BaTiO₃ BASED FERROELECTRIC CERAMICS FOR BACTERIAL REMEDIATION IN AQUEOUS SYSTEMS

A Thesis

Submitted

by

Sandeep Kumar Shukla (D14015)

for the award of the degree of

Doctor of Philosophy



SCHOOL OF ENGINEERING INDIAN INSTITUTE OF TECHNOLOGY MANDI Mandi, Himachal Pradesh -175001

March, 2020

Declaration by the Research Scholar

This is to certify that the thesis entitled "BaTiO3 Based Ferroelectric Ceramics for Bacterial

Remediation in Aqueous Systems" submitted by me to the Indian Institute of Technology

Mandi for the award of the degree of Doctor of Philosophy is a bonafide record of research work

carried out by me in the School of Engineering, Indian Institute of Technology Mandi, under the

supervision of Dr. Satvasheel Powar and Dr. Rahul Vaish. 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.

In keeping with the general practice of reporting scientific observation, due acknowledgements

have been made wherever the work described is based on the findings of other investigators.

I.I.T. Mandi (H.P.)

Sandeep Kumar Shukla

Date: 04/09/2020

i

Thesis Certificate

This is to certify that the thesis entitled "BaTiO3 Based Ferroelectric Ceramics for Bacterial

Remediation in Aqueous Systems" submitted by Mr. Sandeep Kumar Shukla to the Indian

Institute of Technology Mandi for the award of the degree of Doctor of Philosophy is a bonafide

record of research work carried out by him under our supervision in the School of Engineering,

Indian Institute of Technology Mandi. 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. In

keeping with the general practice of reporting scientific observation, due acknowledgements

Dr. Rahul Vaish

IIT Mandi

Associate Professor

School of Engineering

have been made wherever the work described is based on the findings of other investigators.

Dr. Satvasheel Powar Assistant Professor School of Engineering IIT Mandi

Date: Date:

ii

At the outset I remember the almighty for keeping me under his blessings. I pray to God that I need your presence in my soul till it exists.

I am immensely thankful to my Research Supervisors Dr. Satvasheel Powar and Dr. Rahul Vaish of the School of Engineering, Indian Institute of Technology Mandi. Without their support and guidance, it would not have been possible for me to complete my Ph.D research work within stipulated time. Dr. Powar and Dr. Vaish were always there to support my work and encourage me during my pursuit.

I have absolutely no hesitation in specially conveying warm thanks to Dr. Prosenjit Mondel who supported me whole heartedly with his support and advice throughout this research work. The generosity of your time and the kindness you showed me is invaluable.

I also wish to acknowledge the members of doctoral committee, Dr. Rajiv Kumar (Associate Professor, School of Engineering), Dr. Viswanath Balakrishnan (Associate Professor, School of Engineering), and Dr. Amit Jaiswal (Assistant Professor, School of Basic Sciences), for their careful examination of the work and their invaluable comments and insights, which made a deep impact on my research. I want to stretch my special gratitude to Dr. Atul Dhar (Assistant Professor, School of Engineering) for enormous support, love and guidance whenever I needed it.

I am grateful to the officials of numerous organizations who have allowed me to better understand their international venturing. They were willing to tell me both the good and

the bad, for which I am thankful. They were kind enough to give me time to share valuable information and data, without which this study would have been incomplete. Standing by me, my respectable parents, showered blessing in all my academic quests, without which I would not have been here. I submit my gratitude to my whole family who always encouraged me to work hard for achieving academic targets. I have absolutely no hesitation in specially conveying warm thanks to my research colleague Vineeth Daniel, Ankita Sarkar, Moolchand Sharma, Gurpreet Singh, Vishvendra Singh, Raj Kiran, Annirudhh Kumar, Himmat Singh, Surbhi Dogra and V.P. Singh who supported me whole heartedly with their amazing love, support and advice. You provided eternal optimism and encouragement in me. Thank you to my closest ones Vivaan, Arti, Mom, Dad, Dileep and Sanjeev. You all are so precious to me. I could have never done this without your love and support.

Thank you all.



Sandeep Kumar Shukla

CLARATION i

DECLARATION	i
THESIS CERTIFICATE	ii
ACKNOWLEDGEMENT	iii
CONTENTS	v
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	xvi
PREAMBLE	xviii
CHAPTER 1	1-1
1.1 Bacterial infection overview and current status	1-2
1.2 Introduction to ferroelectric materials	1-5
1.3 Catalysis by electric fields/surface potential and mediated catalysis	1-9
1.3.1 Piezocatalysis	1-9
1.3.2 Catalysis by electric field and combination with piezocatalysis	1-13
1.3.3 Pyrocatalysis	1-18
1.4 Ferro-Photocatalysis	1-20

1-22

1-24

1.5 Multicatalytic effect

1.6 Objectives of thesis

1.7 References:	1-25
CHAPTER 2	2-1
2.1 Introduction	2-2
2.2 Experimental Methods	2-4
2.2.1 Synthesis and characterization of BT ceramic	2-4
2.2.2 Photocurrent and photocatalytic activity	2-4
2.2.3 Antibacterial activity	2-5
2.2.4 Extracellular and intracellular ROS estimation	2-6
2.2.5 Bacterial morphology determination	2-7
2.2.6 Biocompatibility studies	2-7
2.3 Results and Discussion	2-8
2.4 Conclusions	2-21
2.5 References	2-23
CHAPTER 3	3-1
3.1 Introduction	3-2
3.2 Experimental	3-4

	Experimental setup	3-4
3.2.2	Synthesis and characterization of BaTiO ₃ ceramics	3-5
3.2.3	Live/dead fluorescent confocal microscopy assay	3-6
3.2.4	Zeta potential and relative intracellular ROS measurement	3-7
3.2.5	Analysis of Bacterial Morphology	3-8
3.2.6	Photocurrent and photocatalysis study	3-8
3.3 Res	sults and Discussion	3-9
3.4 Coi	nclusions	3-23
3.5 Ref	erences	3-24
СНАРТ	ER 4	4-1
	ER 4	4-1 4-2
4.1 Inti		
4.1 Inti	roduction	4-2
4.1 Inti 4.2 Exp	roduction perimental Methods	4-2 4-3
4.1 Into	roduction Derimental Methods Synthesis and characterization of BT powder	4-2 4-3 4-3

4.3.2 Antibacterial effect of BT powder	4-7
4.4 Conclusions	4-15
4.5 References	4-16
CHAPTER 5	5-1
5.1 Introduction	5-2
5.2 Experimental Methods	5-3
5.2.1 Synthesis and characterization of BCZTO ceramics	5-3
5.2.2 Antibacterial activity of BCZTO ceramic	5-3
5.3 Results and Discussion	5-5
5.4 Conclusions	5-13
5.5 References	5-14
CHAPTER 6	6-1