

**LEAD-FREE FERROELECTRIC MATERIALS
SELECTION AND ENERGY HARVESTING
INVESTIGATIONS**

A THESIS

submitted by

GAURAV VATS

for the award of the degree

of

MASTER OF SCIENCE

(BY RESEARCH)



**SCHOOL OF ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY MANDI
FEBRUARY 2014**

*Dedicated to
my Teachers
and
Family*

DECLARATION

I hereby declare that the work reported in this thesis entitled “**LEAD-FREE FERROELECTRIC MATERIALS SELECTION AND ENERGY HARVESTING INVESTIGATIONS**” is entirely original. It was carried out by me under the supervision of Dr. Rahul Vaish, School of Engineering, Indian Institute of Technology, Mandi, Himachal Pradesh, India. I further declare that it has not formed the basis for the award of any degree, diploma, membership, associateship or similar titles of any University or Institution.

February 2014

Gaurav Vats

THESIS CERTIFICATE

This is to certify that the thesis titled **LEAD-FREE ERROELECTRIC MATERIALS SELECTION AND ENERGY HARVESTING INVESTIGATIONS TO IIT MANDI**, submitted by **Gaurav Vats**, to the Indian Institute of Technology Mandi, Mandi for the award of the degree of **Master of Science (Research)**, 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.

Dr. Rahul Vaish
Chairperson
School of Engineering
IIT-Mandi, Mandi
Himachal Pradesh-175001

Date:

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

PREAMBLE

1. INTRODUCTION	1-22
1.1. Introduction	2
1.2. Point Group Symmetry and Materials Classification	5
1.3. Ferroelectric Materials	6
1.4. Pyroelectric Materials and Associated Terminology	11
1.5. Piezoelectric Materials and Associated Terminology	12
1.6. Applications	15
1.6.1. Electrical Energy Storage	15
1.6.2. Electromechanical Applications	16
1.6.2.1. Electromechanical Generators	17
1.6.2.2. Vibration Energy Harvesting	18
1.6.2.3. Ultrasonic Transducer	19
1.6.3. Direct Pyroelectric Power	19
References	21
2. MATERIALS SELECTION METHODOLOGIES FOR LEAD-FREE PIEZOELECTRIC CERAMICS	23-40
2.1. Introduction	24
2.2. Materials and Methods	25
2.2.1. Modified Digital Logic (MDL)	28
2.2.2. VIKOR Method	28
2.2.3. TOPSIS Method	30
2.2.4. Pareto-Optimal Solution	31

2.2.5. Spearman's Correlation Coefficient	32
2.3. Results and Discussions	33
2.4. Conclusions	37
References	38
3. PIEZOELECTRIC MATERIAL SELECTION FOR ULTRASONIC TRANSDUCERS UNDER FUZZY ENVIRONMENT	41-54
3.1. Introduction	42
3.2. Materials and Methods	43
3.2.1. Fuzzy Logic Method	45
3.3. Results and Discussions	48
3.4. Conclusions	52
References	53
4. USER ORIENTED SELECTION OF FERROELECTRIC CERAMICS FOR TRANSDUCERS AND ELECTRICAL ENERGY STORAGE DEVICES	55-68
4.1. Introduction	56
4.2. Materials and Methods	57
4.2.1. Quality Function Deployment (QFD)	60
4.3. Results and Discussions	61
4.4. Conclusions	65
References	66

5.	SELECTION OF OPTIMAL SINTERING TEMPERATURE OF K_{0.5}Na_{0.5}NbO₃ CERAMICS FOR ELECTROMECHANICAL APPLICATIONS	69-84
5.1.	Introduction	70
5.2.	Materials and Methods	71
5.2.1.	Analytic Hierarchy Process (AHP)	72
5.2.2.	Sensitivity Analysis	73
5.3.	Results and Discussions	75
5.4.	Conclusions	81
	References	82
6.	THERMAL ENERGY HARVESTING USING BULK LEAD-FREE FERROELECTRIC CERAMICS	85-100
6.1.	Introduction	86
6.2.	Background	87
6.2.1.	Pyroelectric Energy Harvesting	87
6.2.2.	Ferroelectric Energy Harvesting	89
6.3.	Materials	90
6.4.	Results and Discussions	92
6.5.	Conclusions	97
	References	98
7.	REFRIGERATION AND COLOSSAL LOW GRADE THERMAL ENERGY HARVESTING USING (Bi_{0.5}Na_{0.5})_{0.915}- (Bi_{0.5}K_{0.5})_{0.05}Ba_{0.02}Sr_{0.015}TiO₃ CERAMICS	100-114
7.1.	Introduction	102
7.2.	Pyroelectric Energy Harvesting	103
7.3.	Energy Harvesting Cycles	103
7.3.1.	Olsen Cycle for Peculiar Loop Shift	104

7.3.2. Proposed Ferroelectric Refrigeration Cycle	106
7.4. Results and Discussions	109
7.5. Conclusions	111
References	112
8. ENERGY HARVESTING AND STORAGE ANALYSIS IN MULTIFERROIC EPITAXIAL THIN FILM HETROSTRUCTURES	115-126
8.1. Introduction	116
8.2. Important Parameters for Energy Harvesting and Storage	116
8.3. Materials	118
8.4. Results and Discussions	120
8.5. Conclusions	123
References	124
SUMMARY AND CONCLUSIONS	127
VISTAS AHEAD	130