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# Nickel oxide films by thermal annealing of ion-beam-sputtered Ni: structure and electro-optical properties

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**Abstract**

Nickel oxide films were prepared by thermal annealing of Ni deposited by ion beam sputtering on Si (or glass) substrates. The annealing was carried out in a laboratory furnace open to air at temperatures 350 °C – 500 °C with annealing time 1 - 7 h (1-h step). For as-deposited Ni films the sheet resistance $R_S$ was found to be 8.39 Ω/□ and no significant XRD diffraction peaks were observed. The thermal annealing resulted in significant changes in composition and electrical, structural and optical properties. The oxidation process led to a rapid growth of $R_S$ up to $10^9$ Ω/□, appearance of the optical absorption edge for oxidized Ni, and the formation of a polycrystalline NiO structure with the main NiO (111) diffraction peak. At 350 °C the annealing yielded 3-stage behavior of the sheet resistance due to limited oxidation during short time annealing. Longer processing times (> 3 h) were necessary to successfully oxidize the deposited Ni film, after 1 h annealing the oxygen content (analyzed by nuclear resonance analysis) showed a significantly lower concentration within the depth of a sample; more uniform composition was found after prolonged annealing. XPS analysis showed the formation of a significant amount of nickel hydroxide at the surface. It was confirmed by ERDA. The optical properties were studied by Photothermal Deflection Spectroscopy (PDS). The data correlate with the 3-stage behavior of sheet resistance at 350 °C, suggesting lower oxidation during short-term annealing, while transparent nickel oxide films were formed during longer annealing and at higher temperatures. Based on analysis of the obtained experimental data (from measurement of the sheet resistance, XRD diffraction and optical absorption spectra), the temperature of 400 °C was found to be optimal for the formation of the fully oxidized NiO films.

Keywords: NiO, ion beam sputtering, thermal annealing, nuclear analytical methods, optical properties

## 1. Introduction

Nickel oxide is one of the most extensively studied transition-metal oxide systems because of its interesting properties, e.g., chemical stability, good crystallinity, wide spectral range of transparency, controllable transmittance for incident visible light and thermoelectric behavior [1].

These properties make nickel oxide attractive for a wide range of possible applications, e.g., photovoltaic solar cells [2], UV-detectors [3], electrochromic devices [4], non-volatile resistive random