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Effects of substrate temperature on the degradation of RF sputtered NiO properties

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ABSTRACT

Nickel oxide (NiO) film was grown on Si (100) substrate through RF sputtering of NiO target in Ar plasma at various temperatures ranging from room temperature (RT) to 300 °C. The structural study revealed (200) oriented NiO diffraction peak at RT and at 100 °C, however, by increasing the substrate temperature to 200 °C, intensity of (200) NiO diffraction peak was decreased. At higher temperature (300 °C), crystalline quality of NiO was significantly degraded and the film was decomposed into Ni. The EDS results confirmed an increase of Ni atomic percentage with increase of the substrate temperature. The surface morphology of NiO film at RT and at 100 °C displayed cubical like grains that were changed into elongated grains with further increase of the substrate temperature. The UV–vis reflectance measurements of NiO revealed a small decrease in its band gap by increasing the substrate temperature to 200 °C.

1. Introduction

NiO is one of the most important metal-oxide that has attracted a considerable attention as a promising candidate for use in optoelectronic industry. This is basically due to its inherent potential properties which make it a useful material in electrochromic devices, ultraviolet photodetectors and gas sensors [1–3]. Growth of NiO has been widely investigated by using various techniques like spin coating, chemical bath deposition, spray pyrolysis and RF/DC magnetron sputtering [4–7]. Among these, the magnetron sputtering technique has an advantage of being depositing NiO film on a large area of a substrate with a controlled thickness at low cost. Nandy et al. investigated the growth of NiO in reactive Ar-O_2 environment to deposit NiO film on glass substrate and found that by increasing the oxygen partial pressure, the crystalline quality of NiO is improved. Lei et al. studied the effects of substrate temperature on the growth of NiO film. The results indicated that by increasing the temperature to 400 °C, the structural quality of NiO is enhanced. Similarly, various other studies revealed that by controlling the deposition parameters such as RF power, substrate temperature, and oxygen flow rate, NiO films with better crystalline quality can be obtained [8–10]. The literature shows that in most of the previous studies on the growth of NiO through magnetron sputtering, pure Ni target has been sputtered in reactive oxygen environment to deposit NiO film. In this work, we use NiO target instead of reactive oxygen to deposit NiO film on the Si(100) surface at different temperatures in pure Ar environment.

2. Experimental work

The NiO film was deposited on Si (100) substrate through RF sputtering technique. After RCA cleaning, the Si samples were fixed inside RF sputtering chamber and the chamber was evacuated to ~1.5×10^{-5} mbar. The NiO target was used as a source material for the deposition of NiO film. In the beginning, the NiO target was sputtered at 200 W in 12 sccm Ar environment at RT. The working pressure during the film deposition was ~4.26×10^{-3} mbar. Afterwards, the substrate temperature was increased to 100 °C, 200 °C and 300 °C to deposit NiO film at higher temperatures under similar deposition conditions. After the sputter deposition, the samples were taken out for various characterizations. The structural characterization of NiO films was made through X-ray Diffractometer and surface morphology was studied by using FE-SEM. The elemental analysis was conducted through EDS whereas the optical characterizations of the samples were made through UV–vis reflectance spectroscopy. The results obtained on the properties of NiO at different temperatures were compared with each other to analyze the substrate temperature effects.

3. Results and discussion

The XRD patterns of NiO film at different substrate temperatures are shown in Fig. 1(a–c). The XRD of NiO at RT shows the formation of (200) oriented NiO peak at 43.4°. When the substrate temperature is increased to 100 °C, intensity of the (200) NiO diffraction peak is also

