**UNIVERSITI TEKNOLOGI MARA**

# FABRICATION AND CHARACTERIZATION OF SOLUTION-IMMERSION GROWN NICKEL OXIDE NANOSTRUCTURE-BASED FILMS FOR HUMIDITY SENSOR APPLICATION

**NORFARARIYANTI BINTI PARIMON**

**PhD**

**August 2021**

# AUTHOR'S DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Teknologi MARA. It is original and is the results of my own work, unless otherwise indicated or acknowledged as referenced work. This thesis has not been submitted to any other academic institution or non-academic institution for any degree or qualification.

I, hereby, acknowledge that I have been supplied with the Academic Rules and Regulations for Post Graduate, Universiti Teknologi MARA, regulating the conduct of my study and research.

| | | |
|---|---|---|
| Name of Student | : | Norfarariyanti binti Parimon |
| Student I.D. No. | : | 2017343701 |
| Programme | : | Doctor of Philosophy (Electrical Engineering) – EE950 |
| Faculty | : | Electrical Engineering |
| Thesis Title | : | Fabrication and Characterization of Solution-Immersion Grown Nickel Oxide Nanostructure-Based Films for Humidity Sensor Application |
| Signature of Student | : | ……………………………………………….. |
| Date | : | August 2021 |

# ABSTRACT

Humidity sensors are essential devices for use in controlling environmental moisture in sectors that include electronics, medical, food processing, agricultural, and automotive industries. Apart from that, humidity sensors are also useful in household usages, especially in electrical appliances. Due to the high demand for humidity sensors, low cost, facile synthesis, and excellent performance humidity sensors are required. In this study, resistive humidity sensors from p-type nickel oxide (NiO) nanostructure-based films were fabricated using a facile sol-gel spin coating and immersion method. This p-type metal oxide was considered an alternative because of its distinctive properties, and it has rarely been intensively studied, especially in humidity sensing applications. The NiO seed layer was introduced to act as catalysts for the growth of NiO nanostructures on the glass substrates, replacing conventional indium-doped tin oxide or fluorine-doped tin oxide layers. These sensors were fabricated based on several approaches such as undoped (UD) NiO, manganese (Mn)-doped (MD) NiO, and a novel zinc oxide (ZnO)/NiO nanocomposite. The properties of the sensors were characterized based on the morphological, structural, optical, electrical, and humidity sensing via field emission scanning electron microscopy, field emission transmission electron microscopy, energy-dispersive X-ray spectroscopy, Brunauer-Emmett-Teller, X-ray diffraction, ultraviolet-visible spectroscopy, two-probe current-voltage, Hall effect, and humidity sensor measurement. The results showed that the highly porous NiO nanosheet/nanocarnation-flower-like (NSNC) structure, which was immersed for 2 h and annealed at 500 °C, exhibited the highest sensitivity of 257 due to the high conductivity and its good crystal parameters. The stability of this sample was seen to be lower at higher operating temperatures despite its increased sensitivity. The sensitivity of the NiO NSNC-based humidity sensor was further enhanced to 292 by doping with 1 atomic percent (at.%) Mn (1.0MD) and annealed at 400 °C. The increment in humidity sensitivity of the 1.0MD film is caused by an increased surface area compared to the UD NiO. The UD and MD NiO surface areas were recorded at 5.17 $m^2/g$ and 11.6 $m^2/g$, respectively. The humidity sensing performance further improved to a sensitivity of 312 with a novel ZnO/NiO nanocomposite configuration. This nanocomposite-based heterostructure film offers a heterogeneous interface and synergistic effect to capture more water molecules during sensing activity. Nevertheless, the sensitivity and stability are worsened when this sample is exposed to high operating temperatures. Throughout this study, it was found that the performance of the NiO-based humidity sensor, particularly the sensor developed with the novel ZnO/NiO nanocomposite demonstrates the highest sensitivity value.

# ACKNOWLEDGEMENT


Alhamdulillah, all praise belongs to Allah, Lord of the worlds, the Most Gracious, the Most Merciful. Thank you for the strength and good health that made this journey bearable.

First and foremost, I would like to express my highest appreciation to my supervisor, Assoc. Prof. Ir. Ts. Dr. Mohamad Hafiz bin Mamat for his continuous advice, encouragement, guidance, and excellent supervision throughout this research journey. Indeed, no words can describe how grateful I am for the opportunity to join his research team, and words are not enough to express my gratitude to him. My extended appreciation also to my co-supervisors, Assoc. Prof. Ir. Ts. Dr. Ahmad Sabirin bin Zoolfakar and Ts. Dr. Mohd Firdaus bin Malek for their undivided support and valuable contributions. Also, many thanks to Prof. Engr. Dr. Mohamad Rusop bin Mahmood for his indirectly contributed to this research. Besides, I would also like to thank my co-authors, who are also my supervisors during the student attachment programme in Chennai, India, Prof. Dr. I. B. Shameem Banu, and Assoc. Prof. Dr. N. Vasimalai. Thank you for the valuable experience and knowledge given throughout my stay there for two months, from 2nd December 2019 to 1st February 2020. Not to be forgotten, Prof. Tetsuo Soga from Nagoya Institute of Technology (NITech) for his hospitality and knowledge sharing during my JSPS Sakura Science Programme in Nagoya, Japan, in November 2018.

Furthermore, I would like to thank my dear research colleagues, who made my research journey lively, colourful, cheerful, and memorable. They are Rohanieza, Najwa Ezira, Wan Rosmaria, Al-Hadi, Dr. Syakirin, Sofea, Hasif, Ir. Ts. Musa, Fadzleen, Amir, Dr. Aimi Bazilah, Izaidi, and Dr. Amierah. My appreciation also goes to the technical staffs at NANO-ElecTronic Centre (NET), NANO-SciTech Lab (NST), and Faculty of Applied Sciences of UiTM, especially Mr. Suhaimi, Mr. Azwan, Mr. Asrul, Mr. Azlan, Mrs. Nurul Wahida, Mr. Salifairus, and Mr. Abul for their kind assistance during the measurement and characterization of my research.

I would also like to thank Universiti Teknologi MARA and the School of Electrical Engineering, particularly for the opportunity given to conduct my research here. Not forgettable to the Ministry of Higher Education for the SLAB scholarship and my employer, Universiti Malaysia Sabah, for the financial support. Also, the financial backing of the REI (600-IRMI/REI 5/3 (017/2018)) and FRGS (600-IRMI/FRGS 5/3 (044/2019)) grants facilitated my research to run smoothly.

Special dedication goes to my beloved mother, father, brother, Faridah Abd Razak, Parimon Azar, and Mej. Mohd Norfarizal Parimon to support, encourage, understand, and unconditional love for years. It was their dream that made me successful in this journey. Finally, I would like to express my deepest appreciation to my beloved husband, Mej. Mohd Shawal Idris, and three little heroes, Dzaffrin Iskandar, Dzaffran Izzuddin, and Dzariff Imtiyaz, for being with me in difficult times. I am very grateful to have them around me whenever I need help and encouragement. They are my source of strength to face the twists and turns of challenges throughout this study. Thank you for your endless love.

# TABLE OF CONTENTS