Engineering of Ga_2O_3 based High-Performance Deep Ultraviolet Photodetectors using Facile Growth Techniques

A THESIS

submitted by

ASHISH KUMAR (D15047)

for the award of the degree

of

DOCTOR OF PHILOSOPHY

School of Computing and Electrical Engineering
Indian Institute of Technology Mandi, Himachal Pradesh, India-175005

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QUOTATIONS

The entire world is a family.

One is a relative, the other
stranger,
say the small minded.
The entire world is a family,
live the magnanimous.
Be detached,
be magnanimous,
lift up your mind, enjoy
the fruit of Brahmanic
freedom.

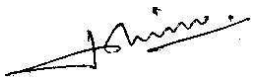
—MAHA UPANISHAD
6.71–75

DEDICATED

To My Parents, Friends, and Best Wishers.

Declaration

I hereby declare that the entire work embodied in this thesis titled **Engineering of Ga_2O_3 based High-Performance Deep Ultraviolet Photodetectors using Facile Growth Techniques** is the result of investigations carried out by me in the **School of Computing and Electrical Engineering**, Indian Institute of Technology Mandi, under the supervision of **Dr. Ankush Bag**, for the award of the degree of **Doctor of Philosophy** and that it has not been submitted elsewhere for any degree or diploma. In keeping with the general practice, due acknowledgements have been made wherever the work described is based on finding of other investigators.



Place: Mandi

Date: 30^{th} September, 2021

Ashish Kumar
School of computing and Electrical Engineering
IIT Mandi, 175005

Declaration

This is to certify that the thesis titled **Engineering of Ga_2O_3 based High-Performance Deep Ultraviolet Photodetectors using Facile Growth Techniques**, submitted by **Ashish Kumar (D15047)**, to the Indian Institute of Technology Mandi, for the award of the degree of **Doctor of Philosophy**, is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Place: Mandi

Date: 30^{th} September, 2021

Dr. Ankush Bag
Research Guide
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Ashish Kumar

ABSTRACT

KEYWORDS: deep UV photodetector, nano-flakes, electrospinning, electrospraying, nano-wires, quasi-2D, quasi-heterostructure, nano-particles, plasmonic.

In the present pandemic scenario, people are using ultra-violet (UV) lamps extensively for disinfection purposes at various places such as homes, hospitals, medical diagnosis labs, etc. Any un-intentional exposure to this UV light can be very harmful to the human body if it exceeds certain limits. The use of photodetectors is one of the ways to control the exposer limits of dangerous UV emission. The modernization of the defense sector is another area where these optoelectronics devices find their wide applications such as detecting missile plumes against the glaring background of daylight, infrared (IR) clutter, and more. UV imaging is also having critical importance for UV astronomy. Wide bandgap semiconducting materials with a relatively larger bandgap ($>$3.23 eV) are suitable for deep UV spectrum sensing. Several semiconducting materials with wide bandgap such as AlGaN, GaN, and ZnO have been proven to be suitable candidates for deep UV sensing. However, these materials require alloying and have various associated defects degrading the detector performance along with expensive fabrication technique. Despite the recent progress in other conducting transparent semiconducting oxides, β-Ga_2O_3 is a perfect candidate of deep UV photodetection with a direct and indirect bandgap of $\sim$4.9 eV and $\sim$4.85 eV, respectively along with excellent chemical, mechanical and thermal stability.

In this context, an inexpensive and scalable electrospinning technique has been opted for the synthesis of various β-Ga_2O_3-nanostructures (NSs) or nanomaterials to fabricate deep UV photodetectors (PDs). We have developed β-Ga_2O_3 nanoflakes (NFs) based deep UV photodetector with impressive photocurrent (I_{ph}) (-9.12×10^{-4} A), and dark current (I_{dark}) (4.13×10^{-8} A) along with very good responsivity (1.4×10^3

AW^{-1}) at 10 V. Moreover, the Ga_2O_3 has been alloyed with Indium (In) to increase the free carriers in the channel for enhancement of the optoelectronic properties of the PDs. The $GaInO_3$ nano-wires (NWs) based deep UV photodetector has shown remarkable responsivity ($>1.2\times10^4$ AW^{-1}) with a comparatively high I_{dark} (2.81×10^{-7} A) at 1 V bias.

However, the high dark current makes the devices a power-hungry unit even at standby operation. Therefore, to reduce the dark current, a novel technique has been employed involving quasi-heterostructure of n-Ga_2O_3/p-CuO based metal-semiconductor-metal (MSM) UV photodetector which reduced the I_{dark} (6.94×10^{-14} A) significantly with extremely high responsivity ($>6.0\times10^3$ AW^{-1}) at 5 V. However, the responsivity and I_{ph} (2.08×10^{-7} A) have decreased in comparison to the earlier works. Hence, Ga-In nanoparticles have been used with the potential plasmonic effect to further improve the photocurrent of the photodetectors. After the incorporation of the nanoparticles on top of the previous heterostructure devices, photo to dark current ratio (PDCR), and I_{ph} (1.14×10^{-5} A) have been enhanced significantly along with a very low dark current (1.03×10^{-13} A) at 5 V. Thus, all the fabricated devices have exhibited a very high photo-to-dark current ratio (PDCR), responsivity, detectivity, and external quantum efficiency as compared to the earlier state-of-the-arts leading to a significant impact on upcoming UV detector technology.

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