SOLUTION-PROCESSED ORGANIC THIN FILM TRANSISTORS FOR HYDROGEN SULFIDE SENSING APPLICATION

**Thesis submitted in partial fulfillment
for the Award of Degree**

DOCTOR OF PHILOSOPHY

BY

VARUN KUMAR SINGH

**DEPARTMENT OF ELECTRONICS ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI-221005, INDIA**

ROLL NO. 18091503

2023

CERTIFICATE

It is certified that the work contained in the thesis intitled " ***Solution-Processed Organic Thin Film Transistors for Hydrogen Sulfide Sensing Application*" by "*Varun Kumar Singh*"** has been carried out under our supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy, and SOTA for the award of Ph.D. Degree.

20.12.2023

Prof. V. N. Mishra

(Supervisor)
Department of Electronics Engineering
Indian Institute of Technology (Banaras Hindu University) Varanasi-221005 India

20/12/23

Signature of Head of Department

Department of Electronics Engineering
IIT (BHU), Varanasi, India

आचार्य व विभागाध्यक्ष/PROFESSOR & HEAD
इलेक्ट्रानिकी अभियांत्रिकी विभाग/Department of Electronics Engineering
भारतीय प्रौद्योगिकी संस्थान (का.हि.वि.)/Indian Institute of Technology (BHU)
वाराणसी/Varanasi-221005 (INDIA)

20/12/23

DECLARATION BY THE CANDIDATE

I, ***"Varun Kumar Singh"***, certify that the work embodied in this thesis is my own bona fide work and carried out by me under the supervision of ***Prof. V. N. Mishra*** *from* ***2018*** to ***2023*** at the ***Department of Electronics Engineering***, ***Indian Institute of Technology (BHU), Varanasi***. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma elsewhere. I declare that I have faithfully acknowledged and accredited to the research communities wherever their works have been cited in the accomplished of this thesis. I further declare that I have not intentionally copied any other's work, paragraphs, text, data, results, *etc.*, reported in journals, books, magazines, reports, dissertations, theses, *etc.*, or available at websites and have not included them in this thesis or cited as my own work.

Date: 20.12.2023
Place: Varanasi

Signature of the Student
Varun Kumar Singh

CERTIFICATE BY THE SUPERVISOR

It is certified that the above statement made by the student is correct to the best of my/our knowledge.

20.12.2023.

Prof. V. N. Mishra

(Supervisor)
Department of Electronics Engineering
Indian Institute of Technology (Banaras Hindu University) Varanasi-221005 India

20/12/23

Signature of Head of Department
Department of Electronics Engineering
IIT (BHU), Varanasi, India

आचार्य व विभागाध्यक्ष/PROFESSOR & HEAD
इलेक्ट्रानिकी अभियांत्रिकी विभाग/Department of Electronics Engineering
भारतीय प्रौद्योगिकी संस्थान (का.हि.वि.)/Indian Institute of Technology (BHU)
वाराणसी/Varanasi-221005 (INDIA)

20/12/23

COPYRIGHT TRANSFER

The undersigned hereby assigns to the ***Indian Institute of Technology (Banaras Hindu University), Varanasi,*** all rights under copyright that may exist in and for the above thesis submitted for the award of the ***Doctor of Philosophy***.

Date: 20.12.2023
Place: Varanasi

Signature of the Student
Varun Kumar Singh

Note: However, the author may reproduce or authorize others to reproduce material extracted verbatim from the thesis or derivative of the thesis for the author's personal use provided that the source and the Institute's copyright notice are indicated.

DEDICATED TO LORD SHIVA & SANKATMOCHANA

FOR THE SUPREMACY AND TO THE REDEEMER OF MY SOUL

DEDICATED TO MY FAMILY

FOR THEIR ENDLESS LOVE, SUPPORT, AND ENCOURAGE-
MENT

DEDICATED TO MY SUPERVISOR

FOR THEIR ENDLESS MOTIVATION, ENCOURAGEMENT, AND

TEACHING SKILL

ACKNOWLEDGMENT

I would like to express my deepest gratitude to the individuals who have contributed to the completion of this thesis. Their support, guidance, and encouragement have played a crucial role in shaping this work.

First and foremost, I am indebted to my thesis advisor, Prof. V. N. Mishra, whose expertise and insightful feedback have been invaluable throughout the research process. Your dedication to excellence and commitment to academic growth have been a constant source of inspiration.

I would also like to extend my appreciation to the members of my thesis committee, Prof. K. K. Shukla, and Dr. Amritanshu Pandey for their valuable insights and constructive criticism that have significantly enriched the quality of this thesis.

I am grateful to Central Instrument Facility (CIF) for providing the necessary resources and environment conducive to research and learning. The Department of the Electronics Engineering and CRME lab has been a supportive academic home, and I appreciate the opportunity to be a part of such a vibrant scholarly community. I would like to express my gratitude to my esteemed seniors, Dr. P. K. Sahu, Dr. Abhishek Kumar Singh, Dr. Vijaya Kumar Devarakonda, Dr. S. N. Chaudhry, Dr. Ashutosh Dikshit, Dr. Tanushree Meena, Mr. A. P. Singh, as well as my colleagues, Dr. Ankit Verma, Mr. Prashant Kumar, Mr. Dharmendra Kumar, Mr. Ravi Saini, Mr. Jogendra Singh Rana, Mr. Bharat Bhushan Upadhyay, Mrs. Shikha Singh, Mrs. Richa Barnwal, Mr. Harshit Srivastav, and Mr. Surya Pratap Singh for their invaluable support and inspiring suggestions.

Special thanks go to my family and friends for their unwavering support and understanding during the challenges of this academic journey. Your encouragement has been my source of strength. Last but not least, I extend my gratitude to all those who, directly or indirectly, have contributed to the development of this thesis. Your influence, whether through discussions, suggestions, or moral support, has made a lasting impact. This thesis is the culmination of a collaborative effort, and I am thankful to each person who has been a part of this endeavour.

Varun Kumar Singh

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Details
AFM	Atomic Force microscopy
OTFT	Organic Thin film transistor
FETs	Field-Effect Transistors
HOMO	Highest Occupied Molecular Orbital
LUMO	Lowest Unoccupied Molecular Orbital
MOS	Metal-oxide-semiconductor
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
OFETs	Organic Field-Effect Transistors
OLED	Organic Light-Emitting Diode
P3HT	Poly(3-hexylthiophene)
ppm	Part per million
ppb	Part per billion
SEM	Scanning Electron Microscopy
TEM	Transmission electron microscopy
TFT	Thin Film Transistor
UV-Vis	Ultraviolet-Visible
XRD	X-ray Diffraction

List of Symbols

Symbol	Abbreviation
E_G	Energy Bandgap
E_C	Bottom of the Conduction Band
E_V	Bottom of the Valence Band
α	Absorption Coefficient
C_{ox}	Capacitance per unit area of Insulator
CV	Capacitance-Voltage
L	Channel Length of Transistor
W	Channel Width of Transistor
R^2	Correlation Coefficient
ϵ_r	Dielectric Permittivity of SiO_2
I_{DS}	Drain to Source Current
V_{DS}	Drain to Source Voltage
E_F	Fermi Energy Level
S	Gas Response
V_{GS}	Gate to Source Voltage
μ	Mobility
t_{ox}	Oxide Gate Thickness
SS	Subthreshold Swing
V_{th}	Threshold Voltage
g_m	Transconductance

TABLE OF CONTENTS