Poling Tuning: A Plausible Solution to Enhance the Performance of Piezoelectric Materials

A thesis

submitted by

Raj Kiran

(S17011)

In the partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

(by research)

School of Engineering

INDIAN INSTITUTE OF TECHNOLOGY MANDI

Mandi, Himachal Pradesh-175001

AUGUST 2019

Dedicated to

my teachers

and

family

Declaration by the Research Scholar

This is to certify that the thesis titled **"Poling tuning: A Plausible Solution to Enhance the Performance of Piezoelectric Materials"** submitted by me, to the Indian Institute of Technology Mandi for the award of the degree of **Master of Science (by research),** is a bonafide record of the research work carried out by me in the School of Engineering, Indian Institute of Technology Mandi, under the supervision of 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.

Raj Kiran
School of Engineering
Indian Institute of Technology Mandi
Mandi, Himachal Pradesh

Date: 1 August 2019

Thesis Certificate

This is to certify that the thesis titled **"Poling tuning: A Plausible Solution to Enhance the Performance of Piezoelectric Materials"** submitted by **Raj Kiran,** to the Indian Institute of Technology Mandi for the award of the degree of **Master of Science (by research),** is a bonafide record of the research work done by him under my 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 have been made wherever the work described is based on the findings of other investigators.

Dr. Rahul Vaish
Associate Professor
School of Engineering
Indian Institute of Technology Mandi
Mandi-175005
Himachal Pradesh

Date: 1 August 2019

Acknowledgements

I would like to express the deepest appreciation to my advisor and mentor, Dr. Rahul Vaish, for his continuous encouragement and unconditional support. He provided me the opportunity to freely choose my path, while sharing his invaluable experience and knowledge as well as his precious time. Without his guidance and persistent help, this project could have not been completed.

I would also like to extend my gratitude to the faculty at IIT Mandi for their teachings and guidance. I would like to especially thank Dr. Rajneesh Sharma and Dr. Arpan Gupta for having taught me the necessary courses to help me progress with my research.

I also wish to acknowledge the members of my thesis committee for their critical appraise of my research and annual progress. My obligations to Dr. Vishal Singh Chauhan, Dr. Viswanath Balakrishanan, Dr. Arpan Gupta and Dr. Satinder Sharma for valuable time and consideration and impartial judgements of my research work.

Much of my efforts would not have been successful without proper help and support from my adorable lab-mates and friends: Anuruddh Kumar, Gurpreet Singh, Saurav Sharma, Moolchand Sharma, Vishvendra Pratap Singh, Ashok Sivarathri and yes, of course, Ajay Bhardwaj.

I offer my enduring gratitude to the faculty and staff at School of Engineering, IIT Mandi. Finally, I would like to thank my family for being aside with me always.

Raj Kiran

August, 2019

Preamble

The piezoelectric materials are well known for their unique electro-mechanical conversion capabilities. These materials produce the electrical voltage when subjected to mechanical strain commonly termed as direct piezoelectric effect. On contrary, these materials under the effect of electric field induce mechanical strain which is known as converse piezoelectric effect. Owing to their unique and multifunctional capabilities these materials have captured a huge market for sensing, actuation and energy harvesting applications. However, most of the commercialized piezoceramics are lead-based and this highly carcinogenic. Additionally, they are often limited by their low output parameters and performance. Therefore, it is the need of the hour to develop such materials which are lead-free and can show enhanced performance. Therefore, this thesis puts forward the poling tuning strategy to enhance the performance of the piezoelectric materials. In particular, it presents the idea of magnifying the sensing and actuation capability of the piezoelectric materials by poling them at a particular angle.

The results obtained in the present investigations have been compiled as five chapters as follows:

Chapter 1 provides a brief introduction about the smart materials. It sheds light on the working principle of piezoelectric materials, their applications, modes of operation, challenges and strategies to overcome the impediments. It also mentions the different routes adopted so far to increase the piezoelectric performance.

Chapter 2 begins with concept of poling tuning in the piezoelectric materials. Initially, the mathematical expressions were derived to take into account the effect of poling direction on sensing and actuation of the piezoelectric materials operating in transverse mode. Later on, the

closed form expressions for optimized angle for actuation and sensing were validated against the finite element simulations for different material systems.

Chapter 3 expands the idea of poling tuning theoretically towards the piezoelectric materials operating in longitudinal mode. Again, the effect of poling direction on sensing and actuation behavior was observed for different materials. Additionally, the distance between the electrodes and electrode width was varied to optimize the actuating and sensing capabilities.

Chapter 4 propounds the novel concept of graded poling in piezo materials with a motivation to capture completely the bending and shear stresses in the piezoelectric elements. The performance of the graded elements was compared with those operating in transverse and shear mode. The results suggested that the introduced concept of graded poling can tremendously increase the capabilities of piezoelectric materials.

Chapter 5 concludes the thesis by summarizing the key findings of the investigation and highlights the best results obtained during individual studies. It also gives an insight of the challenges associated with the work and some of the future directions.

The following publications are largely based on the studies conducted as a part of the research work reported over here:

1. **Kiran, R.**, Kumar, A., Kumar, R. and Vaish, R., 2018. Poling direction driven large enhancement in piezoelectric performance. *Scripta Materialia*, *151*, pp.76-81.
2. **Kiran, R.**, Kumar, A., Kumar, R. and Vaish, R., 2019. Effect of poling orientation on piezoelectric materials operating in longitudinal mode. *Materials Research Express*, *6*(6), p.065711.
3. **Kiran, R.**, Kumar, A., Kumar, R. and Vaish, R., 2019. Deciphering the importance of graded poling in piezoelectric materials: A numerical study. (*Communicated*)

Other articles include:

1. **Kiran, R.**, Kumar, A., Kumar, R. and Vaish, R., 2019. Effect of poling direction and porosity on piezoelectric figures of merit: A numerical study. *The European Physical Journal Plus*, *134*(3), p.103.

2. **Kiran, R.**, Kumar, A., Kumar, R. and Vaish, R., 2019. Poling tuning: A plausible solution for minimizing microphony and secondary pyroelectric coefficient in ferroelectrics (Under Review)

3. Kumar, A., **Kiran, R.**, Kumar, S., Chauhan, V.S., Kumar, R. and Vaish, R., 2018. A comparative numerical study on piezoelectric energy harvester for self-powered pacemaker application. *Global Challenges*, *2*(1), p.1700084.

4. Kumar, A., **Kiran, R.**, Chauhan, V.S., Kumar, R. and Vaish, R., 2018. Piezoelectric energy harvester for pacemaker application: a comparative study. *Materials Research Express*, *5*(7), p.075701.

5. Kumar, A., **Kiran, R.**, Kumar, R., Jain, S.C. and Vaish, R., 2018. Flexoelectric effect in functionally graded materials: A numerical study. *The European Physical Journal Plus*, *133*(4), p.141.

6. **Kiran, R.**, Kumar, A., Chauhan, V.S., Kumar, R. and Vaish, R., 2018. Finite element study on performance of piezoelectric bimorph cantilevers using porous/ceramic 0–3 polymer composites. *Journal of Electronic Materials*, *47*(1), pp.233-241.

7. **Kiran, R.**, Kumar, A., Chauhan, V.S., Kumar, R. and Vaish, R., 2017. Engineered carbon nanotubes reinforced polymer composites for enhanced thermoelectric performance. *Materials Research Express*, *4*(10), p.105002.

Table of contents