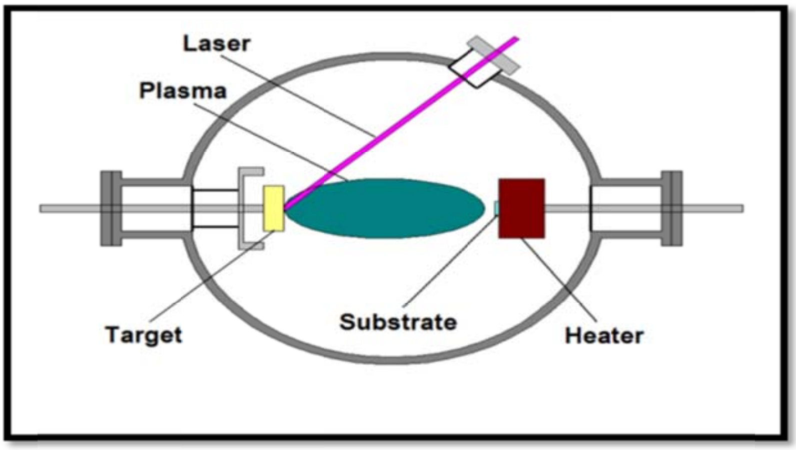


Fig.1: Schematic diagram of PLD system [8].

Result and discussion

1. D.C electrical conductivity

The variation of electrical conductivity as a function of temperature for pure NiO and NiO:Au thin films with different dopant concentrations is displayed in Figs. 2 and 3. It show two slopes from which two values of activation energy can be calculated.

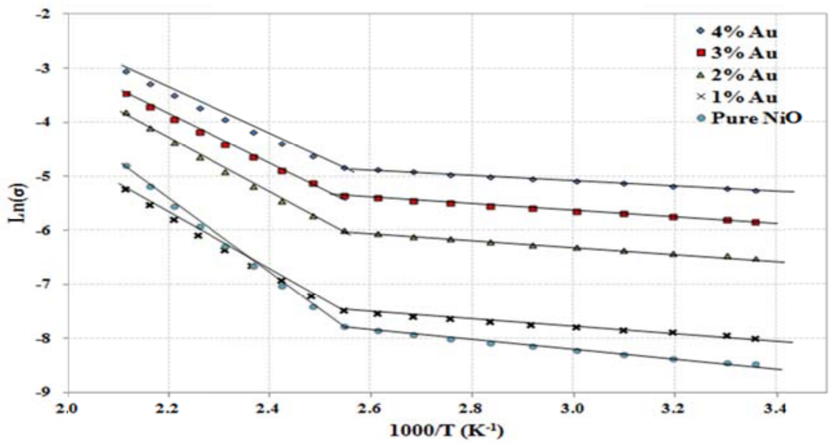


Fig. 2: Lnσ versus 1000/T for pure NiO and NiO: Au thin films at different doping concentrations and R.T.

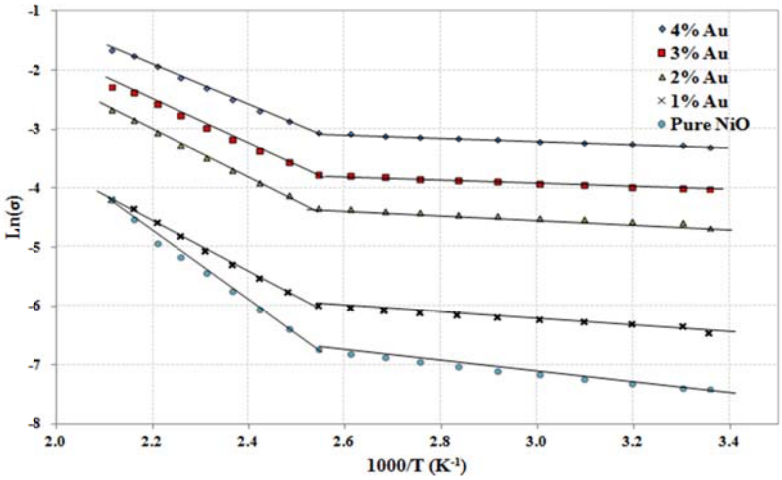


Fig. 3: Lnσ versus 1000/T for pure NiO and NiO: Au thin films at different doping concentrations and 450 ℃ annealing temperature.

