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Properties of nickel films growth by radio frequency magnetron sputtering at elevated substrate temperatures

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ABSTRACT

Pure nickel (Ni) thin films of thicknesses of 100 nm were deposited on glass substrates by radio frequency magnetron sputtering at a power of 100 W and at various substrate temperatures i.e., room temperature, 100, 200, and 300 °C. The crystalline structure, surface topography, surface morphology, electrical resistivity, and optical properties of the deposited films were studied. The properties of the Ni films could be controlled by altering the substrate temperature. Specifically, the films featured a face-centered cubic crystalline structure with predominant (111) crystallite orientation at all the substrate temperatures employed, as observed from the X-ray diffraction analysis. Films deposited at substrate temperatures greater than 200 °C additionally displayed crystalline (200) and (220) diffraction peaks. The surface morphology analysis revealed that the grain size of the Ni thin films increased with increasing substrate temperatures employed. This increase was accompanied with a decrease in the resistivity of the Ni films. The surface roughness of the films increased with increasing substrate temperatures employed, as observed from the atomic force microscopy analysis.

1. Introduction

Nickel films have attracted growing interest owing to their wide range of applications such as in the metallization of ferrites, decorative features, corrosion-resistant coatings, and selective absorbers in solar thermal energy conversion [1]. Furthermore, Ni is a promising material for application in microelectronic devices because of its low electrical resistivity and high oxidation resistance [1]. Particularly, Ni possesses optical properties that are ideal for replacement of silver toward the preparation of cheaper mirrors for domestic use [2,3] as well as for use in solar thermal and solar thermionic applications—such properties allow for the fabrication of films that can exhibit excellent absorption over the entire solar spectrum [4]. Moreover, for such applications, the smooth surface, fine grain, and homogenous structure of Ni thin films are of critical importance.

Many deposition techniques have been used to study the properties of deposited Ni films. Becht et al. [5] investigated the morphology of Ni films grown by chemical vapor deposition. In other reports, Rhee and Yang [6] and Maghazeii et al. [7] studied the properties of Ni films deposited by electron beam evaporation. Furthermore, it was demonstrated that magnetron sputtering techniques i.e., direct-current (DC) magnetron sputtering and radio frequency (RF) magnetron sputtering could control over the sputtering conditions [8–13] and produce very high purity films owing to their clean environmentally friendly closed systems [14]. For instances, Yi et al. [15] and Priyadarshini et al. [16] reported on the structural, magnetic, and magnetoresistance properties, and morphology of Ni films deposited using DC magnetron sputtering. In contrast, the application of RF magnetron deposition for fabricating Ni films with different substrate temperatures is unexplored.

The focus of the present work is to study the effects of substrate temperature on the properties of nickel films deposited by RF magnetron sputtering. The structural and optical properties, surface topology, surface morphology, and electrical resistivity were studied for the films deposited at room temperature, 100, 200, and 300 °C.

2. Experimental details

2.1. Film preparation

Ni films were deposited on clean glass substrates by RF magnetron sputtering using a Ni target (99% purity) with a diameter of 76 mm and thickness of 5 mm. Commercial Ar (99.9% purity) was used as the sputtering gas. The sputtering chamber was evacuated to 1.33×10^{-4} Pa by a turbomolecular pump. To realize a uniform film thickness (i.e., 100 nm), the substrates were rotated at 10 rpm during film deposition. The film thickness during deposition was monitored with an Inficon Model SQM-160 quartz rate/thickness meter. During sputtering, the working pressure and RF power were maintained at 5.33×10^{-1} Pa and 100 W, respectively. The Ar gas flow was controlled

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by a mass flow controller, which was set at a flow rate of 20 sccm. Prior to deposition, the Ni target was pre-sputtered in Ar atmosphere for 10 min to remove any oxide layers. Additionally, the glass substrates were cleaned in an ultrasonic bath with ethanol for 15 min, rinsed with distilled water, dried by blowing dry nitrogen gas of 99.9% purity, and mechanically clamped to the substrate holder in the chamber. Films were deposited on substrates either at room temperature or heated at various temperatures of 100, 200, and 300 °C.

2.2. Film characterization

The structural property of the prepared films was studied by X-ray diffraction (XRD) on a Shimadzu XRD-7000. The XRD patterns were obtained using monochromatic high-intensity Cu Kα ($\lambda = 1.54056$ Å) radiation operated at 40 kV and 30 mA. The patterns were recorded at a scanning rate of 2°/min in the range of $2\theta = 40$–80° and an incident angle of 1.0°. The surface topography of the films was studied by an atomic force microscopy (AFM) on a commercial Nanos (CSM Instruments, Peseux, Switzerland). The measurements were performed in the contact tapping mode. In this mode, the load force on the cantilever was maintained at 2.0 nN, and hence a constant force was applied to the samples. The surface morphology of the films was analyzed by field-emission scanning electron microscopy (FE-SEM) using a JEOL JSM-7610F field-emission scanning electron microscope. Prior to the FE-SEM analysis, the samples were plasma-cleaned to remove organic contamination on the film surfaces. Electrical resistivity measurements of the films were performed using a four-point probe system (Scientific Equipment Roorkee, Roorkee, India) at room temperature with a constant applied current of 8.18 mA. Four probes were placed in contact with the films and positioned in a straight line at equal spacings. To reduce anisotropy defects, the measurements were done by taking the current and voltage values along the sample length, normal to the sample length, and in hexagonal directions. The optical properties of these films were determined using a CARY 5000 UV–Vis-NIR spectrophotometer (Agilent Technologies) in the wavelength range of 300–2500 nm for the optical (total) transmittance measurements, and 300–800 nm for the optical reflectance and diffused transmittance (haze) measurements. The scanning rate was 240 nm/min.