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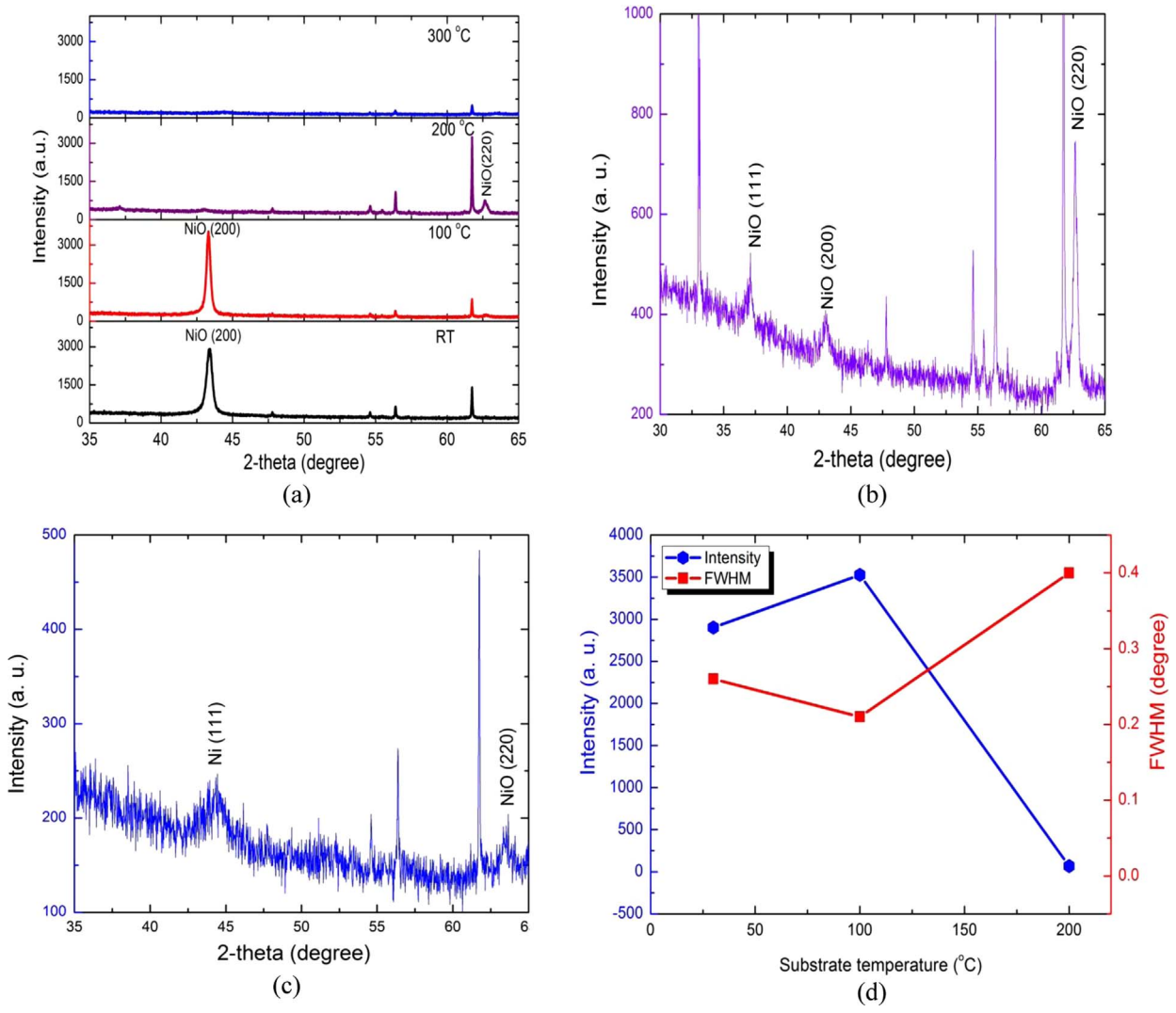

Fig. 1. (a–d) (a) X-ray diffraction patterns of NiO at different substrate temperatures. (b) Magnified X-ray diffraction spectrum of NiO at 200 °C. (c) Magnified X-ray diffraction spectrum of NiO at 300 °C. (d) Variations in intensity and FWHM of NiO with substrate temperature.

Table 1
Structural parameters of NiO films at different substrate temperature.

Substrate temperature	a (Å)	D (nm)	ε (%)	$\delta \times 10^{14}/m^2$
RT	4.1650	33.75	−0.289	8.77
100 °C	4.1740	41.29	−0.074	5.94
200 °C	4.1926	20.38	0.371	24.07
300 °C	–	–	–	–

increased that is followed by a decrease in its FWHM value which indicates an improvement in the crystalline quality of NiO film. With increase of the substrate temperature to 200 °C, intensity of (200) NiO diffraction peak is considerably decreased that is accompanied by an increase of its FWHM value. However, a small diffraction peak of NiO appears along (220) plane that shows a change in its preferred orientation from (200) to (220) plane. By further increasing the substrate temperature to 300 °C, the crystalline quality of NiO is completely degraded and NiO peak along (200) plane was disappeared, instead, diffraction peak of Ni along (111) plane was formed at 44.4°. This shows that by increasing the substrate temperature above 100 °C, the structural quality of NiO film declines. For clearer view of the degradation of structural quality of NiO at 200 °C and at 300 °C, the magnified XRD patterns of NiO at these temperatures are shown in Fig. 1(b–c). The variations in intensities and FWHM of NiO diffraction peaks along (200) plane at different substrate temperatures are shown in Fig. 1(d). The figure shows that the intensity of (200) NiO peak decreases whereas its FWHM increases by increasing the substrate temperature above 100 °C. The structural parameters such as lattice constant 'a' crystallite size 'D', lattice strain 'ε' and dislocation density 'δ' were calculated by using following equations [11,12] and their values are given in Table 1.

$$\frac{1}{d^2} = \frac{h^2 + k^2 + l^2}{a^2} \quad (1)$$

$$D = \frac{0.9\lambda}{\beta \cos\theta} \quad (2)$$

$$\varepsilon = \frac{a - a_o}{a_o} \quad (3)$$

$$\delta = \frac{1}{D^2} \quad (4)$$

The crystallite size 'D' of NiO film was increased with increase of the substrate temperature to 100 °C, however, with further increase of the substrate temperature to 200 °C, the crystallite size was significantly decreased. Similarly, the microstrain calculated inside the NiO film was