Development of metal oxide based formaldehyde (HCHO) sensors using laser ablated nanoparticles

A Thesis submitted by

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In partial fulfilment of the requirements for the award of the degree of

Doctor of Philosophy

Indian Institute of Technology Jodhpur

Electrical Engineering

July 2023

Declaration

I hereby declare that the work presented in this Thesis titled *Development of metal oxide based formaldehyde (HCHO) sensors using laser ablated nanoparticles* submitted to the Indian Institute of Technology Jodhpur in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy, is a bonafide record of the research work carried out under the supervision of Dr Mahesh Kumar, Professor, IIT Jodhpur, Rajasthan, India and Co-Supervision of Dr. Jitendra Singh, Principal Scientist, CSIR-CEERI, Pilani, Rajasthan, India. The contents of this thesis in full or in parts, have not been submitted to, and will not be submitted by me to, any other Institute or University in India or abroad for the award of any degree or diploma.

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Certificate

This is to certify that the thesis titled *Development of metal oxide based formaldehyde (HCHO) sensors using laser ablated nanoparticles*, submitted by *Surajit Das* (P18EE202) to the Indian Institute of Technology Jodhpur for the award of the degree of *Doctor of Philosophy*, is a bonafide record of the research work done by him under our supervision. To the best of our knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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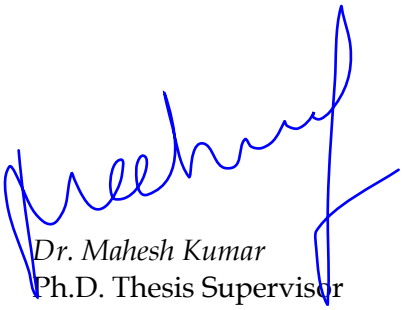

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Symbol	*Description*
θ	Angle of incident
A	Area
E_g	Bandgap energy
Φ_B	Barrier height
k	Boltzmann constant
V_{bi}	Build-in potential
ΔI	Change in current
ΔR	Change in resistance
ΔV	Change in voltage
ΔE_c	Conduction band offset
I_a or I_o	Current in air
I_g	Current in the target gas
E_c	Conduction band energy
τ_{res}	Response time
τ_{rec}	Recovery Current
W	Depletion width
q	Electron charge
G	Electron conduction
χ	Electron effinity
μ	Electron mobility
$q\,\phi_r$	Energy difference in conduction band and Fermi level
υ	Frequency
η	Ideality factor
Pi	Input power
c	Lattice constant
l	Length
Φ_m	Metal work function
T	Operating temperature
h	Plank constant
n	Power coefficient
S	Relative response
R_a	Resistance in air
R_g	Resistance in the target gas
β	Response
E_v	Valance band energy
ΔE_v	Valance band offset
V_a	Voltage in air
V_g	Voltage in the target gas
λ	Wavelength
W	Watt

Abbreviation	*Full form*
MOS	Metal Oxide Semiconductor
AFM	Atomic Force Microscopy
IR	Infra Red
CVD	Chemical Vapor Deposition
PVD	Physical Vaopr Deposition
I-V	Current-voltage
D	Dimentional
TCR	Temperature Co-efficient of Resistance
FESEM	Field emission scanning electron microscopy
VOCs	Volatile Organic Compound
FET	Field-effect transistor
IDE	Interdigitated Electrode
IoT	Internet of Things
LED	Light-emitting diode
LDL	Low detection limit
MFC	Mass flow controller
MOCVD	Metal-organic chemical vapour deposition
Mo	Molybdenum
SnO_2	Tin Oxide
ZnO	Zinc Oxide
NiO	Nickel Oxide
MoS_2	Molybdenum disulfide
NR	Nanorod
NW	Nanowire
1D	One-dimensional
PL	Photoluminescence
ppm	Parts per million
ppb	Parts per billion
RF	Radiofrequency
rGO	Reduced graphene oxide
RT	Room temperature
RH	Relative humidity
SAED	Selected area electron diffraction
SEM	Scanning electron microscopy
S	Sulfur
Sv	Sulfur vacancy
SCCM	Standard cubic centimetres per minute
TE	Thermionic emission
2D	Two-dimensional
3D	Three-dimensional
TMDCs	Transition metal di-chalcogenides
VOC	Volatile organic compound
VA	Vertically aligned
XRD	X-ray diffraction
0D	Zero-dimensional