3. Results and discussion

3.1. Structural properties of the deposited films

Fig. 1 shows the XRD diffraction patterns of the Ni films deposited at different substrate temperatures at a constant RF power of 100 W. As observed, the film deposited at room temperature seemed to display some amorphous features. As the substrate temperature increased to 300 °C, the films displayed better crystallinity as the XRD patterns revealed the growth of grain size. Specifically, an XRD peak with predominant (111) crystallite orientation at 44.5° was detected at all deposition temperatures employed, and can be used to estimate the grain size of the films by the Scherrer formula. The estimated grain size was found to increase from 11 to 16 nm with increasing in substrate temperature from room temperature to 300 °C. Two additional diffraction peaks at 51.8° and 76.4°, corresponding to the (200) and (220) planes, respectively, were detected when the substrate temperature was greater than 200 °C. The three indexed peaks could be correlated to the face-centered cubic (*fcc*) structure, as confirmed with the standard ICDD2010: card no. 00-004-0850. A similar XRD pattern was reported by Maruyama and Tago [1] who prepared Ni films deposited using chemical vapor deposition. The films were composed of crystallites exhibiting a predominant cubic structure, and films deposited at temperatures below 200 °C displayed prominent peaks of the (111) plane, which corresponds to the natural growth plane for a face-centered cubic metal such as nickel. The two additional (200) and (220) diffraction peaks observed herein were also observed in that study [1] when a deposition temperature of 300 °C was employed. Moreover, another study [17] on the growth of crystal planes in NiO films has reported that at high substrate temperatures, the surface mobility of the Ni^{2+} and O^{2-} nuclei is low. However, as the sputtered atoms approach the substrate surface and gain more kinetic and thermal energy, mobility of the Ni atoms, O_2 atoms and NiO clusters on the substrate increases with increasing substrate temperatures [17]. Consequently, this may favor the growth of some simple crystal planes.

3.2. Surface topography of the deposited films

Fig. 2 shows representative AFM images of the deposited Ni films. The images were acquired using a scan area of 2 × 2 μm². To study the surface topographies of the Ni films from the AFM images, it is assumed that the dark regions represent areas with zero or near zero height value along the Z scale (positive direction) and the bright regions represent higher areas i.e. the top of bulging grains. The images show different grain growth in shape and size at different deposition temperatures. As observed from Fig. 2a, the Ni film deposited at room temperature featured a smooth surface with a uniform distribution of fine grains on its surface. The root-mean-square surface roughness (RMS) of the deposited Ni film was 1.69 nm, whereas those of the films deposited at 100, 200, and

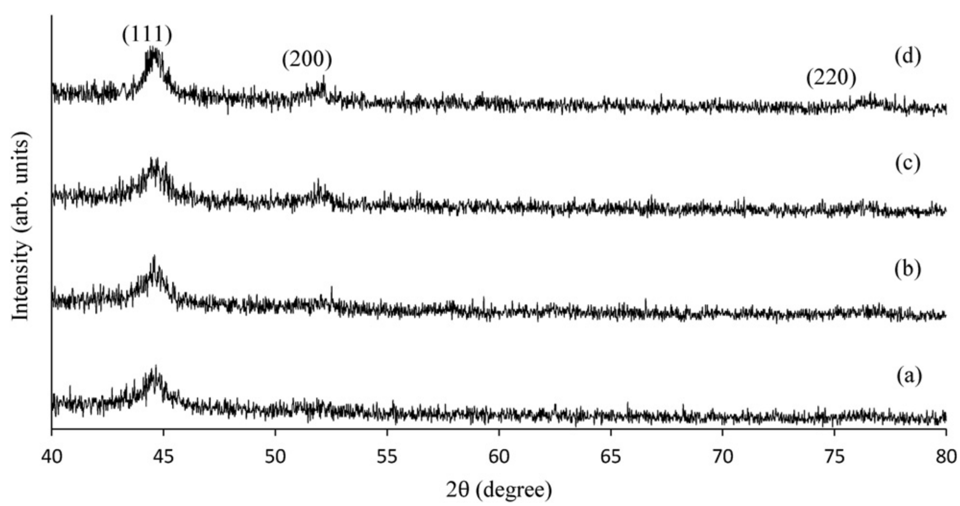

Fig. 1. XRD patterns of the Ni films obtained at different deposition temperatures (a) room temperature, (b) 100, (c) 200, and (d) 300 °C.