Electrical conductivity in polycrystalline thin films of NiO, can be explained through a variety of mechanisms. Extrinsic impurities, can give rise to impurity conduction phenomena at low temperatures, and band conduction near and above room temperature. In addition, the grain boundaries act as charge-carrier traps, leading to band bending and potential barriers all around the grains, thus, affecting the electrical conductivity of the films [9]. In the last case, when the semiconductor is heavily doped, or at low temperatures, the dominating band conduction current is due to thermal-field emission of carriers through the barrier, while in lightly doped material or at high temperatures, thermionic emission over the barrier dominates[10]. These processes are taken into consideration in the analysis of the electrical transport properties of our samples described in the present work. The conductivity of NiO:Au films decreased as the value of 1/T increases at higher temperature, suggesting a thermally activated conduction in this temperature range. Electrical conductivity of NiO:Au films increases from (3.41×10^{-4} to 5.29×10^{-3}) $(\Omega.\text{cm})^{-1}$. The increase in electrical conductivity brought in by the Au doping. The conductivity value of all samples is shown in Table 1 and 2.

Tables 1 and 2 exhibit the electrical coefficients for samples prepared at R.T. and 450 ℃ annealing temperature respectively.

Table 1: The values of the E_{a1} and E_{a2} at R.T.

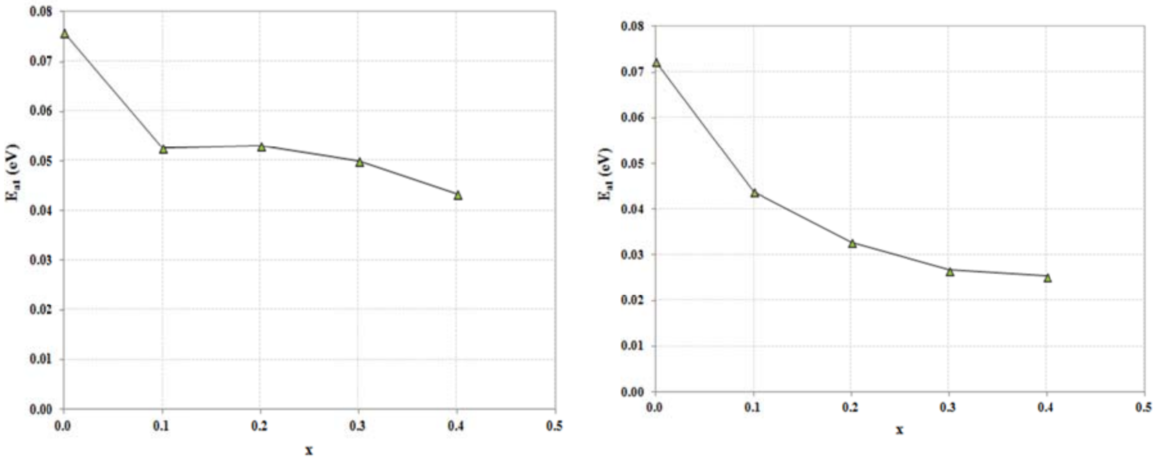
X	E_{a1} (eV)	Range (K)	E_{a2} (eV)	Range (K)	σRT $(\Omega^{-1}.\text{cm}^{-1})$
pure	0.0759	298-393	2.4533	393-472	2.10E-04
0.1	0.053	298-393	0.450	393-473	3.41E-04
0.2	0.053	298-393	0.438	393-474	1.49E-03
0.3	0.050	298-393	0.378	393-475	2.93E-03
0.4	0.043	298-393	0.355	393-476	5.29E-03

Table 2: The values of the E_{a1} and E_{a2} at 450 ^{o}C annealing temperature.

X	E_{a1} (eV)	Range (K)	E_{a2} (eV)	Range (K)	σRT (Ω^{-1}.cm^{-1})
pure	0.0724	298-393	0.4939	393-472	6.08E-04
0.1	0.044	298-393	0.369	393-473	1.56E-03
0.2	0.033	298-393	0.334	393-474	9.42E-03
0.3	0.027	298-393	0.306	393-475	1.82E-02
0.4	0.025	298-393	0.288	393-476	3.71E-02

