CHAPTER I
INTRODUCTION

1.1 Background and motivation

The development of advanced materials has greatly influenced modern technology. Metal oxide thin films, especially bismuth ferrite ($BiFeO_3$ or BFO), have gained a lot of interest because of their unique properties and potential uses in electronic and spintronic devices. BFO is a multiferroic material, which means it shows more than one ferroic order parameter, like ferroelectricity and antiferromagnetism. This rare mix of properties makes BFO a great choice for advanced multifunctional devices, as it can control magnetic states with electric fields and vice versa (Achenbach et al., 2006; Michel et al., 1969; Smolenskii, 1959). The properties of BFO thin films are well known. A key finding was the significant ferroelectric polarization of about 60 $\mu C/cm^2$ in BFO epitaxial thin films grown on $SrRuO_3$ (SRO)/$SrTiO_3$ (STO) substrates, which is about 15 times higher than that of bulk BFO This finding opened new opportunities for using BFO in memory devices and spintronic applications, showing its potential in quantum effects and nanoscale device fabrication. As materials are reduced to the nanoscale, quantum effects become more noticeable, leading to unique and useful physical phenomena (Connerade, 2009). Controlling the size and shape of nanostructures is important for using these quantum effects. Advanced nanomanufacturing techniques, such as focused ion beam (FIB) and electron beam lithography (EBL), help create precise nanostructures needed for devices that use quantum mechanical properties (Hong et al., 2009; Kim et al., 2018).

This research aims to explore and use the unique properties of BFO thin films at the nanoscale. By understanding and manipulating these properties, we hope to improve the performance and function of electronic devices. The research aims to connect basic material science with practical applications, leading to more efficient, reliable, and multifunctional next-generation technologies. Besides the scientific and technological reasons, there is a practical need to develop good methods for making and studying these nanostructures. Techniques like FIB and EBL are not only important for creating precise nanostructures but also for studying how size, shape, and material properties interact at the nanoscale. By improving these techniques and understanding their impact on material properties, we can better control the functionality of the devices. Additionally, integrating nanostructures into devices requires understanding their electrical and mechanical properties. For instance, the piezoelectric and ferroelectric properties of BFO thin films can be greatly affected by factors like crystallinity, grain size, and domain structure. Techniques such as Piezoresponse Force Microscopy (PFM) offer valuable insights into these properties, allowing for detailed characterization and optimization of nanostructures (Kalinin et al., 2002).

In this work, this research focuses on exploring quantum effects in metal oxide thin films, particularly BFO, at the nanoscale and developing advanced nanomanufacturing techniques to control the size and shape of these nanostructures. This work aims to improve the performance and function of future electronic devices, contributing to technological advancement in various fields. We studied the ferroelectric property of BFO with different substrate Nb-doped $SrTiO_3$ (NSTO) and Fluorine-doped Tin Oxide (FTO) glass. Together with, the different shape in nanoscale, generating the pattern by the nanomanufacturing such as FIB and EBL was investigated. The ferroelectric response of Annealed BFO/NSTO in unpattern and pattern areas and Au Nanohole array were demonstrated. Moreover, we explored the piezoresponse of the BFO/NSTO sample under UV irradiation. So, this polarization can be controlled the by UV exposure. These results are crucial for understanding how UV light influences ferroelectric properties and for creating applications in optoelectronic devices that use controlled UV exposure.

1.2 Research objectives

1) To use nanomanufacturing techniques for precision control over the size and shape of BFO nanostructures.

2) To investigate the impact of nanoscale patterning on the ferroelectric properties of BFO thin films

3) To investigate the properties of Bismuth Ferrite (BFO) thin films under light irradiation.

1.3 Outline of thesis

To help you understand the overview of this dissertation, each chapter is described below. The thesis is divided into five main chapters. Chapter I provides an introduction, outlining the background, motivation, research objectives, and the thesis structure. Chapter II offers a comprehensive literature review, discussing the structure, production, and properties of BFO thin films, along with nanopatterning methods and their effects. It also covers the dynamic and non-dynamic mechanisms affecting the films under light irradiation. Chapter III details the methodology, including substrate preparation, sample fabrication, and the equipment used, focusing on metal oxide thin films and nanoscale patterning techniques. Chapter IV presents the results and discussion, examining the crystal structure, surface morphology, and ferroelectric properties of BFO/NSTO and Au nanohole array on BFO/FTO. Finally, Chapter V concludes the thesis, summarizing the key findings and suggesting directions for future research.