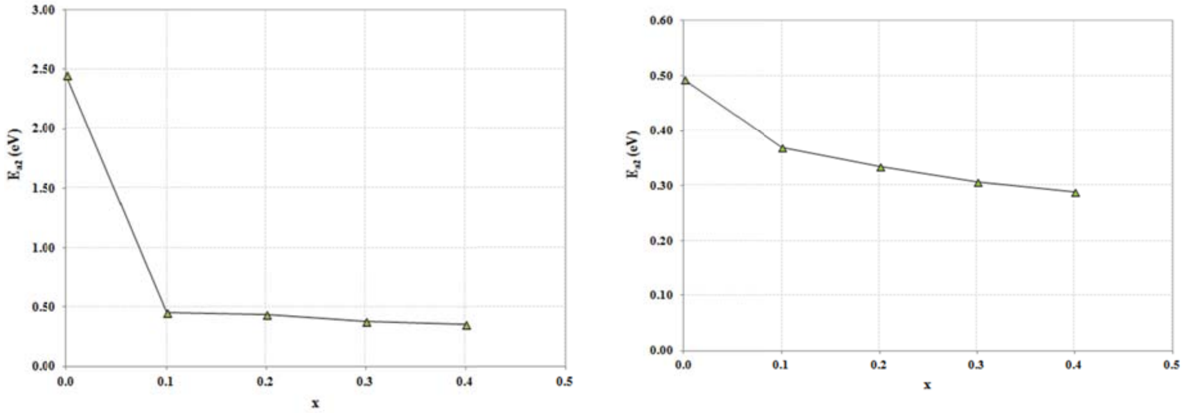
2. Activation energy

The electrical activation energy of pure NiO and NiO:Au thin films that were calculated from lnσ versus (1000/T) plots at different Au-doping concentrations. The activation energy depends on the donor carrier concentration and the impurity energy levels. An increase in donor carrier concentration brings the Fermi level up in the energy gap and results in the decrease of activation energy. This result agrees with other research [11] as shown in Figs. 4 and 5.



a **b**

Fig. 4: E_{a1} versus different doping concentrations for pure NiO and NiO:Au thin films (a) at R.T., (b) at 450 ^{o}C annealing temperature.



a **b**

Fig. 5: E_{a2} versus different doping concentrations for pure NiO and NiO:Au films (a) at R.T. , (b) at 450^{o} C annealing temperature.

3. Hall Effect

The Hall measurements showed that the pure NiO and NiO:Au (different doping concentrations of Au) thin films deposited on glass substrate at R.T. and 450 ℃ annealing temperature are (P- type) semiconductors. The Hall parameters for the P- type films which include conductivity σ, Hall coefficient R_H, carrier concentration n_H, and mobility μ_H are shown in Tables 3 and 4. The data show increased carrier concentration by increasing Au dopant concentration. Such behavior is expected as a result of the substitutional doping of Au^{+3} at the Ni^{+2} site creating one extra free carrier in the process. As the doping level is increased, more dopant atoms occupy lattice sites of nickel atoms resulting in more charge carriers. Thus, the conductivity increases with increasing dopant concentration [12].

The mobilityμ_H of the NiO:Au films decreases with increasing dopant concentration. In this case, a high dopant concentration will lead to ionized impurity scattering from the substitutional donors and scattering from the interstitials [13], resulting a decrease in the mobility of the NiO:Au films. The overall variation in n_H and μ_H can be understood in terms of the position of Au in the NiO lattice. A decrease in μ_H at dopant concentrations may be due to the interstitial occupancy of Au in the NiO lattice. The presence of Au at interstitial sites and grain boundaries in the form of oxide, besides decreasing grain size, may act as scattering centres and result in a decrease in the observed mobility at dopant concentration. From this result, one may conclude that adding a small amount of Au in NiO material enhances the conductivity of the NiO because the conductivity of the Au is higher than NiO.

Table 3: Electrical properties of pure NiO and NiO:Au thin films prepared at different Au dopant concentrations at R.T.

Sample	$\sigma_{R.T}(\Omega.cm)^{-1}$	$R_H(cm^3/C)$	$n\ (cm^{-3})\times10^{12}$	type	$\mu_H\ (cm^2/V.sec)$
pure	4.17E-06	1.56E+07	0.4	p	65.057
0.1	3.35E-04	9.45E+04	66.1	p	31.658
0.2	2.39E-03	3.00E+03	2083.3	p	7.170
0.3	4.69E-03	5.00E+02	12500.0	p	2.345
0.4	8.46E-03	7.15E+01	87412.6	p	0.605

Table 4: Electrical properties of pure NiO and NiO:Au thin films prepared at different Au dopant concentrations at 450° C annealing temperature.

Sample	$\sigma(\Omega.cm)^{-1}$	$R_H(cm^3/C)$	$n\ (cm^{-3})*10^{12}$	type	$\mu_H\ (cm^2/V.sec)$
pure	1.94E-05	5.32E+06	1.2	p	103.194
0.1	7.50E-04	3.50E+04	178.6	p	26.250
0.2	5.18E-03	1.20E+03	5208.3	p	6.216
0.3	1.13E-02	2.00E+02	31250.0	p	2.260
0.4	2.00E-02	2.20E+01	284090.9	p	0.440

Figs. 6-8 show the relationship of conductivity, carrier concentration, and mobility versus ratio doping concentration at two different temperatures. It is seen from these Figures that conductivity (σ) and carrier concentration (n_H) increase exponentially with increasing Au concentration. Whereas Fig. 7 shows inverse relationship between mobility and dopant concentration.

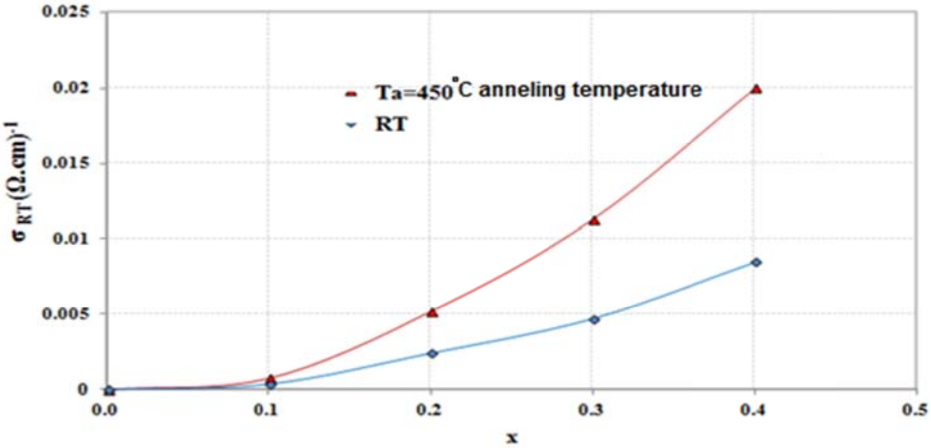


Fig.6: Conductivity (σ) versus different ratio doping concentrations NiO:Au thin films at two different deposition temperature(R.T. and 450^{o}C annealing temperature).

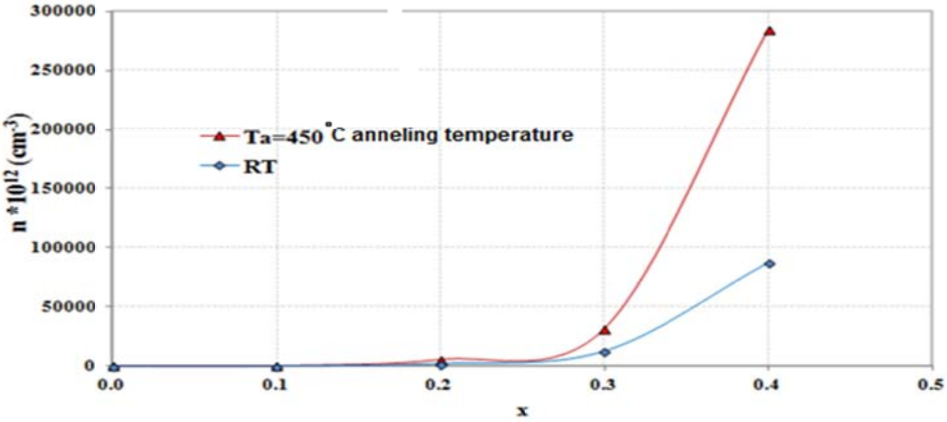


Fig.7: Carrier concentration versus different ratio doping concentrations NiO:Au thin films at two different deposition temperatures(R.T. and 450 ^{o}C annealing temperature).

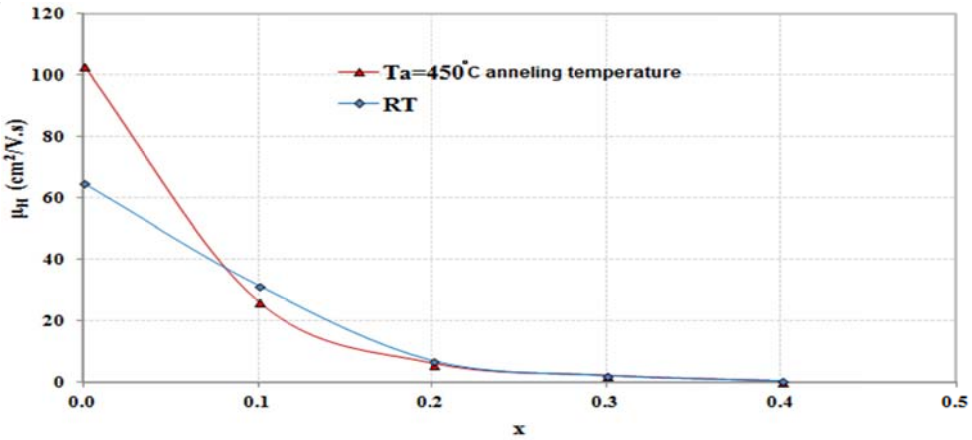


Fig.8: Mobility μ_H versus different ratio doping concentrations NiO:Au thin films at two different deposition temperatures (R.T. and 450 C^o annealing temperature).

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